Chapter 10

Creating the Creators

Gaben, wer hätte sie nicht?	Gifts, who is without them?
Talente—Spielzeug für Kinder.	Talents—mere toys for children.
Erst der Ernst macht den Mann,	Seriousness makes the man,
Erst der Fleiss das Genie.	Application the genius.

Theodor Fontane. 1908. Unter ein Bildnis Adolf Menzels.
Gedichte. Stuttgart/Berlin. p. 325.

Chapters 2–9 and Appendices A–E give an overview of a representative (though certainly not exhaustive) set of revolutionary creators and creations that came out of the predominantly German-speaking research world of the nineteenth and early twentieth centuries. There are many indications that systemic innovation-promoting factors were largely responsible for the production of those creators and creations:

- The German-speaking creators and creations came from a relatively small geographical region within a limited period of time, which should prompt close examination of the systemic practices of that place and time that may have contributed to their success.
- That place and time produced a truly enormous number of revolutionary innovations. In fact, it is difficult to identify as many revolutionary innovations that have been wholly developed by the modern research world (not counting innovations that were made by the earlier German-speaking world but adopted and polished by the modern world).
- The former German-speaking world produced that huge number of revolutionary innovations despite having far fewer researchers than the modern world.
- The earlier German-speaking world produced that large number of revolutionary innovations despite having far less research funding than the modern world.
- The former German-speaking world produced so many revolutionary innovations despite having far less political stability than the modern world. It remained highly productive in spite of forces including German unification, Kaiser Wilhelm II's autocracy, World War I, the financial and political crises of the Weimar period, the savagery of the Third Reich, and the devastation of World War II.

- The earlier German-speaking world was not merely holding its position ahead of international competitors, but rather was actually accelerating further and further ahead of other countries. At the beginning of the nineteenth century, scientific fields were generally dominated by researchers in France, the United Kingdom, and a few other countries, and scientific research projects and science/engineering-based industry in the German-speaking world were scarce or lagged years behind the international competition. German-speaking scientists and engineers seriously entered most fields sometime during the nineteenth century, starting from that position of being far behind. As illustrated by the innovators and innovations in Chapters 2–9 and the appendices, by the end of the nineteenth century, German-speaking scientists were ahead in most fields. By 1945, they had overwhelmingly dominated most fields, contributing most of the major new innovations in each field and running years ahead of their competitors, in many cases by a decade or more (e.g., rockets, chemical synthesis, etc.).

Motivated by the above facts, Section 10.1 first compares the size of the early German-speaking research world to that of the modern U.S. and global innovation systems.

Section 10.2 then identifies several specific factors within the German-speaking world that promoted revolutionary innovation:

10.2.1. Science was socially glorified, from children's activities and amateur science clubs to prestigious jobs and government-lauded scientific heroes.

10.2.2. A century-long steady exponential increase in funding gave scientists, employers, and sponsors much more freedom to pursue higher-risk and/or longer-term research.

10.2.3. Many Ph.D. students were encouraged to propose their own research topics and to pursue them independently.

10.2.4. Scientists received their final degrees nearly a decade earlier in life, and independent research funding up to two decades earlier, than modern scientists do.

10.2.5. Scientists who made major contributions to multiple disciplines, and fraternization among scientists from different disciplines, were much more common than in the modern world.

10.2.6. Instead of peer review, an autocratic yet farsighted scientific management culture of "enlightened despots" granted stable jobs and funding to the most promising creators and creations.

10.2.7. Both scientists and sponsors used a systems analysis approach to focus on the most important problems and the most effective innovations to address those problems.

10.2.8. The lack of natural resources spurred the creation of a wide range of innovative alternatives.

10.2.9. International rivalry (both economic and military) was a powerful driving force for innovation.

10.2.10. German-speaking companies were less afraid of losing their own innovations to each other than of being outstripped by foreign countries, giving them a strong motivation to innovate.

10.2.11. There are also other possible factors that should be investigated by future researchers.

10.1 Comparison of Innovation System Size

Before studying factors that promoted innovation in the German-speaking world, one should first consider the total population of the German-speaking world and the size of its innovation system relative to numbers for the modern world.

10.1.1 Total Population and Scientific Innovators in the German-Speaking World

The population of the German-speaking world was spread among several countries, and those countries, their borders, and their populations changed over time. Table 10.1 gives the populations in millions of people for a few key years.

Country	**1871**	**1900**	**1914**
Austria-Hungary	36.0	45.2	52.5
Germany	41.1	56.4	67.0
Netherlands	3.6	5.1	6.3
Switzerland	2.7	3.3	3.8
TOTAL	**83.4**	**110.0**	**129.6**

Country	**1939**
Austria	6.7
Czechoslovakia	14.8
Germany (within 1937 borders)	69.5
Hungary	9.2
Netherlands	8.8
Poland	34.8
Switzerland	4.2
TOTAL	**148.0**

Table 10.1: Populations (in millions of people) of central European countries that were involved in the German-speaking research world. The 1939 data covers approximately the same geographical area as the data from the earlier years, but some of the country names are different due to the altered borders [Mitchell 1975; https://www.destatis.de; https://www.statistik.at; https://www.cbs.nl; https://www.bfs.admin.ch].

Of course, in some of the countries listed in Table 10.1, only some fraction of the population was actually German-speaking or interacted directly or indirectly with the German-speaking research world. Although the total population was steadily increasing apart from wars, ∼100–130 million people is a good general estimate for the total population of the German-speaking world during the early twentieth century.

Like the postwar U.S. research system, the earlier German-speaking research world was divided into three sectors: academic, corporate, and government laboratories.

1. Many universities had very diverse and advanced research programs, especially those in Berlin, Munich, Göttingen, Vienna, Zurich, Prague, etc.

2. Many German companies maintained very large, very well-funded laboratories where company researchers were encouraged to keep inventing and developing 10–20 years worth of future products for the corporate pipeline. Those companies included the various chemical and pharmaceutical companies that ultimately consolidated into I.G. Farben, electrical companies such as Siemens, AEG, and Telefunken, aerospace companies such as Heinkel and Junkers, etc.

3. Government laboratories included multiple labs run by each branch of the military, various dedicated biology and medical labs, the many different Kaiser Wilhelm Institutes (now called the Max Planck Institutes) in different scientific fields, and even advanced electronics and nuclear laboratories run by the German postal service (Reichspost).

Also like the U.S. system, much of the German-speaking university and corporate research was sponsored by the government, with the rest being funded by companies investing in their own labs and also investing in long-term partnerships with universities and with the Kaiser Wilhelm Institutes.

Good estimates of the total number of people involved in the historical German-speaking research world are difficult to find and depend greatly on the definitions one uses. Some relevant data that can be considered includes:

- Werner Osenberg, head of the planning board of the Reichsforschungsrat (German Research Council), compiled a list of 15,000 significant scientists, engineers, medical research doctors, and technicians during the period 1943–1945 [Jacobsen 2014, p. 41]. (He also listed 1400 research facilities.) Estimates are that ∼15–33% of scientists and engineers fled or were forcibly removed from the German-speaking research world during the Third Reich, primarily due to persecution of those with Jewish ancestry or spouses [Ash and Söllner 1996, p. 7]. This suggests a prewar number of ∼20,000 noteworthy scientists and engineers.

- Over 2000 German-speaking scientists and engineers emigrated to the United States soon after World War II as part of Operation Paperclip and Paperclip-related programs [Linda Hunt 1991, p. 1], over 3000 were employed (willingly or otherwise) by the Soviet Union [Mick 2000], over 1000 by the United Kingdom [Glatt 1994], over 1000 by France [Nouzille and Huwart 1999], and at least many hundreds by other countries [Michael Neufeld 2012]. Adding up those numbers gives a total of at least ∼7,500 scientists who are known to have gone to other countries. Multiplying that number by a factor of ∼2 to account for those who remained in Germany and Austria or who moved to other countries but were not included in the official totals puts this estimate in good agreement with the 15,000 on the Osenberg list. (Indeed, the captured Osenberg list was used by Allied countries in their efforts to recruit German-speaking scientists after the war.) Again factoring in those who fled the Reich gives a rough prewar estimate close to 20,000 scientists and engineers.

- A maximum of approximately 4300 staff worked at German aviation research establishments during World War II [Hirschel et al. 2004, p. 659]. Because aircraft, missiles, and rockets were a large area of focus during the war, that number seems consistent with the above total estimates derived from the Osenberg list and Allied recruiting.

- Deichmann found 445 biologists in Germany, Austria, and the Sudetenland between 1933 and 1945 [Deichmann 1996]. Considering that Deichmann's list omitted many major researchers conducting biology-related research within the Reich (Kurt Blome, Adolf Butenandt, Gerhard Domagk, Eugen Haagen, Heinrich Kliewe, Richard Kuhn, Walter Schreiber, Erich Traub, etc., perhaps because they were medical doctors or chemists conducting biology research, or perhaps because they were part of military research programs) and did not consider German-speaking researchers beyond those geographical regions, the total number of active biology researchers may have been at least twice Deichmann's figure, say perhaps 1000. In view of the number of other fields (chemistry, physics, engineering, etc.) and their popularity relative to biology, the total estimates derived from the Osenberg list and Allied recruiting efforts again seem quite plausible.

- Using the major innovations identified in this book and considering the key innovators behind them (Chapters 2–9 and the appendices), there appear to have been at least ∼2000 especially important German-speaking creators, not all of whom were alive at the same time. This number agrees well with various 1945–1948 Allied lists of key scientists who had been recruited or were targets of recruitment [NARA RG 330 Entry A1-1A].

Based on this data, at a given time in the early twentieth century, the German-speaking world appears to have had no more than ∼2000 creators who were personally making revolutionary discoveries or inventions.

Those creators were part of a system that was approximately a factor of ten times larger and contained ∼20,000 scientists and engineers who at least had documented track records.

(If one were to generously multiply that number by an additional factor of ∼10 to account for all of the people who may have contributed to the system in any fashion from technicians to teaching aides, the total size of the science and engineering world in German-speaking Europe was at most perhaps ∼200,000 people.)

10.1.2 Comparison with the Modern World

Whereas the German-speaking world had a total population of ∼100–130 million people during the early twentieth century, in 2020 the estimated population of the United States was 330 million, and the estimated population of the whole world was 7.7 billion people [www.worldometers.info/world-population]. Thus the earlier German-speaking world had a total population that was ∼1/3 that of the modern United States, and roughly ∼1/70 of the modern global population.

To compare research system sizes, as of 2015 (the most recent year for which fully analyzed statistics are available), there were over 1.3 million people employed in research in the United States, and over 7 million worldwide, as shown on p. 40. (As with the German-speaking world, one might also inflate these modern numbers by a factor of ∼10 to account for all of those people who obtain science or engineering degrees but do not ultimately do research, or who interact with the system in some other fashion.)

Using the estimate of ∼20,000 German-speaking researchers, the early German-speaking scientific world had less than ∼1/65 as many researchers as the modern U.S. innovation system, and less than ∼1/350 as many people as the modern global research system, yet managed to produce the incredible quantity and quality of innovations illustrated by Chapters 2–9 and Appendices A–E.

If modern innovation systems were as effective as the earlier German-speaking innovation system, one would expect them to have produced revolutionary innovations at a rate ∼65–350 times that of the older German-speaking world. Unfortunately they do not appear to have even equalled the output of revolutionary innovations from the earlier German-speaking world (as already noted, not counting innovations that were originally made by the German-speaking world but later adopted and adapted by the modern world).

For this reason, it is of great interest to seek factors that may account for why the German-speaking world was so successful.

10.2 Systemic Factors Promoting Innovation

The objective of this section is to identify and analyze common factors within the German-speaking world that facilitated the success of so many revolutionary scientific creators and creations. As is demonstrated here, there were at least ten different important factors. What all of those factors had in common, though, was that they generally tended to promote greater freedom to pursue longer-term and riskier potential innovations compared to the modern research world.

10.2.1 Cultural Attitudes Toward Science Education and Research

One important factor underlying the scientific innovations from the German-speaking world appears to be cultural attitudes toward education and research that were deeply embedded in German culture throughout the nineteenth and twentieth centuries. Education and research in general, and science and engineering in particular, were highly esteemed, from children's activities and amateur science clubs to prestigious jobs and government-lauded scientific heroes.

The roots of these cultural attitudes can be traced back at least as far as the eighteenth century. While philosophers who were not also scientists are beyond the scope of this book, several German-speaking philosophers played highly influential roles in shaping the intellectual culture of the German-speaking world. In particular, Immanuel Kant (Prussian, 1724–1804), Johann Fichte (German states, 1762–1814), Georg Wilhelm Friedrich Hegel (German states, 1770–1831), and Friedrich Schelling (German states, 1775–1854) placed great emphasis on inquiring into the laws and details of the universe, weighing and even hybridizing alternative explanations to determine the best one (the dialectic, not unlike the scientific method), and finding ways to improve oneself and to help others [Beardsley 1960; EB 2010; Peter Watson 2010].

As discussed later in Section 10.2.5, a number of more scientifically oriented intellectuals applied these same principles to a wide range of fields in science and engineering. Those founding scientific figures included Athanasius Kircher (German states, 1602–1680), Gottfried Leibniz (Saxony, 1646–1716), Leonhard Euler (Swiss, 1707–1783), Johann Wolfgang von Goethe (German states, 1749–1832), and Alexander von Humboldt (Prussian, 1769–1859).

Wilhelm von Humboldt (Prussian, 1767–1835), Alexander's older brother, founded the University of Berlin (now called the Humboldt University of Berlin) in 1811 and is widely credited with developing and promoting the model of universities conducting both education and research in coordination. Drawing upon the earlier work of intellectuals such as those listed above, he articulated ideals that would be characteristic of German-speaking culture throughout the nineteenth and twentieth centuries [Bruford 1975, pp. 13–17, 24]:

> Everyone must seek out his own individuality and purify it, ridding it of the fortuitous features. It will still be individuality, for a portion of the fortuitous is inseparable from the make-up of every individual, and cannot and should not be removed. It is really only in that way that character is possible, and through character greatness.
>
> —
>
> If we imagine a man whose sole aim in life is to cultivate himself, his intellectual activity must finally be concentrated on discovering (a) *a priori*, the ideal of humanity, and (b) *a posteriori*, a clear picture of mankind in reality. When both are as precise and complete

> as possible in his mind, he should, by comparing them, derive from them rules and maxims for action.
>
> —
>
> The true end of man, not that which his transient wishes suggest to him, but that which eternal immutable reason prescribes, is the highest possible development of his powers into a well-proportioned whole. For culture of this kind freedom is the first and indispensable condition.
>
> —
>
> Thus peasants and craftsmen of all kinds could perhaps be developed into artists, that is, into men who loved their particular work for its own sake, improved it through their own initiative and inventiveness and so cultivated their intellectual powers, ennobled their character and refined their pleasures.
>
> —
>
> In general, perhaps the best thing a man can do with his life is to take away with him a living picture of the world, properly unified. For me in particular no task is more suited, more imposed upon me by my nature.
>
> —
>
> He who can say to himself when he dies: 'I have grasped and made into a part of my humanity as much of the world as I could,' that man has reached fulfillment... In the higher sense of the word, he has really lived.

As voiced by Humboldt, these German cultural ideals emphasized (1) individual initiative and creativity, (2) high levels of education and lifelong learning, (3) acquiring and harnessing a comprehensive knowledge of as many fields as possible, and (4) systems analysis to survey everything and then focus on creating solutions for the most important problems.

In Peter Watson's sweeping survey of German intellectual history, *The German Genius,* he explained how these ideals permeated and influenced the German-speaking world [Peter Watson 2010, pp. 53–54, 829–830]:

> There will be a great deal to say about Bildung in this book. Difficult to translate, in essence it refers to the inner development of the individual, a process of fulfillment through education and knowledge, in effect a secular search for perfection, representing progress and refinement both in knowledge and in moral terms, an amalgam of wisdom and self-realization.
>
> [...I]t is clear from what has gone before that Germany was the first country to boast an educated middle class of any size and that this was all important for its emergence as a great power.
>
> A few statistics will underline this. Prussia enforced school attendance for children between the ages of seven and fourteen from the 1820s (in Britain children were not compelled to go to school until 1880) and by the 1890s had two-and-a-half times as many university students in proportion to population as did England. [...I]n Germany, in 1785 there were 1,225 periodicals published, compared with 260 in France. In 1900 Germany had 4,221 newspapers, France roughly 3,000 (and Russia 125). In the early

> nineteenth century, when England had just four universities, Germany had more than fifty. James Bowen, in his three-volume history of Western education, points out that Germany took the lead in the establishment of scientific societies in the early nineteenth century, published the greatest number of journals in the vernacular, and became the leading language of scientific scholarship. In 1900 illiteracy rates in Germany were 0.5 percent; in Britain they were 1 percent and in France 4 percent. By 1913 more books were published annually in Germany (31,051 new titles) than in any other country in the world. [...]
>
> It was the educated middle class that made the exciting advances in scholarship that so attracted academics from abroad (especially from America), that rendered the bureaucracy of the ever-coalescing German state so efficient and creative and led to the groundbreaking scientific achievements of the second half of the nineteenth century, that transformed Germany economically, and on which so much of modern prosperity—not just in Germany—is based. [...]
>
> The development of modern scholarship, the concept of Bildung, and the innovation of the research-based university were seen at the beginning of the nineteenth century as a form of moral progress. Education was not simply the acquisition of knowledge but looked upon as a process of character development during the course of which a person would learn to form critical judgments, make an original creative contribution, *and* learn about his or her place in society with its duties, rights and obligations. Education as Bildung involved a process of *becoming,* a form of secular perfection or salvation that was, for the educated middle class, the very *point* of life in a world between doubt and Darwin.

Throughout the nineteenth and early twentieth centuries, German-speaking universities expanded and became more advanced, and the social status of people who taught at or graduated from the universities increased in parallel. Ulrich Wengenroth, a scientific historian at the Deutsches Museum in Munich, described that social status [Landes et al. 2010, p. 284]:

> At the same time a new source of respect and status emerged. Kaiser Wilhelm, himself a great admirer of science and engineering, very much against the opposition of the traditional universities created the title of "doctor of engineering" for the *Technische Hochschulen* (institutes of technology). This opened new opportunities for ambitious engineers to gain the kind of respect and recognition that had been the privilege of the humanistic elites of the traditional worlds of learning. And it was a watershed; academic titles in engineering and science soon displaced the Kommenzienrat and the Geheimer Kommenzienrat, while the *Honorarprofessor* (honorary professor), which in everyday life often was stripped of its somewhat depreciating prefix *Honorar* to sound like a bona-fide professorship, carried the status of nobility. Whatever the dubiousness of some honorary degrees, the currency of status and vanity had changed. More prestigious universities would look more closely at the validity of reasons to confer academic distinction. The Honorarprofessor, even if a CEO, would have to teach students and often was interested in fostering common research programs in his company and his university. The academization of entrepreneurial prestige through the twentieth century was as much an expression as a strengthening of a knowledge-based approach to managing product development.

The very high social status and high relative pay for scientists and academics in the German-speaking world were apparently deeply ingrained in the culture, so they persisted throughout the political and financial upheavals of the German-speaking world in the nineteenth and twentieth centuries. Hariolf Grupp and his colleagues remarked on how stable the German scientific system was despite these political instabilities [Shavinina 2003, pp. 1038, 1041]:

> Most astonishingly, the German innovation system was very *stable*, although it witnessed several political system changes in the past century. The total amount of government spending on science and innovation followed similar quantitative tracks after its formation in the 19th century, the First World War and after the Second World War. The respective central power was not a strong pillar in science and technology. Contrary, the science and technology operation was maintained and was always reconstructed by the German states before the central power found ways to establish itself as dominating. However, considerable differences are observed when regarding the strong role of enterprises on innovation after the Second World War, which was—in pecuniar terms—not as visible before. Only after reunification in 1990, the acting power was the federal government at a time when enterprises were largely dominating the financing of R&D. This was definitely different hundred years ago.
>
> In terms of the basic sectorial structures in science and technology, the strong and the weak sides were almost the same whatever regime and territorial boundaries existed. This *persistence* of the innovation system points to a *resistant innovation culture* in and around Germany, which may not be influenced too much by external shocks or incentives, be it in monetary or institutional form. [...] Even the isolation of the former GDR and its subjection under the communist regime could not change much.
>
> There seems to be a specific German understanding of the opening and prosecution of technology trajectories. The industrial research system in Germany was one of the first in the world to be formed and developed. Other countries followed that pattern more or less closely. Yet the subjects of research seemed to be different between the countries and remained largely constant over long periods. Obviously the technical and scientific elites in Germany succeeded to follow their interests in any political system collectively. For the research and education policy this means that soft factors like group identity, schools of thought and personal exchange are more reliable and more efficient government instruments than the traditionally monetary incentive systems. This sustainable culture imprint can only be analyzed and detected in historical time series.

Because this reverence for science was so deeply imbedded in the culture of the German-speaking world, children in that world grew up with dreams of making revolutionary scientific discoveries and inventions. In his published dissertation, Peter Fisher gave an overview of some of the science fiction that was popular in the German-speaking world in the early twentieth century [Fisher 1991, pp. 104, 115, 221]:

> "In cities throughout Germany, people eagerly lined up at newspaper kiosks," recalled Hans Dominik proudly, "in order to buy the latest part of my serial novel in the *Woche*." [...] An electrical engineer who had turned to journalism and popular science, Dominik and his publisher, the conservative Scherl Verlag, were the undisputed masters in producing and marketing a type of formula fiction which they called the *technischer Zukunftsroman*. [...]

> Dominik was not the only science fiction author who sought to assuage the readers' feelings of hurt national pride by concocting stories of potent German inventors creating and controlling future upheavals. Other highly successful authors of popular fiction like Otfrid von Hanstein, Fritz Mardicke, and Otto Willi Gail, or amateur writers like Paul Thieme, also tried their hand in the still new genre. [...] The political drift of these stories manifested itself in an appeal for the recognition of Germany's achievements and (supposedly) superior culture—as witnessed by remarkable advances in science and technology—and by thinly veiled threats that these could be employed against hostile nations. [...]
>
> Dominik's protagonists, like those in other German science fiction of the 1920s, were constructs of an imagination hopefully awaiting salvation in the form of an engineer-messiah. Lämmel even spoke of a day of "technological liberation" and an age of "technological Bismarcks." The repeated sense of wonder and mystery that surround these saviors was meant to suggest that they were emanations of a divine will, driven forward to right the wrongs of recent history. [...]
>
> The writers' favorite props—atomic energy, ray guns, powerful submarines, and light-metal and giant aircraft—serve to reveal hitherto unattained power, but usually appear more like magic wands than believable inventions. Yet, despite the vague imagery of the new superweapons, it seems that there was a wide measure of belief in the imminent creation of such revolutionary armaments.
>
> [...T]he fictive scientists and engineers strove to create powerful inventions that would "free" the nation. While the rightist dictators tamed the masses, the inventors controlled the equally awesome forces of technology. [...]
>
> The technological successes imagined by Weimar's science fiction authors expressed an ambivalent mood—a desire for the recognition of spiritual and technological greatness, as well as a wish to avoid another world war.

These science fiction stories were wildly popular and were avidly consumed by children and adults throughout Germany. They emphasized individualism and presented fictional role models for how a young engineer or scientist could invent or discover something so important that it would change the fate of the country or of the entire world (Fig. 10.1). Early films depicted similar stories about creating a life-like robot (Fritz Lang and Thea von Harbou's *Metropolis*, 1927), building a moon rocket (Lang and von Harbou's *Frau im Mond*, 1929), and accomplishing other technological feats (Fig. 10.2).[1]

At the same time, real-life scientific heroes from Albert Einstein to Fritz Haber were lauded by the media and the government (Fig. 10.3). Amateur science societies such as the Society for Space Travel (Verein für Raumschiffahrt) allowed children and adults to conduct their own research and development projects (Fig. 10.4).

It would be difficult to overestimate the importance of all of these fictional and real role models in shaping the interests and individuality of young future scientists and engineers.

[1] Bogdanovich 1967; Eisenschitz and Bertetto 1994; Eisner 1977; Jenkins 1981; McGilligan 1997.

Hans Dominik (1872–1945) wrote many popular science fiction novels

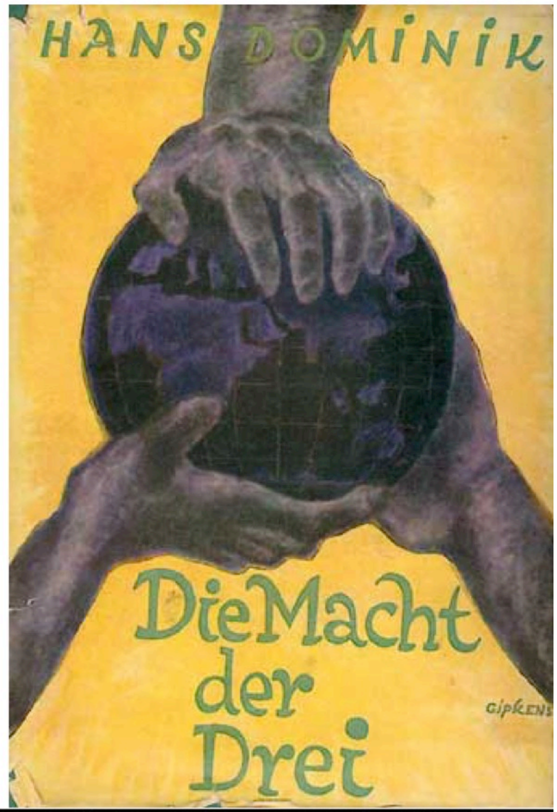

Figure 10.1: Hans Dominik wrote many popular science fiction novels.

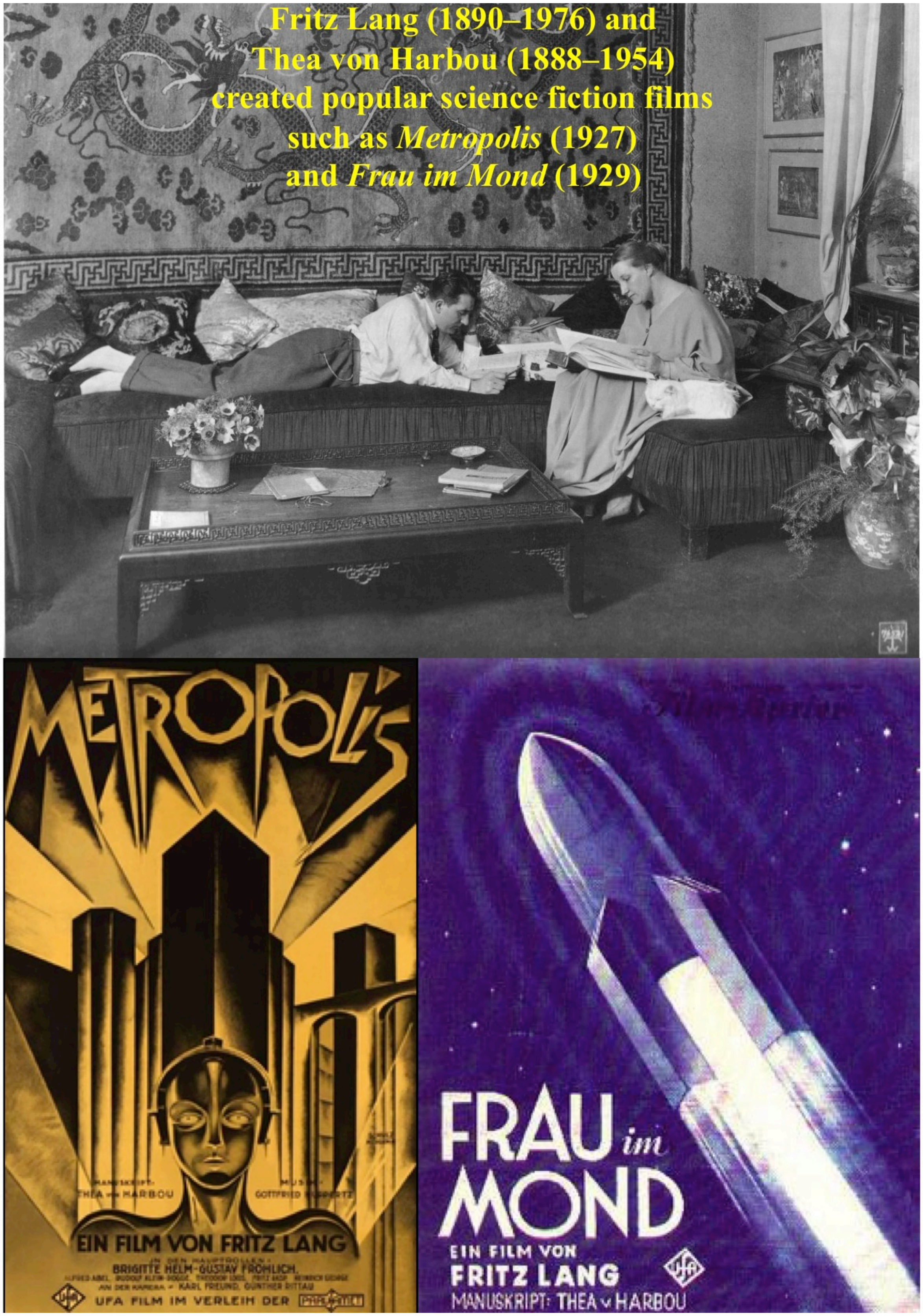

Figure 10.2: Fritz Lang and Thea von Harbou created popular science fiction films such as *Metropolis* (1927) and *Frau im Mond* (1929).

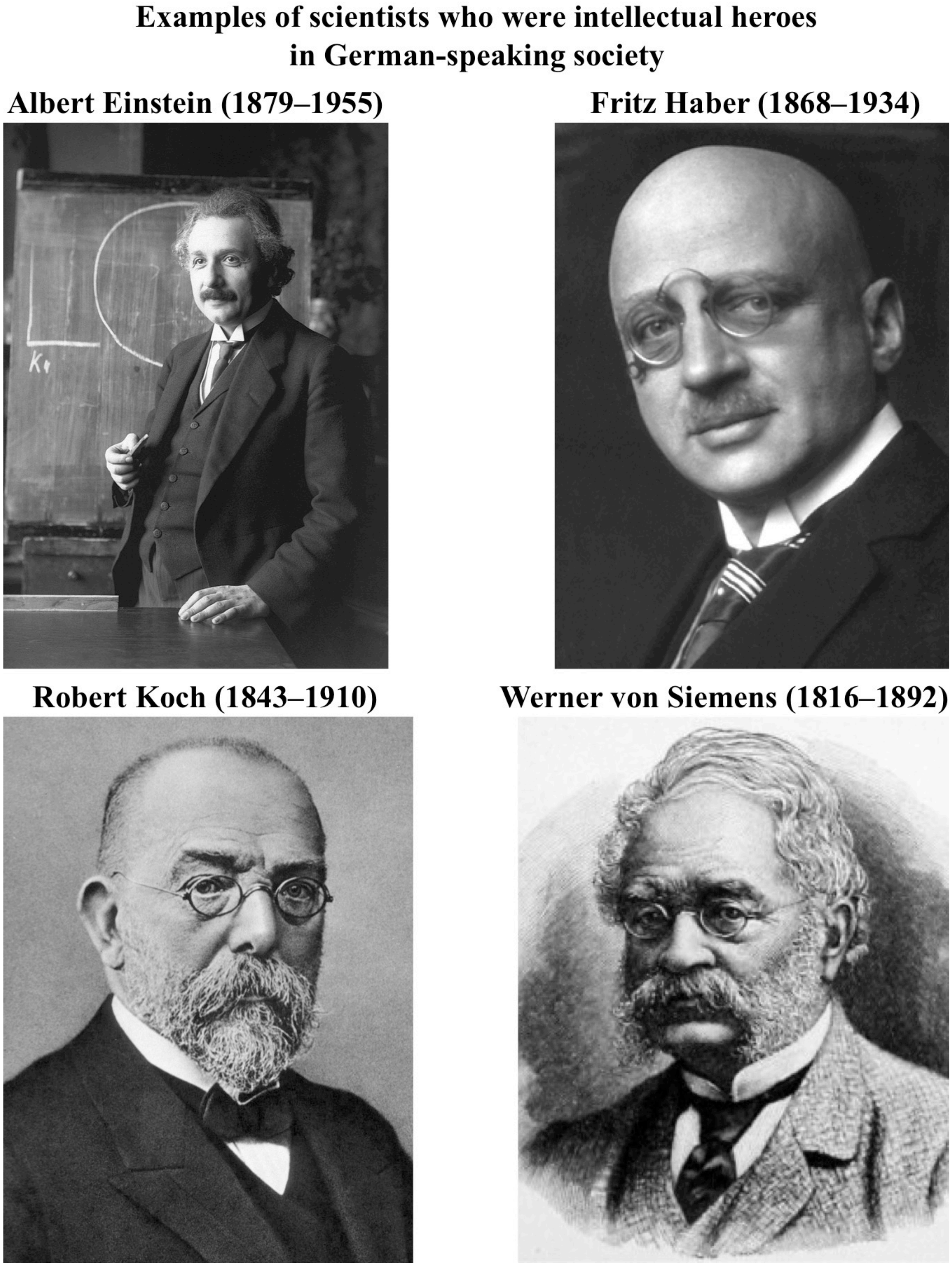

Figure 10.3: Examples of scientists who were intellectual heroes in German-speaking society include physicist Albert Einstein, chemist Fritz Haber, biologist Robert Koch, and electrical engineer Werner von Siemens.

Figure 10.4: There were many amateur science clubs such as the Verein für Raumschiffahrt (Society for Space Travel), which published its own journal and included members such as Rudolf Nebel (lower left) and Wernher von Braun (lower right).

10.2.2 Funding Levels

The amount of funding committed to scientific research obviously has a large effect on the quantity and quality of the resulting work. Data for total public expenditures for science in Germany during the period 1860–1938, converted into inflation-adjusted values (millions of 1913 Reichsmarks), is readily available and summarized in Table 10.2 [Nelson 1993, p. 125].

Year	Annual budget (millions of marks)	Inflation-adjusted (millions of 1913 marks)	% of gross domestic product
1860	6.0	10.7	0.06
1870	10.5	14.7	0.08
1880	27.3	33.6	0.16
1890	32.7	37.4	0.14
1900	53.2	59.9	0.16
1910	91.2	94.8	0.20
1913	101.9	101.9	0.19
1925	282.9	206.8	0.42
1930	359.6	241.3	0.55
1938	513.4	446.6	0.52

Table 10.2: Total public expenditures for science in Germany during the period 1860–1938.

There does not appear to be good data on German industrial research spending during that time. Hariolf Grupp and colleagues summarized this problem [Shavinina 2003, pp. 1021, 1029]:

> Pfetsch undertook adding up scientific expenditure between 1850 and 1975, so that rough estimates about the degree of R&D financing can be derived from this; however, these data records only include *public* expenditure, disregarding the private sector. Consequently, industrial innovation indicators must be researched separately. [...]
>
> It is still difficult to prove the companies' increasing R&D expenditure for such an undeniable success. In particular, no complete data records are available about monetary expenditure or research personnel prior to the end of the Second World War, i.e. the data record established by Pfetsch regarding public scientific expenditure has no counterpart for industry. Today's statistics about R&D expenditure and personnel of the Federal Republic systematically start from the year 1962; certain presumptions allow the reconstruction of the corresponding indicators starting from 1948/1949 [...]

Despite the absence of comprehensive pre-1945 industrial spending data, postwar data shows that during the period 1950–2000, the percentage of total German research expenditures coming from industry instead of government varied between 40% and 60% [Grupp 2002, p. 13], or in other words industrial research spending was roughly equal to government research spending for at least half a century after the war. In the absence of rigorous pre-1945 data, it seems plausible to assume that industrial research spending was also roughly equivalent to government research spending during this period, and that trends in government funding were indicative of trends in total scientific funding.

Similarly, pre-1945 funding data for other geographical regions of the German-speaking world is difficult to find. Nonetheless, it seems reasonable to assume that funding in other German-speaking areas either followed the same trends as the funding in Germany or else was significantly smaller than the German funding. In either case, the rate of increase for German government funding would be a good indicator for the rate of increase for funding for the entire German-speaking research world.

Based on the above data, Fig. 10.5 shows a semilogarithmic plot of total public science funding in Germany from 1860 to 1938 (plotting the data points from Table 10.2 as red circles, measured in inflation-adjusted millions of 1913 marks). Over this 78-year period, funding increased by a factor of 41.7 (red dotted line), equivalent to doubling every 14.5 years on average, or to increasing by a factor of 6.8 over a typical full scientific career of 40 years.

Although the data in Table 10.2 only begins in 1860, German research had been steadily increasing since around 1800, as illustrated by the numerous examples in Chapters 2–9. Likewise, although the data in Table 10.2 ends in 1938, World War II spurred further increases in R&D, as shown by the examples in Appendices A–E. Thus the exponential trend in funding seems to have persisted for at least a full century, and likely more like a century and a half.

Figure 10.6 plots the same data on total public science funding in Germany from 1860 to 1938 from Table 10.2, but instead shown as a percent of gross domestic product (GDP).

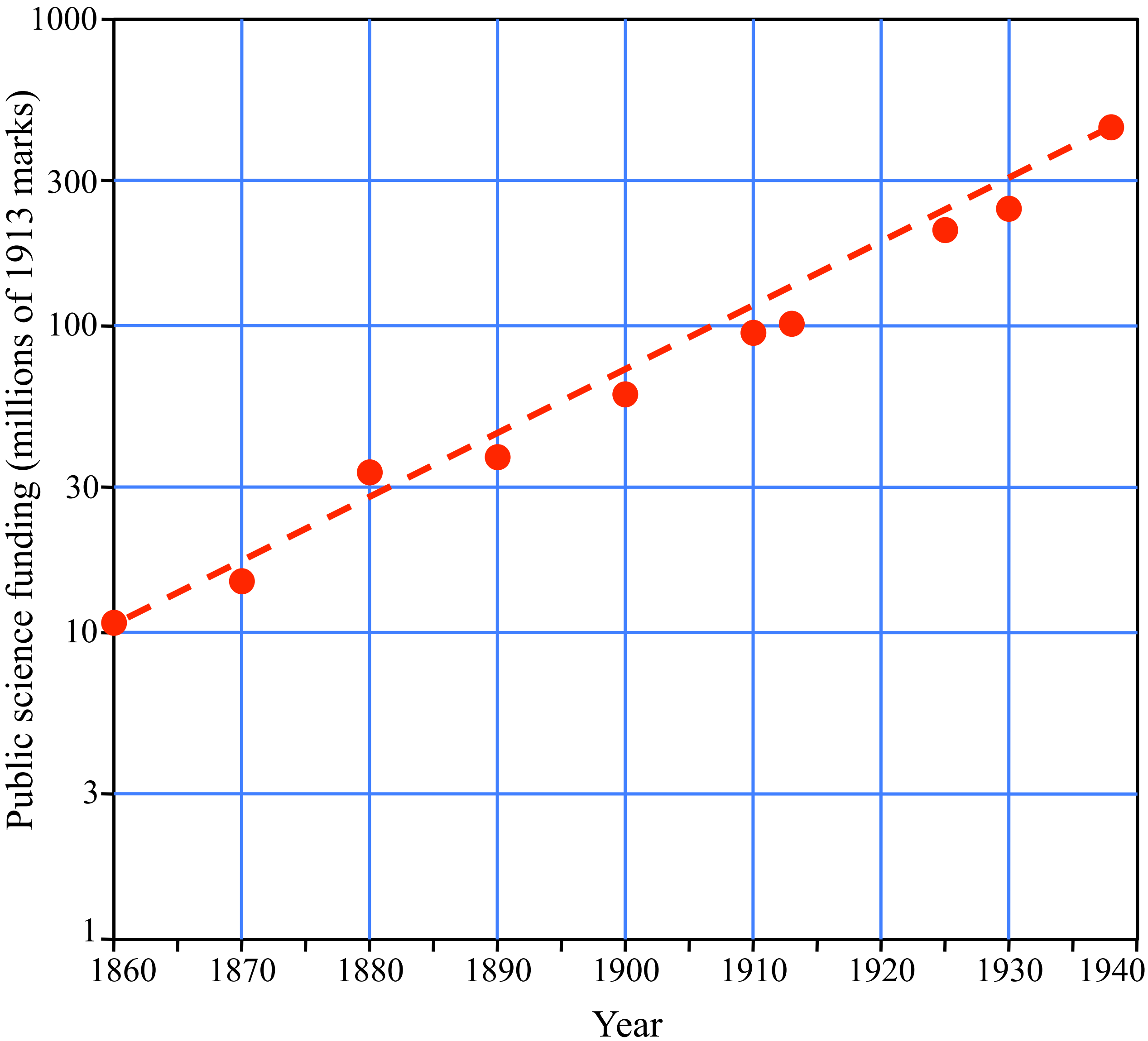

Figure 10.5: Semilogarithmic plot of total public science funding in Germany from 1860 to 1938 (data points as red circles, measured in inflation-adjusted millions of 1913 marks). Over this 78-year period, funding increased by a factor of 41.7 (red dotted line), equivalent to doubling every 14.5 years on average, or to increasing by a factor of 6.8 over a typical career of 40 years.

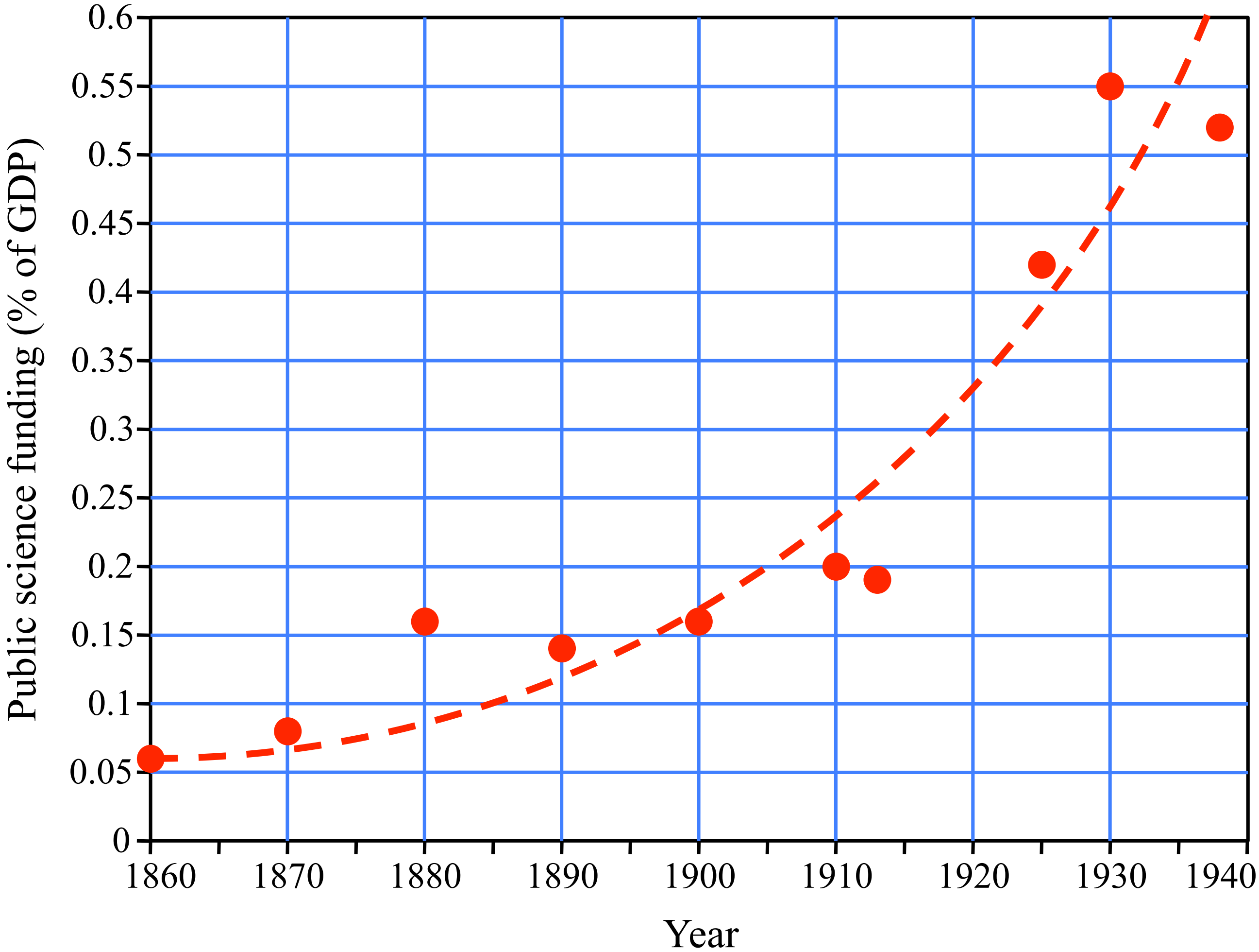

Figure 10.6: Total public science funding in Germany from 1860 to 1938 as a percent of gross domestic product (data points as red circles, extrapolated trend as red dotted line).

In addition to the obvious effect of increased spending resulting in increased research during this more than a century-long period of exponential growth in the German research world, there are less obvious yet critical effects:

- Modern funding levels are nearly flat, and effectively long-term career positions only become available as the people currently holding them retire or die, creating ferocious competition among far too many science graduates for far too few jobs, research grants, and publication slots in high-profile journals. In contrast, because the total funding in the older German-speaking system steadily increased by a factor of 6.8 over typical career times of 40 years, roughly 6.8 times as many graduating students were able to find good jobs in the research system as would have been possible with flat funding levels (assuming that the cost per scientist remained approximately constant). In fact, since some graduating students could find jobs as the German-speaking research world expanded outside Germany, and many graduating students found jobs by emigrating to the United States, United Kingdom, and other countries, the number of graduating students able to find good jobs was significantly higher. The wars in the nineteenth and twentieth centuries also culled a significant percentage of the population. Thus the number of graduating students able to find good research jobs may have been effectively ~ 15 times or more higher for the historical German-speaking world than for the modern research world.

- Greatly increasing the amount of funding and jobs greatly lowered the age at which newly graduated researchers could pursue their own independent research, giving them more years to produce innovations, especially more years when they were young, full of energy, very creative, and less weighed down by family and professional obligations.

- Greatly increasing the amount of funding and jobs greatly reduced the amount of time and energy that researchers had to devote to pursuing funding and jobs, and greatly increased the amount of time and energy that they could devote to conducting actual research.

- Greatly increasing the amount of funding and jobs greatly reduced the pressure both on the researchers and on those responsible for selecting which researchers to support. Reducing that pressure made it much more acceptable for researchers to pursue longer-term work without an immediately demonstrable payoff, as well as more innovative higher-risk work that was less guaranteed to yield results than very incremental, low-risk work. When slots for new researchers were plentiful, it was much easier for employers and sponsors to gamble that some of them would ultimately pay off and some would not.

10.2.3 Mentoring Style

Many creators who were educated in the German-speaking world described the mentorship that they received from their doctoral dissertation advisors. Although there was considerable variation, and not all had a positive experience, a great number of the creators described a style of mentoring that was very different than that typically experienced by Ph.D. students in the modern U.S. system:

- In the German-speaking world, many doctoral advisors (not all, but many) encouraged and supported their students to independently propose and pursue their own research topics and methods. In fact, students were praised and evaluated specifically on how independently they had acted in finding a dissertation topic and carrying out their research on it. In contrast, students in the modern U.S. system are generally expected to work on a specific dissertation topic assigned by their advisor, using the specific methods and materials provided by their advisor, a process which neither teaches nor rewards creativity in young scientists.

- Doctoral advisors in the German-speaking world typically did not claim credit for their students' research. They usually allowed their students to publish or patent the resulting research discoveries by themselves, without adding the doctoral advisor's name to the publication or patent. That was very different than the modern U.S. system, where every resulting publication or patent bears the advisor's name as the authoritative final author, even if the advisor made no real contribution to the actual scientific discovery.

- In the German-speaking world, doctoral advisors generally did not use students as cogs in their own machine. Advisors were expected to serve their students by teaching them, mentoring them, and allowing them to pursue their own independent research. In the modern U.S. system, students typically serve their advisor by carrying out work essential for the advisor's own project, by publishing papers featuring the advisor's name to build up the advisor's reputation, and by helping the advisor to write grant proposals, teach classes, or do anything else requested by the advisor.

- Doctoral advisors in the German-speaking world usually were personally carrying out their own research projects. In laboratories and symposia, various mentors and students were constantly rubbing shoulders as fellow researchers. Such a rich environment provided excellent role models for the students, promoted independence and creativity, and facilitated cross-pollination of ideas among all of the mentors and students. In contrast, doctoral advisors in the modern U.S. system generally spend most of their time writing research grant proposals and issuing orders to their students to carry out specific tasks for those research grants. That modern approach does not give the students good role models for research, does not cultivate independence and creativity, and does not allow many inspiring interactions among all of the mentors and students at the university.

As just a few examples of this mentorship style, the doctoral dissertation experiences of some German-speaking creators are given on the following pages.

Leo Szilard explained that students could either propose their own doctoral dissertation topic or ask their advisor to suggest a topic; Szilard asked his advisor Max von Laue for a topic, but ended up coming up with his own original idea and pursuing that [Weart and Szilard 1978, pp. 9–11]:

> A student of physics had great freedom in those days in Berlin. Boys left high school when they were eighteen years old. They were admitted at the University without any examinations. There were no examinations to pass for four years, during which time the student could study whatever he was interested in. When he was ready to write a thesis, he either thought of a problem of his own or he asked his professor to propose a problem on which he could work. At the better universities, and Berlin belonged to them, a thesis in order to be acceptable had to be a piece of really original work. If the thesis showed the student to be really able and was accepted, the student had to pass an oral exam.
>
> At some point, rather early, I went to von Laue, who was professor of theoretical physics, and asked him whether he would give me a problem on which I could work to get my doctor's degree... I had this problem [in the theory of relativity] which von Laue gave me, but I couldn't make any headway with it. As a matter of fact, I was not even convinced that this was a problem that could be solved. [...]
>
> I went for long walks and I saw something in the middle of the walk; when I came home I wrote it down; next morning I woke up with a new idea and I went for another walk; this crystallized in my mind and in the evening I wrote it down. There was an onrush of ideas, all more or less connected, which just kept on going until I had the whole theory fully developed. It was a very creative period, in a sense the most creative period in my life, where there was a sustained production of ideas. Within three weeks I had produced a manuscript of something which was really quite original.
>
> [...] I took the manuscript to von Laue. I caught him as he was about to leave his class and I told him that while I had not written the paper which he wanted me to write, I had written something else, and I wondered whether he might be willing to read it and tell me whether this could be used perhaps as my dissertation for the Doctor's degree. He looked somewhat quizzically at me, but he took the manuscript. And next morning, early in the morning, the telephone rang. It was von Laue. He said, "Your manuscript has been accepted as your thesis for the Ph.D. degree."

In 1929, Michael Polanyi articulated the German-speaking system of higher education in science [István Hargittai 2016]:

> In Germany the professors grab the students' hands, if he is supposed to be gifted. They are like art collectors whose obsession is discovering talent. They educated me and gave me a position where I could address myself to my abilities. They gave me everything and demanded nothing of me. They trust that who gets to know the joy of scientific work, will never leave it as long as he lives.

Michael Polanyi also practiced the same approach that he had observed and praised. One of his doctoral students was Eugene Wigner. Wigner gave an especially detailed description of how Polanyi mentored him while allowing him to independently pursue his own ideas of how to apply quantum physics to chemical reactions, even though Polanyi himself was not interested in quantum physics [Szanton 1992, pp. 76–81]:

And there at the Kaiser Wilhelm Institute worked a man who decisively marked my life: Dr. Michael Polanyi. Few people in this century have done such fine work in as many fields as Polanyi. After László Rátz of the Lutheran gimnázium, Polanyi was my dearest teacher. And he taught me even more than Rátz could, because my mind was far more mature. After Rátz and my parents, Polanyi was my greatest influence as a young man. [...]

But his finest gift was to encourage my work in physics, and this he did with all of his very great heart. In all my life, I have never known anyone who used encouragement as skillfully as Polanyi. He was truly an artist of praise. And this praise was vital to me because it was often missing at the great afternoon physics colloquia.

Because Polanyi was a decade my senior and held a far higher position, it was not quite proper for him to befriend me as he did. But Polanyi cared nothing for formal questions of age and status. That was part of his great sweetness. Polanyi was concerned instead that young men should love science and labor to understand it. He was concerned that he could never fully share his love and the knowledge he had gathered.

Like me, Polanyi enjoyed asking questions outside the realm of basic science: Why is the world divided into separate nations? Why do all nations have governments? How should a man live his life in a world filled with evil? Polanyi even taught me some poetry. He made learning a great pleasure.

Dr. Polanyi and I did not always see eye to eye. Polanyi found quantum theory too mathematical for his liking. I was the only one in his lab deeply interested in it. [...]

Polanyi advised my doctoral dissertation at the hochschule. I chose a topic far from the crystallography of Weisenberg or Herman Mark: chemical reaction rates. I wondered: How do colliding atoms form molecules? We knew that hydrogen and oxygen make water in a container, but how soon? How much depends on pressure and how much on temperature? I pursued such questions with elements far more complex than hydrogen and oxygen.

Polanyi was a wonderful advisor. He understood chemical reaction rates both in theory and practice. He accepted my proposal that angular momentum is quantized and that the atoms collide in a proportion consistent with Planck's constant. This idea is now widely known, but then it was rather brash. And studying chemical reaction rates taught me much about nuclear reaction rates that would be useful in future years. [...]

So Herman Mark was a strong teacher, but Michael Polanyi was really the miraculous one. Polanyi loved to ask the fundamental question: "Where does science begin?" He listened to the thoughts of others on this question, but he also had his own well-crafted answer: "When a body of phenomena shows coherence and regularity."

Polanyi loved and honored the scientific method with great truth and devotion. He managed to keep all of science within his fond gaze and a great deal more besides. What a mentor Michael Polanyi was.

Herbert Fraenkel recounted how John von Neumann produced his own revolutionary doctoral dissertation in mathematics, a work that bore the stamp of genius so clearly that Fraenkel and other professors who did not know von Neumann but read the draft dissertation could "recognize the lion by its claw" (*ex ungue leonem* in Latin) [Macrae 1992, pp. 95–96]:

> Around 1922–23, being then professor at Marburg University, I received from Professor Erhard Schmidt of Berlin a long manuscript of an author unknown to me, Johannes von Neumann, with the title "Die Axiomatisierung der Mengenlehre" [The Axiomatization of Set Theory], this being his eventual doctoral dissertation... I was asked to express my views since it seemed incomprehensible. I don't maintain that I understood everything, but enough to see that this was an outstanding work and to recognise "ex ungue leonem."

Hans von Ohain's doctoral advisor at the University of Göttingen was Robert Pohl, an expert on solid state and optical physics. Ohain was already independently pursuing his own longer-term ideas which would lead to the first jet aircraft, but he needed to pick a doctoral dissertation research topic that could be accomplished within a shorter period of time. That topic, a microphone that used light waves instead of electricity to pick up sound waves, was also independently proposed and pursued by Ohain. Ohain described how Pohl gave him general advice, encouraged him to create innovations that were as revolutionary as possible, and allowed him to pursue his ideas on his own [Conner 2001, p. 17]:

> He left me pretty much alone, but we had nice discussions about physics and became better acquainted. He gave me one personal lecture that I remember well: "You know, Hans, the thing is this, either you do good physics or you do really creative applications. I would hate to see you, as my student, making nothing out of technology but doodle signs, so to speak, and nothing really creative." I told him about my ideas on the turbine for aircraft and he said, "When you have something which really revolutionizes technology by employing physics, this is fine, but don't do mediocre stuff." He encouraged me very much to go into the applications area because "You have a flair and a talent for that."

Ohain's independence in proposing and pursuing his doctoral dissertation research topic was central to Pohl's written evaluation of that dissertation when it was completed [Conner 2001, p. 23]:

> The light relay constructed by Mr. von Ohain has meaning, not only for the technical purpose specified in the work, but is also adaptable for application in many physical tasks. Mr. von Ohain conceived the idea for this design entirely on his own and carried out the physical investigation of the relay's characteristics with a refreshing self-reliance. With the completion of the work, not only has he pulled off a great experimental undertaking, but also demonstrated the ease with which he could apply his knowledge of theoretical physics to practical problems. I can without reservation recommend a grade of "Very Good" for Mr. von Ohain's work.

Similarly, Wernher von Braun was able to pursue his own ideas for rockets as a doctoral dissertation, with the support of Erich Schumann as his advisor [Neufeld 2007, p. 68]:

> As spring finally came to northern Germany, von Braun completed his University of Berlin physics dissertation, "Design, Theoretical and Experimental Contributions to the Problem of the Liquid-Fuel Rocket," in mid-April. A major section on the theory of combustion in a rocket engine can fairly be described as physics, but most of the typescript was actually an engineering treatise on his rocket motors, the A-1 vehicle, and the test instrumentation. Ordnance considered the work so sensitive that the dissertation was given a cover name, "Regarding Combustion Experiments," a boring and opaque pseudotitle that would appear in his graduation paperwork and on his doctoral diploma. Schumann and Wehnelt, his two examiners in physics, were so impressed with the work that they gave it the Latin distinction "*eximium*"—extraordinary, the highest possible grade.

As shown in Fig. 10.7, in a 14 September 1969 letter (after the first manned moon landing), Wernher von Braun wrote to Erich Schumann [Bundesarchiv Militärarchiv Freiburg N822/6]:

> Angesichts dieses welthistorischen Durchbruchs der Raketentechnik und Raumfahrt denke ich mit besonderer Dankbarkeit an die Hilfestellung und grosszuegige Foerderung zurueck, die Sie mir haben angedeihen lassen. Ich weiss nur zu gut, dass meine berufliche Entwicklung ohne den Erfahrungsschatz und die Anleitung zur systematischen Verfolgung praktischer und theoretischer Entwicklungs- und Forschungsprobleme, die Sie mir seinerzeit zuteil werden liessen, wohl kaum zu dem bisherigen Ziele gefuehrt haette.

> In view of this world-historical breakthrough in rocket technology and space travel, I think back with special gratitude to the support and generous encouragement you have given me. I know only too well that my professional development would hardly have led to my present goals without the wealth of experience and guidance in the systematic pursuit of experimental and theoretical development and research problems that you gave me at the time.

Just as von Ohain and von Braun were allowed to pursue their own revolutionary ideas as students, once they received their Ph.D.s, people like Ernst Heinkel (p. 2021) gave them the freedom and resources to continue to pursue their own ideas. The other creators were similarly successful in being able to continue to pursue their own ideas.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER, ALABAMA 35812

IN REPLY REFER TO: DIR

SEP 14 1969

Herrn Professor
Dr. E. Schumann
Wall 2
493 Detmold / West Germany

Sehr verehrter, lieber Herr Professor Schumann,

Es war fuer mich eine ganz besondere Freude, Ihre Briefe und Glueckwuensche zu erhalten. Darf ich Ihnen hiermit meinen herzlichsten Dank fuer die Gratulationen sagen, die Sie mir liebenswuerdigerweise auch im Namen meiner frueheren Vorgesetzten und Kollegen uebermittelten. Ich bin Ihnen aufrichtigst verbunden fuer Ihre persoenliche Anteilnahme an der ersten Mondlandung unserer Apollo 11-Astronauten. Wie Sie verstehen werden, sind meine hiesigen Mitarbeiter und ich ueberaus gluecklich darueber, dass sich die von uns entwickelte Saturn V-Rakete auf dem Wege zum Mond so gut bewaehrt hat und dass es uns vergoennt war, einen Beitrag zu dieser Pioniertat zu leisten.

Angesichts dieses welthistorischen Durchbruchs der Raketentechnik und Raumfahrt denke ich mit besonderer Dankbarkeit an die Hilfestellung und grosszuegige Foerderung zurueck, die Sie mir haben angedeihen lassen. Ich weiss nur zu gut, dass meine berufliche Entwicklung ohne den Erfahrungsschatz und die Anleitung zur systematischen Verfolgung praktischer und theoretischer Entwicklungs- und Forschungsprobleme, die Sie mir seinerzeit zuteil werden liessen, wohl kaum zu dem bisherigen Ziele gefuehrt haette.

Wir sind hier gerade ueberaus stark mit Plaenen zur Intensivierung der Monderkundung und der Vorbereitung groesserer Raumstationen in Erdumlaufbahnen beschaeftigt. Ich hoffe zuversichtlich, dass der Errichtung des ersten Brueckenkopfs auf einer anderen Welt viele weitere aufschlussreiche Mondexkursionen und Fluege in die Fernen des Weltraums folgen werden.

Mit herzlichsten Gruessen verbleibe ich in steter Dankbarkeit

Ihr sehr ergebener

Wernher von Braun

Wernher von Braun
Direktor

Figure 10.7: 14 September 1969 letter from Wernher von Braun (after the first manned moon landing) thanking Erich Schumann, who had been his Ph.D. advisor in the 1930s [Bundesarchiv Militärarchiv Freiburg N822/6].

It is interesting to note that this frequent (but not universal) style of mentorship in academia was similar to the frequent (though not universal) style of management in science and engineering companies, suggesting that this tendency was a general (but not universal) element of German-speaking culture. For example, immediately after World War II, Allied investigators visited the Leitz company and wrote a glowing report about what they found [BIOS 1436 pp. 10–11]:

> 60. The main items of production at the time of inspection, besides the Leica camera, were binoculars, projection apparatus and microscopes. The microscopes included the H. Powder Binocular, Students, Panphot and Ortholux. [...]
>
> 61. The Leitz factory is a well-run, happy organisation, this being due in no small measure to the family nature of the business and to its importance in the neighborhood. Discipline is strict without being severe and one gets the impression of great interest by employees of every grade in the work being performed.
>
> 62. This pride in workmanship and the just pride all have in their world-wide reputation for quality work is the permeating spirit of the place and helps greatly to offset apathy caused by the present dismal state of the country.
>
> 63. The products coming from the Leitz works are equal to any turned out before the war although in some cases the finish is inferior due to poor materials, especially paints and enamels.
>
> 64. The team came away with the impression that the Leica camera is still worthy of its pre-eminent position and that the skill of the craftsmen is very much in evidence in the Leitz factory.

Thus many German-speaking companies, like many German-speaking academic labs, treated junior members as craftsmen who should be aided and rewarded in developing their own skills and given their proper place. In the modern U.S. system, unfortunately too many senior people in both academia and industry seem to consider students or employees to be interchangeable, disposable units whose primary purpose is to enrich the professors or executives at the top (see Section 1.1 and references therein).

10.2.4 Average Age for Final Degree

The ages at which the German-speaking creators received their highest degrees (not counting those whose education was delayed by factors such as war, work, or illness) tended to be remarkably low by modern standards, or even by the standards of the early U.S. research system. A major reason is that in the older German-speaking world, students could (and very often did) graduate from the Gymnasium (the German-speaking equivalent of a U.S. high school) at age 18 or so, then directly enter a doctoral program at a university and receive their final degree four or so years later.[2] In contrast, students in most of the modern world (and even in the early U.S. research system) typically spend many years earning a bachelor's degree (and often a master's degree) between the time they graduate from high school and when they finally enter a doctoral program. Modern doctoral programs can also be much longer than those in the earlier German-speaking world, although that does not necessarily mean that they are better.

As a representative data set to illustrate this pattern of ages for final degrees, one can consider scientists who were educated primarily or entirely in the German-speaking world and:

1. Won a Nobel Prize in Physiology or Medicine prior to 1991 (Table 10.3, choosing this cutoff date to exclude most of those who were educated after 1945).

2. Won a Nobel Prize in Chemistry prior to 1991 (Table 10.4).

3. Won a Nobel Prize in Physics prior to 1991 (Table 10.5).

4. Created certain major innovations but did not win a Nobel Prize (Table 10.6, to pick some representative major creators who worked in fields such as engineering, mathematics, earth science, and other areas not considered for Nobel Prizes).

In order to keep the data set focused on the German-speaking educational system, scientists who had some of their training in that system but a significant part of their training outside that system (e.g., Americans such as Irving Langmuir who completed their education in Germany, or Germans such as Ernst Chain who completed their education outside the German-speaking world) are omitted from these tables.

Unless otherwise noted, all of the individuals in these four tables graduated with a Ph.D. Where noted, some received an M.D. (especially among the winners of a Nobel Prize in Physiology or Medicine). As indicated in the tables, a handful of these individuals (such as Albert Einstein) graduated with a final degree that was not a doctorate. As also noted, a few individuals were delayed in receiving their final degree, due to military service, war disruptions, serious illness, or work obligations.

[2] See for example: Arnold 1882; Ash 1997; Beier 1902; Ben-David 1992; Brown 1911; Herrlitz 2009; Paulsen 1906, 1908; Röhrs 1995; Russell 1899; Schrader 1893; Schwinges 2007.

Students could graduate at any time of year, depending on when their doctoral thesis was completed and approved. In most cases only the year of graduation and not the exact date was readily available. In such cases, the graduation was assumed to have occurred on average in the middle of the year, and the students' ages at graduation calculated accordingly. Any errors caused by this assumption should mostly cancel each other out when averages are taken over entire groups of people.

Nobel Prize	Name	Born	Graduated	Age
1901	Emil von Behring	15 March 1854	1878	24 (M.D.)
1905	Robert Koch	11 December 1843	January 1866	22 (M.D.)
1908	Paul Ehrlich	14 March 1854	1882	28 (M.D., work)
1909	Theodor Kocher	25 August 1841	March 1865	23 (M.D.)
1910	Albrecht Kossel	16 September 1853	1877	23 (M.D.)
1914	Róbert Bárány	22 April 1876	1900	24 (M.D.)
1922	Otto Meyerhof	12 April 1884	1909	25 (M.D.)
1924	Willem Einthoven	21 May 1860	1885	25 (M.D.)
1927	Julius Wagner-Jauregg	7 March 1857	1880	23 (M.D.)
1929	Christiaan Eijkman	11 August 1858	13 July 1883	24 (M.D.)
1930	Karl Landsteiner	14 June 1868	1891	23 (M.D.)
1931	Otto Warburg	8 October 1883	1906	22
1935	Hans Spemann	27 June 1869	1895	25 (work)
1936	Otto Loewi	3 June 1873	1896	23
1937	Albert Szent-Györgyi	16 September 1893	1917	23 (M.D.)
1939	Gerhard Domagk	30 October 1895	1921	25 (M.D., war)
1947	Carl Cori	5 December 1896	1920	23 (M.D.)
1947	Gerty Cori	15 August 1896	1920	23 (M.D.)
1948	Paul Müller	12 January 1899	1925	26 (work)
1949	Walter Hess	17 March 1881	1906	25 (M.D.)
1950	Tadeusz Reichstein	20 July 1897	1922	24 (work)
1953	Hans Krebs	25 August 1900	1925	24 (M.D.)
1953	Fritz Lipmann	12 June 1899	1924	24
1956	Werner Forssmann	29 August 1904	1929	24 (M.D.)
1957	Daniel Bovet	23 March 1907	1929	22
1961	Georg von Békésy	3 June 1899	1926	26 (war)
1964	Feodor Lynen	6 April 1911	March 1937	25
1969	Max Delbrück	4 September 1906	1930	23
1973	Karl von Frisch	20 November 1886	1910	23
1973	Konrad Lorenz	7 November 1903	1928	24 (M.D.)
1973	Nikolaas Tinbergen	15 April 1907	Spring 1932	25
1978	Werner Arber	3 June 1929	1958	29 (military)
1984	Georges Köhler	17 April 1946	April 1974	28 (work)

Table 10.3: Ages at final degree for scientists who were educated primarily or entirely in the German-speaking world and won a Nobel Prize in Physiology or Medicine prior to 1991.

Nobel Prize	Name	Born	Graduated	Age
1901	Jacobus van 't Hoff	30 August 1852	1874	21
1902	Emil Fischer	9 October 1852	1874	21
1905	Adolf von Baeyer	31 October 1835	1858	22
1907	Eduard Buchner	20 May 1860	1888	28 (work)
1909	Wilhelm Ostwald	2 September 1853	1878	24
1910	Otto Wallach	27 March 1847	1869	22
1913	Alfred Werner	12 December 1866	1890	23
1915	Richard Willstätter	13 August 1872	1894	21
1918	Fritz Haber	9 December 1868	May 1891	22
1920	Walther Nernst	25 June 1864	1887	22
1923	Fritz Pregl	3 September 1869	1894	24 (M.D.)
1925	Richard Zsigmondy	1 April 1865	1889	24
1927	Heinrich Wieland	4 June 1877	1901	24
1928	Adolf Windaus	25 December 1876	1900	23
1929	Hans von Euler-Chelpin	15 February 1873	1895	22
1930	Hans Fischer	27 July 1881	1908	26 (M.D.)
1931	Carl Bosch	27 August 1874	1898	23
1931	Friedrich Bergius	11 October 1884	1907	22
1936	Peter Debye	24 March 1884	1908	24
1937	Paul Karrer	21 April 1889	1911	22
1938	Richard Kuhn	3 December 1900	1922	21
1939	Adolf Butenandt	24 March 1903	1927	24
1939	Leopold Ružička	13 September 1887	1910	22
1943	George de Hevesy	1 August 1885	1908	22
1944	Otto Hahn	8 March 1879	1901	22
1950	Otto Diels	23 January 1876	1899	23
1950	Kurt Alder	10 July 1902	1926	23
1953	Hermann Staudinger	23 March 1881	1903	22
1959	Jaroslav Heyrovský	20 December 1890	1918	27 (war)
1963	Karl Ziegler	26 November 1898	1920	21
1967	Manfred Eigen	9 May 1927	1951	24 (war)
1971	Gerhard Herzberg	25 December 1904	1928	23
1973	Ernst Otto Fischer	10 November 1918	1952	33 (war)
1975	Vladimir Prelog	23 July 1906	1929	22
1979	Georg Wittig	16 June 1897	1926	29 (war)
1988	Johann Deisenhofer	30 September 1943	1974	30 (military)
1988	Robert Huber	20 February 1937	1963	26 (military)
1988	Hartmut Michel	18 July 1948	June 1977	28 (military)

Table 10.4: Ages at final degree for scientists who were educated primarily or entirely in the German-speaking world and won a Nobel Prize in Chemistry prior to 1991.

Nobel Prize	Name	Born	Graduated	Age
1901	Wilhelm Röntgen	27 March 1845	1869	24
1902	Hendrik Lorentz	18 July 1853	1875	21
1902	Pieter Zeeman	25 May 1865	1893	28
1905	Philipp Lenard	7 June 1862	1886	24
1909	Karl Braun	6 June 1850	1872	22
1910	Johannes van der Waals	23 November 1837	June 1873	35 (work)
1911	Wilhelm Wien	13 January 1864	1886	22
1913	Heike Kamerlingh Onnes	21 September 1853	1879	25
1914	Max von Laue	9 October 1879	1903	23
1918	Max Planck	23 April 1858	February 1879	20
1919	Johannes Stark	15 April 1874	1897	23
1921	Albert Einstein	14 March 1879	1900	21 (no doctorate)
1925	James Franck	26 August 1882	1906	23
1925	Gustav Hertz	22 July 1887	1911	23
1932	Werner Heisenberg	5 December 1901	1923	21
1933	Erwin Schrödinger	12 August 1887	1910	22
1936	Victor Francis Hess	24 June 1883	1910	26
1943	Otto Stern	17 February 1888	1912	24
1945	Wolfgang Pauli	25 April 1900	July 1921	21
1952	Felix Bloch	23 October 1905	1928	22
1953	Frits Zernike	16 July 1888	1915	26
1954	Max Born	11 December 1882	1906	23
1954	Walther Bothe	8 January 1891	1914	23
1961	Rudolf Mössbauer	31 January 1929	1958	29 (work)
1963	Eugene Wigner	17 November 1902	1925	22
1963	Maria Goeppert Mayer	28 June 1906	1930	23
1963	Johannes Hans Jensen	25 June 1907	1932	24
1967	Hans Bethe	2 July 1906	1928	22
1971	Dennis Gabor	5 June 1900	1927	27 (war)
1984	Simon van der Meer	24 November 1925	1952	26 (war)
1985	Klaus von Klitzing	28 June 1943	1972	28 (work)
1986	Ernst Ruska	25 December 1906	1933	26
1986	Gerd Binnig	20 July 1947	1978	30 (work)
1986	Heinrich Rohrer	6 June 1933	1960	27 (military)
1987	Johannes Georg Bednorz	16 May 1950	1982	32 (work)
1987	Karl Alexander Müller	20 April 1927	1957	30 (war)
1989	Hans Georg Dehmelt	9 September 1922	1950	27 (war)
1989	Wolfgang Paul	10 August 1913	1940	26 (war)

Table 10.5: Ages at final degree for scientists who were educated primarily or entirely in the German-speaking world and won a Nobel Prize in Physics prior to 1991.

Field	**Name**	**Born**	**Graduated**	**Age**
Aerospace	Wernher von Braun	23 March 1912	1934	22
Aerospace	Adolf Busemann	20 April 1901	1924	23
Aerospace	Hans von Ohain	14 December 1911	1935	23
Aerospace	Herbert Wagner	22 May 1900	1923	23 (war)
Biology	Edith Bülbring	27 December 1903	May 1928	24 (M.D.)
Biology	Alfred Kühn	22 April 1885	1908	23
Biology	Erwin Popper	9 December 1879	1903	23 (M.D.)
Chemistry	Gerhard Herzberg	25 December 1904	1928	23
Chemistry	August Kekulé	7 September 1829	1852	22
Earth science	Beno Gutenberg	4 June 1889	1911	22
Earth science	Alfred Wegener	1 November 1880	1905	24 (work)
Electronics	Paul Eisler	1907	1930	23
Electronics	Julius Lilienfeld	18 April 1882	18 February 1905	22
Electronics	Heinz Schlicke	13 December 1912	1937	24
Mathematics	Richard Courant	8 January 1888	1910	22
Mathematics	John von Neumann	28 December 1903	1926	22
Mathematics	Hermann Weyl	9 November 1885	1908	22
Mechanical	Rudolf Diesel	18 March 1858	January 1880	21 (no doctorate)
Mechanical	Wilhelm Nusselt	25 November 1882	1907	24
Optics	Ernst Abbe	23 January 1840	23 March 1861	21
Physics	Edward Teller	15 January 1908	1930	22
Physics	Carl Friedrich von Weizsäcker	28 June 1912	1933	21
Physics	Arnold Sommerfeld	5 December 1868	24 October 1891	22
Physics	Victor Weisskopf	19 September 1908	1931	22
Physics	Hans Geiger	30 September 1882	23 July 1906	23
Physics	Leo Szilard	11 February 1898	1922	24 (war)

Table 10.6: Ages at final degree for selected scientists who were educated primarily or entirely in the German-speaking world and created major innovations but did not win a Nobel Prize.

Table 10.7 summarizes the average ages at graduation for the scientists from Tables 10.3–10.6, excluding those whose education was delayed by war, work, or illness. These German-speaking creators tended to receive their highest degree at:

- Between ages 22 and 23 for a Ph.D. This pattern holds across all fields, as illustrated by the examples in Tables 10.3–10.7.

- Between ages 23 and 24 for an M.D. In the German-speaking world, obtaining an M.D. generally required about one year longer than obtaining a Ph.D.

Using these same methods, Section 11.2.4 analyzes the ages at graduation for scientists who were educated primarily or entirely in the United States and won a Nobel Prize in Physiology or Medicine, Chemistry, or Physics prior to 1991. For ease of comparison, the results of that analysis (again excluding those whose educations were delayed) are also summarized here in Table 10.7. As may be seen, on average those U.S.-educated scientists took approximately two years longer to complete their education than their contemporary counterparts from the German-speaking world. A two-year head start on an independent research career can be quite significant, especially when those are two years when the scientists are at the peak of their creative powers and energies, and presumably less hindered by obligations to family and bureaucracy than they would be later in their careers.

As a further comparison, the current situation in the U.S. educational system is even worse. For those receiving a doctorate in 2017, the median age at graduation was 31.6 [https://ncses.nsf.gov/pubs/nsf19301/data]. That is nearly a decade older than students who received a Ph.D. from the earlier German-speaking world.

Category of people	**Age at graduation from German-speaking world**	**Age at graduation from U.S. system**
Ph.D., Physics Nobel 1901–1990	23.2 years	25.1 years
Ph.D., Chemistry Nobel 1901–1990	22.4 years	24.7 years
Ph.D., Medicine Nobel 1901–1990	23.6 years	25.2 years
M.D., Medicine or Chemistry Nobel	23.8 years	25.0 years
Final degree, all science Nobelists	23.0 years	24.9 years
Ph.D., non-Nobel sample	22.4 years	—
Ph.D., Nobel + non-Nobel sample	22.7 years	25.0 years
M.D., Nobel + non-Nobel sample	23.8 years	25.0 years
Final degree, Nobel + non-Nobel sample	22.9 years	24.9 years

Table 10.7: Ages at final degree for selected scientists educated in German-speaking and U.S. systems.

A modern observer might object that students need to learn much more now, yet physics, chemistry, mathematics, engineering, and other fields had already been well developed by the early twentieth century, and German-speaking students took extensive coursework in them. For example, Hans Bethe's university transcripts show that he took the courses listed in Table 10.8 [Schweber 2012, pp. 402–403, 419–420]:

Differential and Integral Calculus I with Exercises	Physical Laboratory for Advanced Students
Higher Arithmetic	General Chemistry II: Atomics
Exercises for Higher Arithmetic	Chemical Laboratory in Inorganic Chemistry
Experimental Physics I	Continuum Mechanics (Carathéodory)
The Experimental Foundations of Atomistics	Physical Chemistry II
General Chemistry I (Inorganic Chemistry)	Chemical Forces and Constitution
Accounting with Exercises	Partial Differential Equations of Physics
Mechanics	Exercises—Partial Differential Equations of Physics
Exercises in Mechanics	Theory of Magnetism
Experimental Physics II	Theory of Band Spectra
General Physical Chemistry	Dispersion of Light and X-Rays
General Chemistry II (Inorganic Chemistry)	Physics Exercises for Advanced Students
Seminar on Inorganic Chemistry	Psychology
Inorganic Chemistry Laboratory	Introduction to Politics
The Mechanical and Electrical Properties of Matter	Electrochemistry
The Foundations of Modern Physics	Experiments in Electricity and Light
Organization of People and States	Theoretical Physics Seminar
Differential Geometry	Exercises—Mechanics
Special Topics in Theoretical Physics (Quantum Theory, Theory of Relativity)	Selected Problems in Quantum Theory
Modern Spectroscopy	Experimental Physics for Advanced Students
Physics Laboratory for Beginners	The Political Parties of the Reichstag
Electrochemistry	Colloid Chemistry
Chemical Thermodynamics	Experimental Methods, Properties, and the Theory of Crystal Lattices
Seminar on Inorganic Chemistry	Continuum Mechanics (Sommerfeld)
Chemical Laboratory in Inorganic Chemistry	Exercises—Continuum Mechanics
Differential Equations in the Real Domain	Structure of Matter
Exercises in Differential Equations	Electrodynamics
Mechanics	Exercises—Electrodynamics
Advanced Experimental Physics I: Mechanics, Acoustics, Heat	Quantum Mechanics
Exercises in Advanced Experimental Physics	Physics of the Sun
Universal Physical Constants and the Methods of Their Determination	Optics
Exercises in Theoretical Physics	Wave Mechanics
	Theoretical Physics Seminar (Summer 1927)
	Theoretical Physics Seminar (Winter 1927)
	Theoretical Physics Seminar (Summer 1928)

Table 10.8: University courses taken by Hans Bethe.

Lest one worry that the quality of the above courses may not have matched their quantity, it should be noted that the classes on Bethe's transcript were personally taught by Walther Gerlach, Otto Hahn, Arnold Sommerfeld, Wilhelm Wien, and other scientific luminaries.

Bethe's university transcript is fairly typical for German-speaking science students of that time. The courses in a Gymnasium were so extensive, so advanced, and so rigorous that German-speaking students graduated at age 18 or so having already learned much of what modern students learn after high school for their bachelor's degree. Moreover, doctoral dissertations at German-speaking universities tended to focus much more on the novelty of the student's ideas and solutions than on how many years the student had toiled on that research. That allowed students in German-speaking doctoral programs to still spend several years taking a wide range of university courses. In contrast, many modern doctoral programs only allow students to take a few courses before they are expected to spend many years on the research assembly line for the rest of the program.

One might try to argue that modern Ph.D. students accomplish much more than students in the older German-speaking world by spending more of their university years doing research. However, the dissertation research of the German-speaking creators resulted in some of the seminal papers in their fields, whereas modern Ph.D. students may spend years toiling away primarily to pad their Ph.D. advisor's CV with extra papers that few people ever read.

The net effect is that the German-speaking creators were free to pursue independent research careers on average approximately two years sooner than their contemporary peers in the United States, and nearly a decade sooner than modern U.S. scientists. Relative to modern scientists, that means not just nearly a decade of additional work, but nearly a decade of additional work performed when the scientists were at their peak energy and creativity in life, and also generally less weighed down by family and professional obligations. That difference is demonstrated by the dramatic accomplishments of most of the German-speaking creators by the time they had reached 31 or 32 years old, the age at which average Ph.D. students are just finally graduating in the modern United States.

In fact, the real difference is even larger than that. Many (though certainly not all) of the German-speaking creators were able to conduct truly independent research as soon as they obtained their doctoral degrees, if not before. In contrast, scientists who receive a Ph.D. or M.D. in the modern U.S. system typically then have to spend many years following older supervisors' instructions in postdoctoral jobs (often multiple postdoctoral jobs in a row), residencies, or entry-level positions at corporate or government laboratories.

In 2020, the average age at which Ph.D. scientists received their first National Institutes of Health (NIH) research project grant was 43, and the average age at which M.D. scientists received their first NIH research grant was 46 [https://nexus.od.nih.gov/all/2021/11/18/long-term-trends-in-the-age-of-principal-investigators-supported-for-the-first-time-on-nih-r01-awards/]. **Thus many German-speaking creators achieved scientific and creative independence two whole decades in life earlier than scientists in the modern U.S. system.**

As discussed in more detail in Chapter 12, this data suggests that one way to improve the modern innovation system would be to eliminate redundancies between high school and undergraduate education, streamline the graduate school educational process, greatly lower the average ages at which scientists receive their final degrees and their first financial grants, and give young scientists much more independence during their most energetic and creative years.

10.2.5 Interdisciplinary Approach

Scientists who made major contributions to multiple disciplines, and fraternization among scientists from different disciplines, were much more common in the older German-speaking world than in the modern world. That interdisciplinary approach apparently facilitated production of and support for innovators and innovations.

Although broadly supportive innovation systems did not begin to assume a coherent form in the German-speaking world until the early nineteenth century, there were many examples of individual German-speaking creators who arose earlier, and who served as role models for the much larger numbers of later creators. Most of those early role models were strongly interdisciplinary, and they were revered by the German-speaking world for that trait (among others). As shown in Fig. 10.8, some examples included:

- Athanasius Kircher (German states, 1602–1680), who conducted groundbreaking research on geology and microbiology, analyzed Egyptian hieroglyphs, and built novel clocks, image projectors, and musical instruments [Findlen 2004; Joscelyn Godwin 2009].

- Gottfried Leibniz (Saxony, 1646–1716), who made major contributions to math, physics, engineering, computing machinery, geology, paleontology, biology, economics, philosophy, and other subjects [Antognazza 2009].

- Leonhard Euler (Swiss, 1707–1783), who did seminal work in math, physics, engineering, astronomy, optics, fluid mechanics, logic, and other areas [Calinger 2015; Richeson 2008].

- Johann Wolfgang von Goethe (German states, 1749–1832), who was revered for his novels, plays, poetry, memoirs, and studies in geology, paleontology, botany, color, and other fields [Douglas Miller 1988].

- Alexander von Humboldt (Prussian, 1769–1859), who made major contributions to botany, geography, meteorology, archaeology, and other subjects [Wulf 2015].

- Wilhelm von Humboldt (Prussian, 1767–1835), Alexander's older brother, who did important work in linguistics, philosophy, and political science, but had the greatest impact on the development of all levels of education in the German-speaking world [Borsche 1990].

These and other early multidisciplinary role models had a profound impact on the developing German-speaking innovation systems, making the German-speaking world especially enthusiastic about training, employing, and celebrating multidisciplinary scholars. In particular, Wilhelm von Humboldt's ideas were central to the German-speaking education and research systems. As already noted (see p. 1977), those ideas of Bildung included (1) promoting learning for its own sake, not just to enter a career, which encouraged education that was much broader than was actually needed by any specific job, and (2) promoting lifelong learning, long after leaving formal schools, which allowed a person to explore more and more fields over the course of a lifetime.

Figure 10.8: Some examples of very early, highly influential interdisciplinary scholars in the German-speaking world included Athanasius Kircher, Gottfried Leibniz, Leonhard Euler, Johann Wolfgang von Goethe, and the brothers Alexander and Wilhelm von Humboldt.

As a result of this longstanding and deeply ingrained multidisciplinary culture in the German-speaking world, there were a large number of creators in the nineteenth and twentieth centuries who made major contributions to multiple fields. Tables 10.9–10.10 list some representative examples. Even scientists who only worked in one field frequently rubbed shoulders with those in other fields, as students, as professors, at seminars and conferences, and in the coffeehouses outside of work. All of these interactions served to promote new insights and innovations within fields and cross-fertilization of ideas between fields.

That broad, interdisciplinary approach is in stark contrast to the microspecialization that is widespread in modern education and research.

Creator	**Fields of creations**
Otto Ambros	Magnetic recording, synthetic rubber, organophosphates
Manfred von Ardenne	Television, electron microscopes, radar, nuclear physics, plasma physics
Heinrich Barkhausen	Magnetic recording, radar
Emil(e) Berliner	Microphone, record player, helicopter
Friedrich Bessel	Astronomy, mathematics
Felix Bloch	Solid state physics, NMR/MRI, nuclear physics, radar
Konrad Bloch	Cholesterol metabolism, hormones, fatty acid metabolism
Karl Braun	Radio, television, radar, semiconductor devices
Adolf Butenandt	Hormones, gene mutations
Peter Debye	Photons, solid state physics, solution chemistry, polymers, X-ray diffraction
Max Delbrück	Quantum electrodynamics, radiation, DNA mutations, bacteriophage
Krafft Ehricke	Rockets, nuclear engineering, solar system
Walter Elsasser	Quantum physics, nuclear physics, geomagnetism, systems biology
Anton Flettner	Teleoperated robots for land, water, and air; rotor ships; helicopters
James Franck	Photoelectric effect, nuclear physics, photosynthesis
Otto Frisch	Quantum physics, nuclear physics, laser scanning
Gustav Fritsch	Neuroanatomy, zoology, astronomy, ethnography
Herbert Fröhlich	Solid state physics, biophysics
George Gamow	Nuclear physics, cosmology, genetic code
Carl Friedrich Gauss	Mathematics, astronomy, electromagnetism, telegraph
Thomas Gold	Astronomy, biophysics, aerospace engineering, geophysics
Peter Goldmark	Television, phonograph, magnetic recording
Hermann Grassmann	Math, physics, linguistics
Helmut Gröttrup	Avionics, rockets, chip card
Erich Habann	Radar, rockets, semiconductors
Hermann von Helmholtz	Vision, hearing, electromagnetism, thermodynamics
Ulrich Henschke	Prostheses, neural interfaces, cancer brachytherapy, flight simulators
Gerhard Herzberg	Molecular spectroscopy, molecular structures, free radicals
George de Hevesy	Chemistry, nuclear physics, biomolecule isotope labels
Fritz Houtermans	Nuclear physics, astrophysics, geophysics

Table 10.9: Some examples of German-speaking creators who made contributions in multiple fields.

Creator	**Fields of creations**
Gustav Franz Hüttig	Nuclear physics, radar, rockets
Theodore von Kármán	Solid state physics, aerodynamics, R&D strategy
Gustav Kirchhoff	Circuits, spectroscopy, elements, thermal radiation
Richard Kuhn	Vitamins, organophosphates, antibiotics
Hermann Lehmann	Hemoglobin, pharmacokinetics
Ernst Mach	Aerodynamics, optics, relativity, hearing/balance
Hans Mauch	Jets, prostheses, neural interfaces, space suits, aviation controls
Walther Nernst	Thermodynamics, chemistry, solid state physics, acoustics
John von Neumann	Mathematics, computers, physics, economics, etc.
Heinrich Olbers	Astronomy, mathematics, ophthalmology, vaccination
Rudolf Peierls	Solid state physics, Manhattan Project
Auguste Piccard	Atmospheric science, cosmic rays, oceanography
Michael Polanyi	Physical chemistry, materials science, medicine, economics, philosophy, epistemology, etc.
Eugen Sänger	Space shuttles, ramjets, antimatter propulsion
Rudolf Schoenheimer	Biomolecule isotope labels, cholesterol/atherosclerosis
Erwin Schrödinger	Quantum physics, color vision, theoretical biology
Erich Schumann	Acoustics, shaped explosive charges, nuclear physics, rockets, biological weapons, chemical weapons
Werner von Siemens	Sea mines, telegraph, electric elevator, dynamos, speaker, trolley
Leo Szilard	Nuclear physics, statistical physics, molecular biology, etc.
Edward Teller	Nuclear physics, physical chemistry, climate change, etc.
Stanislaw Ulam	Nuclear engineering, computers, mathematics, bioinformatics
Rudolf Virchow	Cell biology, pathology, sanitation, archaeology
Herbert Wagner	Wings, jet engines, smart bombs, missiles, nuclear engineering
Hellmuth Walter	Rockets, aircraft, submarines
Emil Wiechert	Electron, electromagnetic fields, seismography, geophysics
Eugene Wigner	Physical chemistry, nuclear engineering, particle physics
Richard Willstätter	Chlorophyll, chromatography, gas mask filters, enzymes
Karl Zimmer	Nuclear physics, DNA mutation
Fritz Zwicky	Jet propulsion, astrophysics, ionic crystals and electrolytes

Table 10.10: More examples of German-speaking creators who made contributions in multiple fields.

10.2.6 Scientific Leadership and Decision-Making Style

During the nineteenth and early twentieth centuries, German-speaking areas in Europe often tended toward rather autocratic styles of government, with examples including numerous regional monarchies before 1871 and some afterward, Otto von Bismarck, Kaiser Wilhelm II, and the Third Reich [Berghahn 2005; Fullbrook 2004; Kitchen 1996; Mann 1968; Thomson 1962]. Perhaps because of this culture, the German-speaking research world during this time was also populated by a number of autocratic leaders. Of course, an autocratic scientific leader can do great harm if that individual is personally malicious and/or scientifically incompetent, as demonstrated by the profoundly negative impact of Joseph Stalin's hand-picked biology leader Trofim Lysenko (1898–1976) on real biologists and real biology research in the Soviet Union for many decades. However, if autocratic scientific leaders are very well-intentioned and well-informed, they can potentially bypass a number of bureaucratic obstacles, champion promising ideas and talented scientists that might otherwise be overlooked by the crowd, and push rapid and sustained progress in key areas of research. The German-speaking research world appears to have greatly benefited from a number of such "enlightened despots" or technocrats during the nineteenth and early twentieth centuries.

These enlightened despots had different individual styles, various opportunities, and differing levels of success. They were all imperfect in their scientific judgment and/or personal character. Indeed, some of them had profound moral flaws that certainly should not be countenanced, let alone emulated. Nonetheless, like their counterparts in the 1940s–1960s U.S. research system (Section 11.2.6), each of these German-speaking despots had three characteristics that could also be useful in the modern research system:

- The strong and direct support of very high authorities (in many cases to the very top of the government).
- A keen eye for revolutionary innovators and innovations.
- The ability to directly offer steady employment and funding for any innovators and innovations they deemed worthy, essentially unencumbered by any bureaucratic processes for application, review, approval, renewal, etc.

There were many examples of such enlightened despots in the German-speaking world; just a few are given in this section.

Justus von Liebig (German, 1803–1873), shown in Fig. 10.9, is considered the founder of organic chemistry and made major discoveries in biochemistry and botany. However, he made an even greater impact by designing the first formal university teaching curriculum and research program for chemistry, successfully lobbying for government funding for it, and recruiting and training over 700 students. Thus he was the father of all of the chemistry research and education system for which Germany became so famous, and the earliest of the enlightened scientific despots presented here. In the next century, the Nobel-Prize-winning chemist Fritz Haber wrote of von Liebig [Farber 1961, p. 537]:

> He felt in himself the call for an accomplishment for which no man's strength and life span could be sufficient. He meant to build up chemistry, of which there was nothing in Germany, and outside of Germany only a modest knowledge in the realm of inanimate nature, so richly and splendidly that there would be order, light, coherence, and system. Through his example and his teaching he meant to show the direction and pave the way for young people, the path which led to an understanding of the events in animate nature, and a new flourishing of industry. What he wanted has become in our day the common will of a great branch of science that he created. What we have gained was accomplished because the succeeding generations stood on his shoulders.

Leopold Graf von Thun und Hohenstein (Austrian, 1811–1888), also shown in Fig. 10.9, was the Austrian minister of education 1849–1860. In that capacity, he had a great impact by reforming Austrian universities and other schools and by hiring very innovative scientists and engineers. *Encyclopedia Britannica* summarized his approach [EB 1911, https://en.wikisource.org/wiki/1911_Encyclopædia_Britannica/Thun-Hohenstein]:

> At first he threw himself with great energy into the task of building up an adequate system of schools. He summoned experienced teachers, Protestant as well as Catholic, from Germany, established middle and higher schools in all parts of the empire, superseded the antiquated textbooks and methods of instruction, and encouraged the formation of learned societies and the growth of a professional spirit and independence among the teachers. It is noticeable that at this time he insisted on the use of German in all schools of higher education. [...] His high social position, his influence at court, his character, as well as his undoubted abilities and learning, not often in Austria found in a man of his rank, gave him great influence.

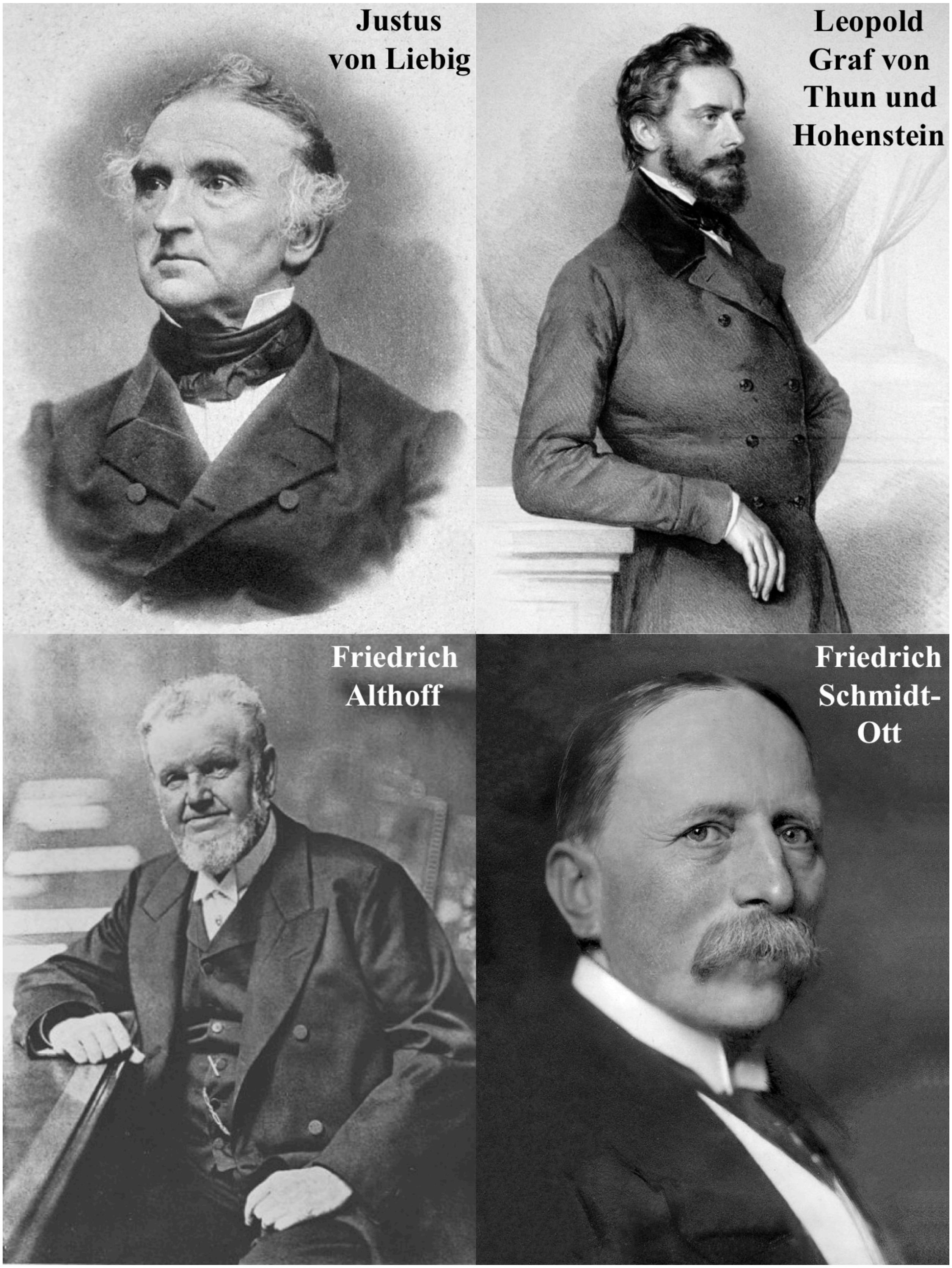

Figure 10.9: Examples of scientific "enlightened despots" who had a very large impact on the German-speaking world: Justus von Liebig, Leopold Graf von Thun und Hohenstein, Friedrich Althoff, and Friedrich Schmidt-Ott.

Friedrich Althoff (German, 1839–1908), shown in Fig. 10.9, was perhaps the most important enlightened scientific despot in the history of the German-speaking world [Baumgart 1980; vom Brocke 1991b; Sachse 1928; Senn 1993]. Althoff's major position was the Prussian minister of culture for a quarter of a century, 1882–1907, in which capacity he held state government funding power over educational and research institutions within the Prussian state of the larger unified Germany. Yet because Prussia was the founding and most powerful state of unified Germany, and because Althoff had so many powerful connections and was so talented with Machievellian political methods behind the scenes, his power was immense and reached throughout the German-speaking world, even assisting Arnold Sommerfeld in Bavaria.

Althoff gave direct financial and political support to a large number of scientists who ultimately made major discoveries, many of whom in turn also acted as enlightened despots to offer financial and political support to later talented young scientists. Some scientists and engineers who directly benefited from Althoff's support included:

- **Emil von Behring (German, 1854–1917)**, who would win a Nobel Prize in 1901 for developing therapeutic antibodies.
- **Paul Ehrlich (German, 1854–1915)**, who would win a Nobel Prize in 1908 for his work on immunology and therapeutics.
- **Heinrich Hertz (German, 1857–1894)**, who demonstrated electromagnetic waves and laid the foundation for everything from radio to radar.
- **Felix Klein (German, 1849–1925)**, shown in Fig. 10.10, who introduced a number of innovations in mathematics but even more importantly built up the University of Göttingen as a major research and educational center with direct assistance from Althoff.
- **Robert Koch (German, 1843–1910)**, shown in Fig. 10.10, who would win a Nobel Prize in 1905 for studying bacterial infections.
- **Walther Nernst (German, 1864–1941)**, who would win a Nobel Prize in 1920 for physical chemistry.
- **Max Planck (German, 1858–1947)**, shown in Fig. 10.10, who would win a Nobel Prize in 1918 for quantum physics, handled all theoretical physics papers in the major physics journal, *Annalen der Physik*, almost single-handedly from 1895 until 1943, and educated and supported a large number of young scientists including Max Abraham, Walther Bothe, Gustav Hertz, Erich Kretschmann, Max von Laue, Julius Lilienfeld, Walther Meissner, Lise Meitner, Fritz Reiche, Moritz Schlick, and Walter Schottky.
- **Ludwig Prandtl (German, 1875–1953)**, shown in Fig. 10.10, who pioneered mathematical aerodynamics and was also a strong political advocate for the same agenda as Althoff.
- **Arnold Sommerfeld (German, 1868–1951)**, shown in Fig. 10.11, who pioneered much of quantum and solid state physics, and who found, mentored, and supported a vast number of talented young scientists including Karl Bechert, Hans Bethe, Peter Debye, Paul Epstein, Paul Ewald, Herbert Fröhlich, Erwin Fues, Ernst Guillemin, Werner Heisenberg, Walter Heitler, Helmut Hönl, Ludwig Hopf, Walther Kossel, Adolf Kratzer, Herbert Krömer, Alfred Landé, Otto Laporte, Wilhelm Lenz, Wolfgang Pauli, Linus Pauling, Rudolf Peierls, Walter Rogowski, Werner Romberg, Rudolf Seeliger, Heinrich Welker, and Gregor Wentzel.

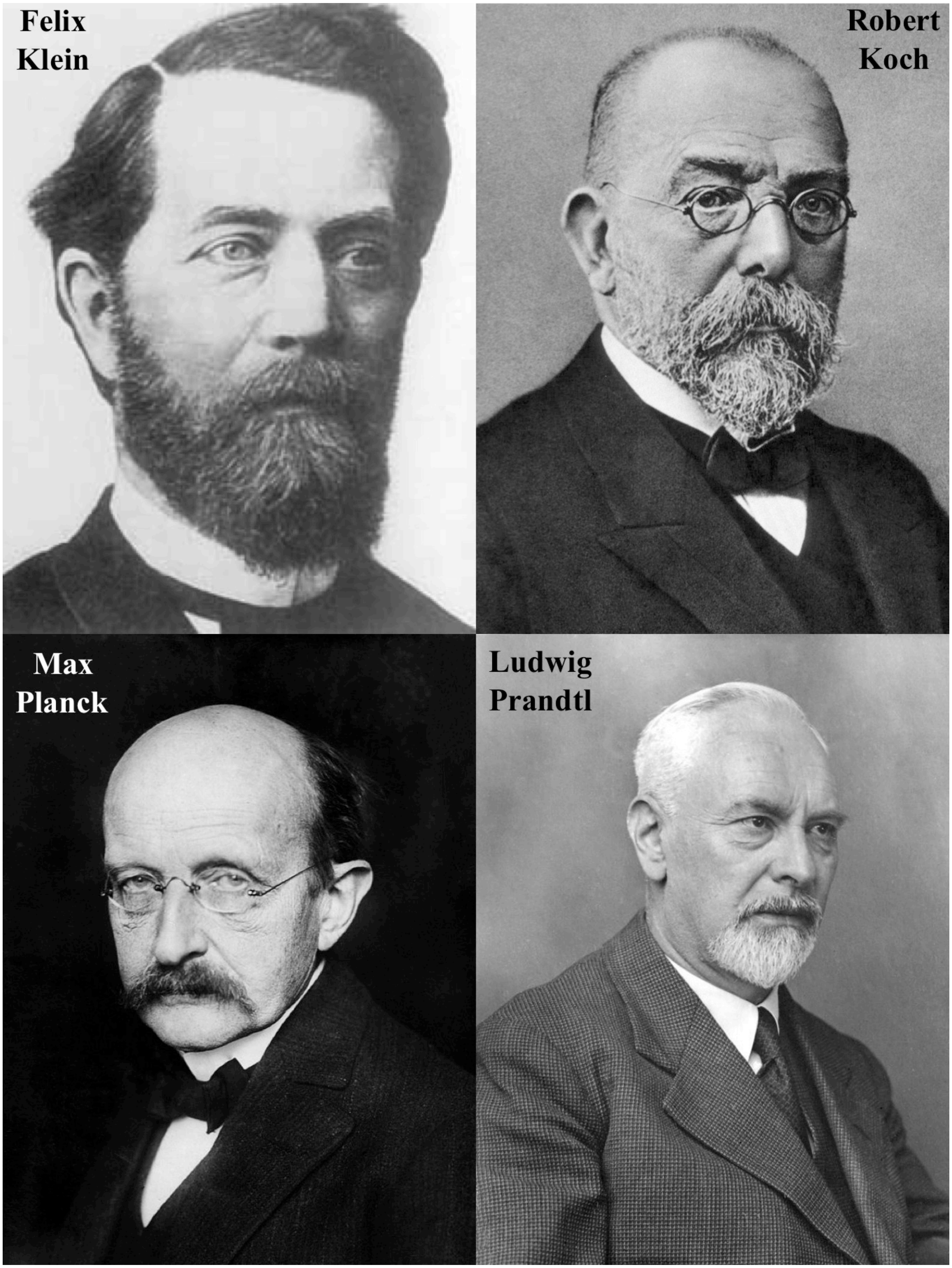

Figure 10.10: More examples of scientific "enlightened despots" who had a very large impact on the German-speaking world: Felix Klein, Robert Koch, Max Planck, and Ludwig Prandtl.

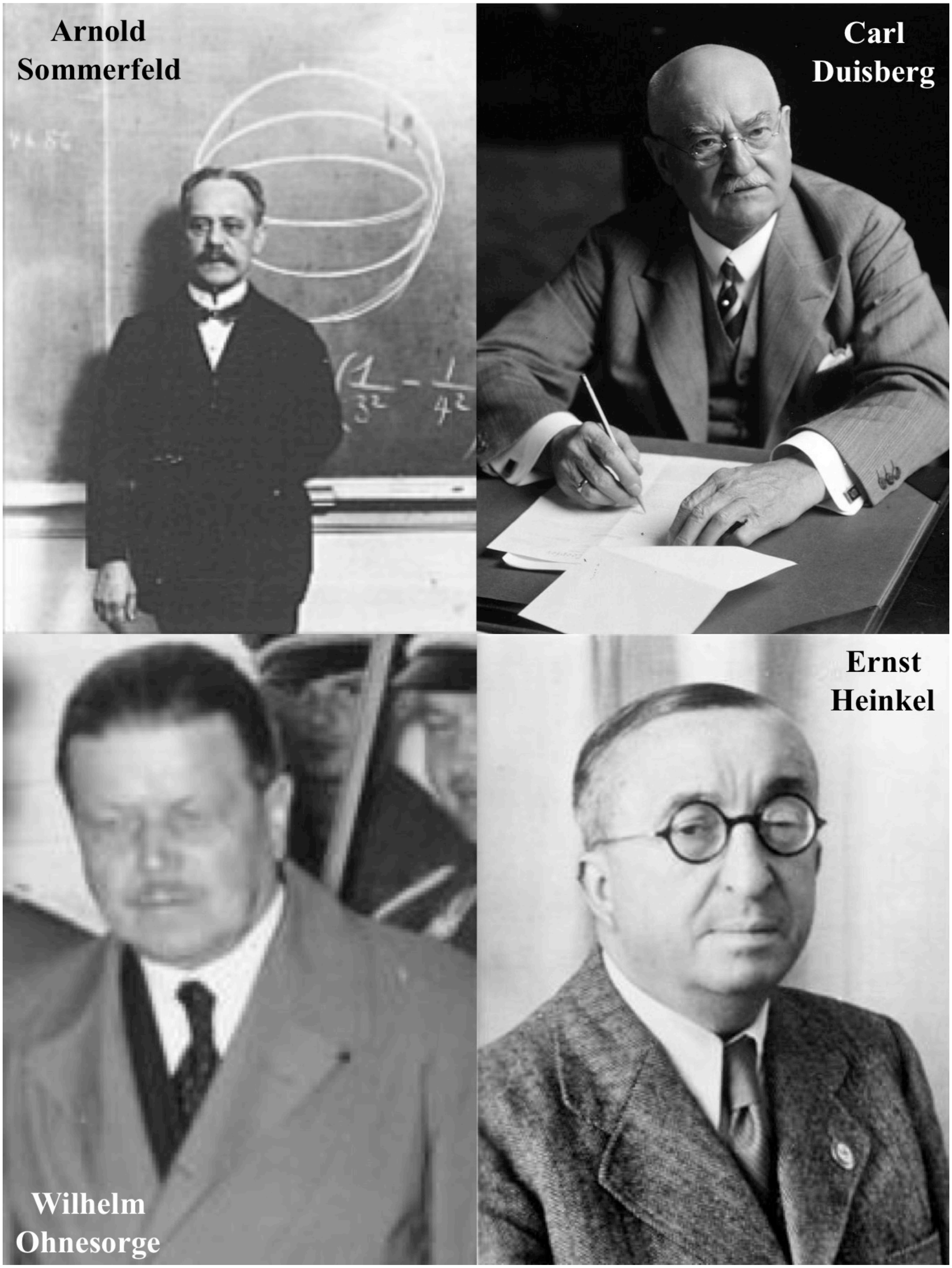

Figure 10.11: More examples of scientific "enlightened despots" who had a very large impact on the German-speaking world: Arnold Sommerfeld, Carl Duisberg, Wilhelm Ohnesorge, and Ernst Heinkel.

As just one example of the enormous impact of Althoff on individual careers, Paul Ehrlich wrote the following note of gratitude to Althoff on 27 July 1907 [Sachse 1928, p. 235]:

> Ich persönlich danke Ihnen meine ganze Karriere und die Möglichkeit, meine Ideen nutzbringend auszugestalten. Als Assistent herumgeschubst, in die engsten Verhältnisse eingezwängt—von der Universität gänzlich ignoriert—kam ich mir ziemlich unnütz vor. Ich habe nie einen Ruf an die kleinste Stelle erhalten und galt als Mensch ohne Fach, d. h. vollkommen unverwertbar. Wenn Sie da nicht mit starker Hand und genialer Initiative für mich eingetreten wären, wenn Sie mir nicht mit rastlosem Eifer und gütiger Freundschaft die Arbeitsmöglichkeiten zurechtgemacht hätten, unter denen ich mich entwickeln konnte, wäre ich vollkommen brachgelegt gewesen.

> I personally thank you for my entire career and the opportunity to make my ideas useful. As an assistant pushed around, squeezed into the tightest conditions—completely ignored by the university—I felt rather useless. I never received a call to the least position and was considered a person without specialty, in other words completely unusable. If you had not been there for me with a strong hand and ingenious initiative, if you had not showered me through untiring zeal and benevolent friendship with employment opportunities, through which I could develop myself, I would have been totally broken down.

In 1911, the German sociologist and political economist Max Weber summed up both the enlightened and the despotic aspects of Althoff's approach to scientific management, as well as their legacy in the German-speaking world [Baumgart 1980, p. 9]:

> Es ist sehr schwierig über diesen Mann zu sprechen. Er war wirklich nicht nur ein guter Mensch im spezifischen Sinne des Wortes, sondern er war ein Mann von sehr weiten Gesichtspunkten,... dem die deutschen Universitäten Dinge verdanken, die in gewissem Sinne unsterblich sind... Und in personaler Hinsicht kann nicht nachdrücklich genug betont werden...: Nepotismus gab es unter ihm nicht... Aber... die Mittel, mit welchen die preußische Unterrichtsverwaltung arbeitete, waren die denkbar rücksichtslosesten. ... Der Einfluss des Althoffschen Systems hat direct korrumpierend gewirkt.

> It is very difficult to talk about this man. He really was not just a good man in the specific sense of the word, but he was a man with a very broad point of view, ... to whom the German universities owe things that are unending in a sense... And in personal terms it cannot be stressed strongly enough...: there was no nepotism under him... But... the means by which the Prussian educational administration worked were the most ruthless conceivable. ... The influence of Althoff's system has had a directly corrupting effect.

Althoff also played a critical role in establishing several whole research institutions, including the many Kaiser Wilhelm Institutes (which had an enormous impact on all scientific fields in the following decades, and became the Max Planck Institutes after World War II), the Koch Institute for Infectious Diseases (Berlin), the Institute for Serum Research and Therapy or the Georg-Speyer-Haus (Frankfurt), the Institute of Hygiene and Experimental Therapy (Marburg), the International Association Against Tuberculosis, the University of Münster, the Royal Academy in Poznan, the Gdansk Institute of Technology, the Wroclaw Institute of Technology, and the early plans of what would become the Friedrich Loeffler Institute on Riems island after Althoff's death. Likewise, Althoff greatly expanded several existing institutions, including the University of Berlin, the University of Göttingen, and the Berlin Charité research hospital.

As already noted, many of Althoff's scientific protégés, such as Felix Klein, Max Planck, Ludwig Prandtl, and Arnold Sommerfeld, became enlightened despots themselves, greatly advancing different parts of the German-speaking research world (Figs. 10.10–10.11). As covered below, Friedrich Schmidt-Ott was arguably Althoff's most powerful and most influential protégé, even though he was not a scientist (just as Althoff was not a scientist). Thus Althoff's protégés, and the people whom they supported, exponentially multiplied the effect that Althoff had on the German-speaking world.

Friedrich Schmidt-Ott (German, 1860–1956), shown in Fig. 10.9, was Friedrich Althoff's assistant for many years. When Althoff retired and then died, Schmidt-Ott continued to play the same role that Althoff had, through his positions in several science funding organizations. Schmidt-Ott was the Prussian minister of culture (like Althoff before him), president of the Emergency Association of German Science (Notgemeinschaft der Deutschen Wissenschaft, which he helped to establish in 1920), a vice president and member of the advisory boards of the Kaiser Wilhelm Institutes, and chairman of the Donor Federation of the Emergency Association of German Science (Stifterverband der Notgemeinschaft der Deutschen Wissenschaft, which he also helped to create in 1920).

In an interview with István Hargittai, the DNA pioneer Erwin Chargaff (see p. 94) recounted his interaction with Schmidt-Ott. The episode also serves as an excellent example of how the enlightened despots made funding decisions [István Hargittai 2000–2006, Vol. I, p. 24]:

> *[Interviewer] How did they decide who should get support?*
>
> It was very different. They didn't believe in peer review, and neither do I, for that matter. I can tell you about my case. I was told by Martin Hahn that if I wanted to supplement what the Department paid me, I should make an application to the Deutsche Notgemeinschaft for a grant. A certain amount would then be branched off to supplement my salary, and I could buy chemicals, etc. I made an application and got an invitation in writing to see, and this was incredible, the chief of the Notgemeinschaft who wasn't even a scientist. His name was Schmidt-Ott and he was an orientalist. I was let into the office of His Excellency, and he made me sit down and we started talking about what books I was reading at that time. Then he asked me about my plans and I told him that I had written a proposal about my work on polysaccharides of tubercle bacilli and so on. He asked me what was a polysaccharide. I explained and then he said that I would soon hear from him. Three days later I had the grant. This is not as stupid as it may seem. If you get the right people they don't have to spend too much time on it. I find it silly when they call this proposal valuable and the other proposal not valuable. Most proposals are half so and half so because one doesn't know yet, and if it is good it may still not work. So the peer reviews are completely useless except that they grow into old boys networks. I think the most important is to get the general behavior, the general way of thinking of the person rather than to decide that this is a marvelous problem. They are not marvelous except in lucky hands, in very gifted hands. The hands you can't look at in a proposal.

As illustrated by the following examples, other enlightened scientific despots at that time or later appear to have arisen independently of Althoff, again perhaps because of the generally autocratic government style that was pervasive in that region at that time.

Carl Duisberg (German, 1861–1935), shown in Fig. 10.11, ran one of the first large corporate research programs at Bayer and then engineered the creation of the even larger research and development entity, I.G. Farben, by the merger of Bayer with other companies, ultimately resulting in a whole range of innovative medical, chemical, and materials science products. Historian Ulrich Marsch described the impact of Duisberg's strategy [Marsch 1994a, pp. 56–59]:

> When IG Farben was founded in late 1925 the organization of research was not a major issue. Decentralization of research had been practiced by all constituent companies for more than forty years was thus simply continued. [...]
>
> IG was under control of the technical men: members of the Managing Board and the key Technical Committee. A decisive element in the technical structure of IG became the TEA-Büro, though it was never meant to play that role. Here the scientific and technical directors of the works and laboratories met and proposed via the Technical Committee, TEA, new projects or investment. We have also seen that the decision to place a product on the market was made by scientifically trained middle managers (heads of works laboratories, and technical commissions) after the successful completion of tests and application processes. Unlike DuPont, where salesmen were more involved in future products, at IG the scientists were in charge.
>
> There are even more differences between IG and DuPont that are worth noting. As it was put recently, IG had a much "leaner" management with fewer hierarchies between production and administration, and especially a closer contact between researchers, research directors and the top management. The project and budget system and the absence of a rigid controlling system of the laboratories' expenses exemplify the relative autonomy of the scientific men inside IG Farben. Also, the existence of independently working individual scientists within the organized research work of the large laboratories and the close contact between those scientists and the research directors shows the importance of the individual scientist right into the 20th century and casts doubts on the absolute priority of team work stressed today. [...]
>
> The argument that the absence of a centralized Research and Development Department at IG caused strategical disadvantages is somewhat misleading: all major German chemical firms before 1925 had grown that way. Putting the main focus only on the Main Laboratories means telling only a small part of the whole story. It was the close connection between research and production and the parallel existence of centralized scientific laboratories, scientific works laboratories, product works laboratories and many technical stations that built the basis for the success of the German chemical companies for more than forty years. IG continued this tradition successfully. The innovative process happened in many locations, and the more research and application sites there were, the more likely was invention and innovation.

Wilhelm Ohnesorge (German, 1872–1962), shown in Fig. 10.11, studied physics as a university student yet made a career in the German Post Office (Reichspost). From that position, he single-handedly turned the Post Office into a strong sponsor of a wide variety of innovative research on particle accelerators, isotope separation, fission reactions and explosives, radar, television, electron microscopy, robotics, and other projects. Ohnesorge gave strong financial and political support to scientists including Manfred von Ardenne, Siegfried Flügge, and others. Helmut Joachim Fischer, a physics Ph.D. who was highly placed in the SS, gave a good description of Ohnesorge [Helmut Fischer 1988, pp. 133–134]:

> Die Reichspost hatte von jeher technische Aufgaben zu bewältigen und stützte sich daher auf umfangreiche Forschungs- und Entwicklungsarbeiten auf dem Gebiet der Fernmeldetechnik und anderer für das Postwesen nützlichen Techniken. Dafür gab es in Darmstadt ausgedehnte Laboratorien neben dem Reichspostzentralamt in Berlin-Tempelhof, dessen Präsident Prof. Gladenbeck war.

> The Reichspost has always had to cope with technical tasks and therefore relied on extensive research and development work in the field of telecommunications technology and other technologies useful for the postal system. To this end, Darmstadt had extensive laboratories alongside the Reichspost central office in Berlin-Tempelhof, whose president was Prof. Gladenbeck.

> Diesen vorgegebenen Rahmen sprengte der ehrgeizige Reichspostminister Ohnesorge. Er hatte einst bei Lenard Physik studiert und interessierte sich allgemeiner für wehrwissenschaftliche Probleme und schaltete zu ihrer Bearbeitung Mitarbeiter und Einrichtungen der Reichspost ein. Reichspost-Forschungsanstalten entstanden in der Nachbarschaft von Berlin in Kleinmachnow und in Miersdorf. Sie betrieben naturwissenschaftliche Grundlagenforschung, und das Institut in Miersdorf unter Dr. Banneitz befaßte sich sogar ernsthaft mit Kernphysik, wobei die Herstellung einer Atombombe angestrebt wurde. Überdies spannte Ohnesorge, der über genügend Geldmittel verfügen konnte und auf die Hilfe des Reichsforschungsrates nicht angewiesen war, auch Hochschulinstitute (wie etwa in Heidelberg) und zudem den tüchtigen Privatforscher Manfred von Ardenne mit seinem eigenen Laboratorium in Berlin-Lichterfelde für seine Forschungsziele ein. Sowohl in Miersdorf als auch im Institut Ardennes begann der Bau je einer 60-Millionen-Volt-Zyklotron-Anlage und von Hochspannungsgeräten, die mit einer Million Volt arbeiten.

> The ambitious Reichspost Minister Ohnesorge went beyond this rigid framework. He had once studied physics with Lenard and was more interested in military science problems in general and called in employees and institutions of the Reichspost to deal with them. Reichspost research institutes were established in the vicinity of Berlin in Kleinmachnow and in Miersdorf. They carried out basic scientific research, and the institute in Miersdorf under Dr. Banneitz was even seriously concerned with nuclear physics, with the aim of producing an atomic bomb. In addition, Ohnesorge, who had sufficient funds at his disposal and was not dependent on the help of the Reich Research Council, also employed university institutes (such as Heidelberg) and the capable private researcher Manfred von Ardenne with his own laboratory in Berlin-Lichterfelde for his research goals. Both in Miersdorf and at Ardenne's Institute, construction began on 60 million volt cyclotron facilities and on high-voltage equipment operating at one million volts.

Ernst Heinkel (German, 1888–1958), shown in Fig. 10.11, was the formidable founder and manager of the Heinkel Flugzeugwerke aircraft company. He personally recruited, directly financed, and politically defended a number of revolutionary creators and their creations, including the development of turbojet engines by Hans von Ohain, Herbert Wagner's research group, and others; the development of rocket planes by Wernher von Braun, Hellmuth Walter, and others; the development of advanced airfoils and jet aircraft by Siegfried and Walter Günter and others; the first practical ejection seats in aircraft; and other projects. Heinkel described his recruitment and support of young scientists and engineers [Heinkel 1956, pp. 210–231]:

> In November, 1935, I met a young man, today famous, but who at that time was unknown. Wernher von Braun, since his first year at college, had been passionately interested in the development of rockets.
>
> When I met him he was testing a primitive rocket engine on the artillery testing grounds at Kummersdorf. [...]
>
> "With this rocket engine," von Braun said to me, "one should be able to propel a plane." [...]
>
> This was the beginning of my close association with von Braun. I drove to Kummersdorf, where he was working with some of his friends in a dreary shed. After our first discussions, I delivered to him the fuselage of the He 112 fighter, complete with undercarriage. I also lent him a team of riggers headed by my engineer, Walter Künzel. At the beginning of 1936 this team moved to Kummersdorf. [...]
>
> While these first bench experiments in Kummersdorf—a matter of life or death for those who took part, particularly for the pilot—were being carried out, I received a letter from Professor Pohl, head of the Science Institute at the University of Göttingen. He informed me that he had an assistant, Pabst von Ohain, who was working on a new power unit for airplanes, which did not use a propeller. Von Ohain was very capable. He had already spent his private means carrying out experiments, but now he had reached the end of his resources. Pohl assured me that the young man's ideas were scientifically sound and that it should be possible to put them into practice.
>
> I wrote at once and arranged for von Ohain to come to Warnemünde on March seventeenth. He turned out to be a very likeable young man, scarcely twenty-four years old, a brilliant scientist obviously filled with a burning faith in his idea. He admitted that he as a pure theoretician, and needed both technicians and money to realize his theories. His theories corresponded to what I have already outlined about turbine or jet propulsion, and were primarily concerned with the type of engine that was later known as a centrifugal jet unit.
>
> I hired von Ohain at once, together with a technician named Hahn who had been his assistant in Göttingen. I pledged both of them to utmost secrecy. The same was true for the Günter brothers and Schwärzler, whom I now took into my confidence. Within a month I had a special shed built in Marienehe, completely cut off from the rest of the factory. No one had access to it apart from those directly engaged in the work. I placed this shed at the disposal of Ohain and Hahn.

> When Wagner's jet unit group first approached the Ministry they were told that all preliminary experiments and experiences must be turned over to an aircraft engine works, which alone could guarantee the necessary "practical application." The result was that most of Wagner's people quit Junkers and returned to the Aviation Institute in Berlin. Some of them, however, had apparently heard of the progress of my own work. They applied for jobs in my factory and I took them on. [...]
>
> While the group under Ohain devoted its main attention to an engine with a centrifugal compressor similar to the He S 3, I decided to form a new group, partly composed of the new technicians but under the general direction of Ohain, to undertake the construction of an engine with an axial compressor. I meant to pursue two parallel lines of development in order to determine which one produced the best results. [...]
>
> The second engine group, however, also had its eye on other types of propulsion unit, particularly the mixed type which, designated as a "compound engine," [turboprops or turbofans] is today fairly common in America for large airplanes of moderate speed.
>
> This resulted in the formation of several special divisions which concerned themselves with the development and testing of the most diverse new kinds of engines. The divisions had such code designations as TL (Turbo-jet; *Turbine-Luftstrahl*); STL (ramjet-turbo-jet; *Staurohr-Turbine-Luftstrahl*); or ML (reciprocating engine and jet; *Motor-Luftstrahl*). [...] For the time being I went along with this trend, because nothing can be so instructive as a number of parallel developments. [...]
>
> ...at that stage of development in a new field it was not possible to adopt certain types and write off others, as could be done later. The capable scientists and designers now working together under me already knew the snags to be avoided—for our parallel developments embraced nearly the entire field.
>
> This apparently was also Udet's opinion when finally, at the end of 1939, I won him over to the idea that this new development was of the utmost importance. [...] Udet also found a way to protect me from Mauch's and Schelp's obstructionist tactics...

Adolf Baeumker (German, 1891–1976) ran research programs for the Air Force (Luftwaffe) from a series of increasingly elevated positions during the period 1924–1945 (Fig. 10.12). After the war, he advised both the United States and West Germany on Air Force research programs until the 1960s, proving how widely his talent as a research manager was recognized. Aerospace historian Ernst Hirschel gave a brief overview of Baeumker's importance [Hirschel et al. 2004, p. 72]:

> Baeumker may be considered as one of the first "Science Managers" in Germany. He established the "Aeronautical Research Council" ("Forschungsrat für Luftfahrt"), initiated by Prandtl and von Kármán, to promote the exchange between research and industry. [...] 1935 he created the "Lilienthal-Society" [...] and he founded in 1936 the "German Academy for Aeronautical Research" ("Deutsche Akademie der Luftfahrtforschung"). [...] 1945 he goes to the USA, where he worked for various military offices. 1958 he is transferred to the European Headquarter of the American Air Force (USAFE) in Wiesbaden to work for the cooperation in research and development between the Federal Republic of Germany and the USA. He advises in the sixties German and American head offices in Bonn, among other things, also to unite non-university German aerospace research.

Figure 10.12: More examples of scientific “enlightened despots” who had a very large impact on the German-speaking world: Adolf Baeumker, Erich Schumann, Hans Kammler, and Wernher von Braun and Walter Dornberger.

Erich Schumann (German, 1898–1985), shown in Fig. 10.12, was a physics professor at the University of Berlin, chief physicist of the Army Ordnance Office (Heereswaffenamt), and member of the Reich Research Council (Reichsforschungsrat). In those positions, he led or was directly involved in research on rockets (he was Wernher von Braun's doctoral dissertation advisor), armor-penetrating shaped charge conventional explosives, fission reactions and explosives, fusion reactions and explosives, biological weapons, quite likely chemical weapons, and other areas [Nagel 2012a]. Schumann recruited scientists for all of these areas and supported them both financially and politically. Ultimately all of these technologies that he helped to develop became critical components of Cold War military arsenals and strategies for the United States, Soviet Union, and other countries. The historian Rainer Karlsch gave a thumbnail sketch of Schumann, the many hats that he wore, and the many ways that various other people perceived him [Karlsch 2005, pp. 31–32]:

> Die Forschungsstelle des HWA ging bei allen Projekten vom Grundsatz aus, die vorhandenen Strukturen, dazu gehörten Universitäten, außeruniversitäre Forschungseinrichtungen und Firmen, in ihrem Sinne zu nutzen und zu steuern. Im HWA selbst wurden nur Forschungen angesiedelt, die aufgrund ihrer militärischen Bedeutung nicht "außer Haus" gegeben werden konnten.
>
> Leiter der Forschungsabteilung des HWA war seit 1934 Ministerial-dirigent Professor Erich Schumann. Er war in kurzer Zeit zu einem Multifunktionär aufgestiegen. Seit 1929 leitete er die Abteilung für Akustik am Physikalischen Institut der Berliner Universität und lehrte experimentelle und theoretische Physik. Zum Direktor des neu gegründeten II. Physikalischen Instituts wurde er 1934 ernannt. Sein Interesse galt vor allem der Sprengstoffphysik. Gegenüber den Hochschulkreisen war Schumann stets bemüht, seine Rückendeckung durch die Wehrmacht zu betonen. Seine Einstufung als Ministerial-dirigent entsprach beim Heer etwa dem Rang eines Generalmajors. Nicht wenigen seiner Gesprächspartner blieb er als "General" in Erinnerung, beeindruckend in Uniform und durch sein temperamentvolles und dynamisches Auftreten.

> In all its projects, the Army Ordnance Office's research center was based on the principle of using and controlling the existing structures, including universities, non-university research institutions and companies, in their interests. In the Army Ordnance Office itself the only research that was conducted was that which could not be sent "out of the house" due to its military implications.
>
> Since 1934 Professor Erich Schumann had been head of the research department of the Army Ordnance Office. Within a short time he had become a multifunctional official. From 1929 he headed the Department of Acoustics at the Physics Institute of Berlin University and taught experimental and theoretical physics. He was named director of the newly founded Second Physics Institute in 1934. His main interest was in explosives physics. Schumann was always anxious to emphasize his support by the military to the university circles. His classification as a ministerial official was roughly equivalent to that of a major general in the army. Not a few of his interlocutors remembered him as "General," impressive in uniform and with his spirited and dynamic appearance.

Über Schumanns Qualitäten als Wissenschaftsorganisator gingen die Meinungen der Zeitgenossen weit auseinander. Die einen sahen in ihm einen fähigen Wissenschaftler und großen Förderer der Kampfstoffforschung und Sprengstoffphysik, die anderen nannten ihn einen Scharlatan, der sich in den Dienst von windigen Projekten stellte. [...] Doch Schumann auf die Rolle eines eitlen Machtmenschen zu reduzieren, hieße seine wissenschaftliche Kompetenz und sein organisatorisches Talent zu unterschätzen.

The opinions of his contemporaries differed widely about Schumann's qualities as a scientific organizer. Some saw him as a capable scientist and great supporter of warfare research and explosives physics; others called him a charlatan who was at the service of windy projects. [...] But to reduce Schumann to the role of a vain power man would be to underestimate his scientific competence and organizational talent.

Hans Kammler (German, 1901–?), shown in Fig. 10.12, is worthy of special mention [Agoston 1985]. He had a doctoral degree in engineering and rose to the level of General (Obergruppenführer) in the SS. Over the course of World War II, Kammler gained control over more and more of the military's advanced R&D programs. By the end of the war he controlled virtually all of the major programs—rockets, missiles, jets, nuclear technology, directed energy technologies, etc.—and then he mysteriously vanished. New evidence proves that he was secretly captured and interrogated by the United States (pp. 4977–5005). It is unclear how much Kammler contributed to the success of all of those programs versus how much he simply took over already successful programs, but at a minimum it is clear that he had formidable political skills and a strong taste for very innovative, high-impact research. Of course, he also ordered or assisted in the murder of large numbers of people, so he is certainly not a role model. Helmut Fischer, a physics Ph.D. who was highly placed in the SS's security office, succinctly described Kammler [Helmut Fischer 1988, p. 64]:

Eine besondere Rolle spielte dabei der Leiter der Gruppe C des WVHA [Wirtschafts- und Verwaltungs-Hauptamt], SS-Gruppenführer Hans Kammler. Anlässlich der Erstellung von Bauten in Peenemünde, wo die Vergeltungswaffe V 2 geschaffen wurde, kam Kammler mit den Verantwortlichen für die V-Waffen in Berührung. Er machte sich bald unentbehrlich, riss immer mehr Zuständigkeiten an sich und wurde schliesslich zum massgeblichen Mann für die Fertigung der Vergeltungswaffen. Aber damit nicht genug! Der ehrgeizige Kammler schaltete sich auch in die Forschungs- und Entwicklungsarbeiten zur Konstruktion neuartiger Waffen ein. Dazu erlangte Kammler auch die Befehlsgewalt über die Sondereinheiten der Wehrmacht, die für den Fronteinsatz der V-Waffen aufgestellt worden waren. Kammlers Machtstellung wurde schliesslich so stark, dass Speer als Reichsminister für Rüstung und Kriegsproduktion um seine Stellung fürchsten musste.

A special role was played by the leader of Group C of the WVHA [Economic and Administrative Main Office], SS-Gruppenführer Hans Kammler. On the occasion of the construction of buildings in Peenemünde, where the reprisal weapon V-2 was created, Kammler came into contact with those responsible for the V-weapons. He soon made himself indispensable, increasingly took over responsibilities and eventually became the key man for the production of retaliatory weapons. But that is not all! The ambitious Kammler also turned to the research and development work on the construction of novel weapons. Kammler also gained command of the special forces of the Armed Forces, which had been set up for the front line of the V-weapons. Kammler's position of power was finally so strong that Speer had to worry about his position as Minister of Armaments and War Production.

Wernher von Braun (German, 1912–1977), Walter Dornberger (German, 1895–1980), and their military and government sponsors provided very strong, driven, focused, long-term support for the development of large liquid propellant rockets; see Fig. 10.12. Boris Chertok, a leader of the Soviet rocket programs from the time they acquired experts and technology in Germany in 1945, described von Braun's management style [Chertok 2005–2012, Vol. 1, pp. 305–306]:

> Von Braun's story is no longer novel, thanks to numerous publications by American, German, and Soviet researchers, and even television documentaries. For that reason I will not cram my memoirs with yet another version of von Braun's biography. Gröttrup said that one of von Braun's very good traits was his striving to attract the most talented people. In doing so, he did not take age into account, and he was not afraid of competition.
>
> Von Braun had been named technical director of Peenemünde-Ost at the age of twenty-five! For Germans this was quite unusual. But this shows how highly they valued his talent, initiative, and rare intuition. According to Gröttrup, von Braun was very attentive to senior, experienced specialists. He made fundamental decisions after having first gathered and listened to diverse opinions. There was no voting; von Braun always had the last word, but he managed not to offend the other staff. In spite of his youth, his authority was not called into question.
>
> Fifty years after this assessment of von Braun's management style, I met with an American engineer named Jerry Clubb, who was a participant in the Apollo-Saturn lunar program, which had been directed by the no longer twenty-five but fifty-five-year-old, world-renowned creator of the first long-range ballistic missiles. The American talked about von Braun's working style in the United States in the same way that I had heard Gröttrup describe it in 1945 over a cup of coffee with whipped cream. [...]
>
> Von Braun had been valued and trusted by Dornberger and the higher military leadership of the infantry forces who had financed the construction of Peenemünde. He did not have to fear intrigue against himself, and he was able to work confidently as the technical director. Dornberger, who had become a general at Peenemünde, had always shielded von Braun. They were a powerful duo.
>
> In spite of various nuances in political views, the main leadership staff had worked rather harmoniously and very selflessly.

Thus the German-speaking research world appears to have greatly benefited from a number of enlightened despots during the nineteenth and early twentieth centuries. As shown in Section 11.2.6, this same sort of enlightened despot approach to identifying and supporting scientific innovators and innovations was also employed by very successful German-inspired U.S. research and development programs during their heyday in the 1940s through 1960s. Innovation experts have argued for bringing back this sort of management approach to improve the modern innovation system, either as an alternative to or as a supplement for the more conservative modern peer-review/consensus-based methods [e.g., p. 2260; Azoulay et al. 2019; Braben 2004, 2008, 2014].

10.2.7 Systems Analysis

One factor in the success of the earlier German-speaking world appears to have been widespread explicit or implicit application of systems analysis. As shown in Fig. 10.13, systems analysis is a top-down approach to:

- First identify a whole range of important problems.
- Then choose the most important problem that can be addressed with the available resources.
- Next enumerate all potential types of solutions to that problem, systematically covering all possibilities and demonstrating that they form a complete set with no omissions.
- Then consider which potential solutions are ruled in or out by laws of nature or by their inherent disadvantages or advantages.
- Finally focus on pursuing the most promising solutions for the most important problems.

This systems analysis mindset appears to have been deeply ingrained in German-speaking culture and can be traced back at least as far as Wilhelm von Humboldt at the beginning of the nineteenth century (see for example the quotes on p. 1977). It was most clearly and fully articulated by Fritz Zwicky (1898–1974), a Swiss physicist who emigrated to the United States and who referred to the systems analysis method as the "morphological approach" [Zwicky 1969, pp. 36–37, 105–108]:

> It has often been stated that it is no longer possible today to know all or even several fields of science well, let alone to contribute materially to their advancement. This erroneous belief, as well as the rather astounding fact that among men of research there are but a very few who can make discoveries and inventions in widely separate fields, proves that the majority of them are either quite incapable of thinking morphologically or they have not yet learned or been taught to view the world as a whole. Contrary to the currently entrenched idea that universality of knowledge is a thing of the past, those who can visualize the true world image will nevertheless be capable of successfully doing research on many diverse subjects. They will also succeed in producing discoveries and inventions that have escaped the specialists in all domains of human activity because such specialists lack that type of universal outlook which, as I hope to show, automatically leads to the recognition of entirely new insights. [...]
>
> (a) Morphological research is totality research, which in a completely unbiased way attempts to derive all the solutions of any given problem.
>
> (b) The morphological approach has developed its own characteristic procedures, such as the method of the morphological box which will be explained and applied in this chapter.
>
> (c) The morphological approach gives us the maximum guarantee that no circumstance is overlooked that might be of importance for the satisfactory accomplishment of any task before us. [...]

> (h) The morphological approach enables us to systematize our inventiveness. It allows us to make discoveries and inventions methodically, and in some cases almost automatically. Without that, we are forced to resort to haphazard procedures of trial and error.
>
> (i) Expressing it pointedly, we may say that the morphologist is a professional genius. In other words, it is his profession to be a genius who is capable of pursuing original research and making discoveries and inventions in all fields of human endeavour. Those who are commonly thought to be geniuses are actually amateurs whose accomplishments in restricted fields are more or less accidental and bear the mark of dilettantism. [...]
>
> For the construction of any morphological box and for the subsequent evaluation of the information that may be contained in it we proceed as follows:
>
> First Step. The problem to be solved must be very concisely formulated.
>
> Second Step. All of the parameters that might be of importance for the solution of the given problem must be localized and analyzed.
>
> Third Step. The morphological box or multidimensional matrix, which contains all of the potential solutions of the given problem, is constructed.
>
> Fourth Step. All the solutions contained in the morphological box are closely scrutinized and evaluated with respect to the purposes that are to be achieved.
>
> Fifth Step. The optimally suitable solutions are being selected and are practically applied, provided the necessary means are available. This reduction to practice requires in general a supplemental morphological study.

This systems approach that was described so explicitly by Zwicky appears implicitly throughout the German-speaking world, both in how the creators selected important problems to address (such as those summarized in Chapters 2–9), and also in how the creators exhaustively explored all viable solutions for those problems (for example a whole range of different types of engines, organic molecules, aerospace vehicles, etc.).

This top-down approach similarly appears to have been the guiding principle for Friedrich Althoff and the other enlightened despots managing the German-speaking world as they decided which creators and creations were the most important to support. For example, as shown on p. 2021 of this chapter, Ernst Heinkel and the engineers working for him used systems analysis to consider all the major types of possible jet engines, and to pursue the most promising ones in parallel in order to determine which ones would be best.

As another example, Donald Putt's postwar U.S. investigations into wartime German missile research reported how systems analysis had been thoroughly exploited to consider all possibilities in the missile programs [Putt 1946a]:

> Many of Germany's research laboratories and several large commercial firms concentrated on this field of endeavor. This tremendous effort resulted in 138 guided missiles and assorted devices, including their modifications. These were of types wholly unknown

> to laymen in the United States. At the outbreak of the war some of these were strictly "out of this world"—to use a current phrase. In addition, German scientists had developed other equipment of a type we had considered impracticable, such as the ram jet.
>
> The stupendous effort in basic research expended by the Germans in the guided missile field was designed to cover the complete field of potentialities for such weapons. The losses incurred in Germany by heavy bomber raids can in no way be charged to lack of preliminary research on missiles. Weapons of this category were divided into the following classifications:
>
> A. Ground to air.
>
> B. Air to air.
>
> C. Air to ground.
>
> D. Ground to ground.
>
> E. Underwater to underwater.
>
> F. Underwater to ground.
>
> G. Underwater to air.
>
> Moreover, every known type of remote control and fusing means was exploited. These included radio control, wire control, radar, continuous wave, acoustics, infrared, light beams, and magnetics.
>
> Likewise, all methods of employing jet propulsion for subsonic and supersonic speeds were exploited.

Fritz Zwicky was trained in the earlier German-speaking world, and by the time he wrote his 1969 book (quoted above) in the United States, he sounded disappointed that like-minded innovators had become so scarce in that time and place. They had been much more common in the German-speaking world.

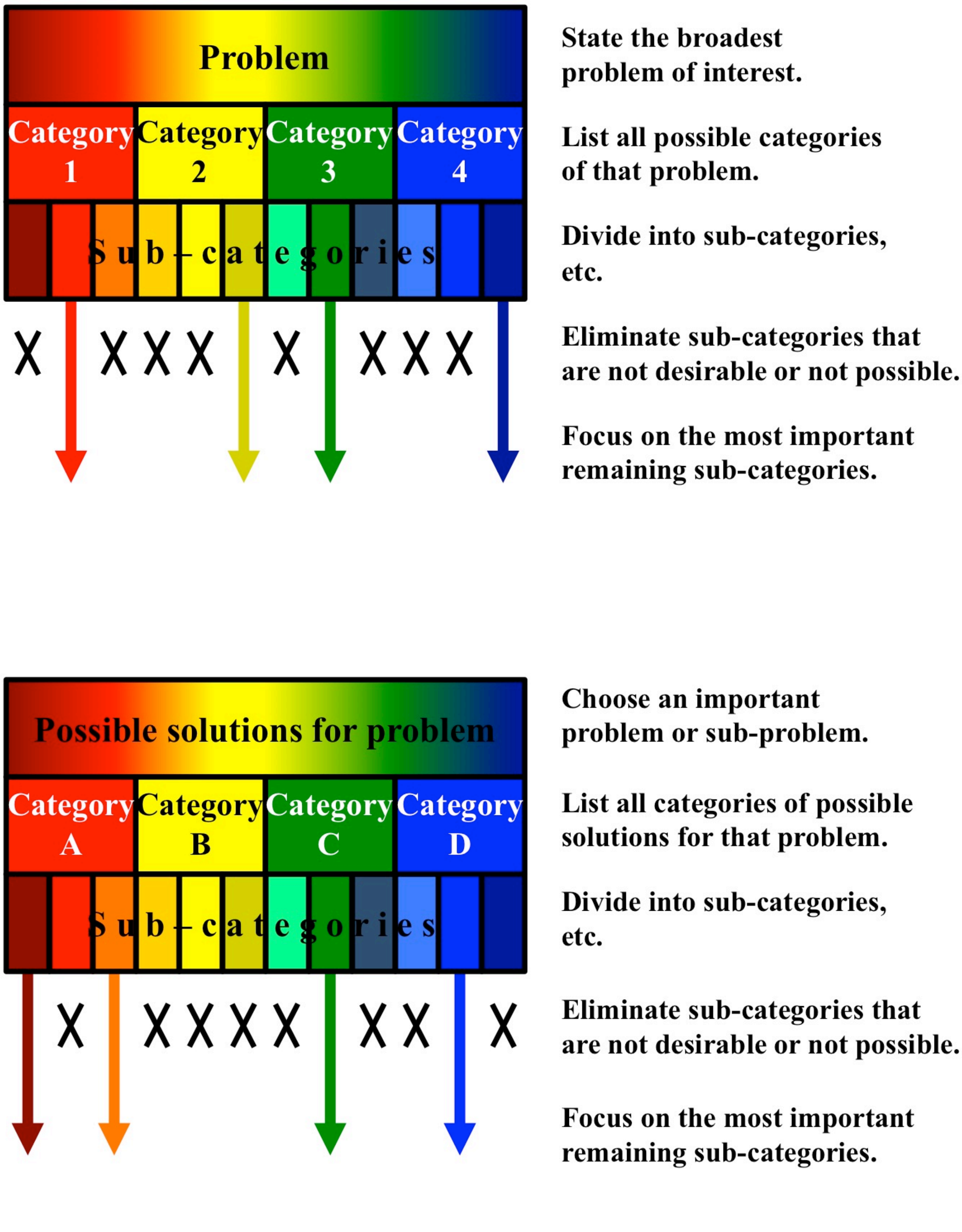

Figure 10.13: Systems analysis is a methodical, top-down approach for considering all possible categories of problems of interest, and all possible categories of solutions to those problems, in order to identify and focus on the most promising solutions for the most important problems.

10.2.8 Limited Natural Resources

The German-speaking world had tremendous economic and military needs or aspirations, yet extremely limited natural resources that could be harnessed to fulfill those requirements. This limitation provided an incredibly powerful incentive to create revolutionary new technologies, processes, and materials that could meet those needs with the available resources. That was especially true during wartime, yet even between wars, Germany's lack of resources spurred it to develop synthetic materials to be more economically competitive against foreign industry. As shown in Fig. 10.14, examples of that industrial innovation included synthetic dyes, the Haber-Bosch ammonia production process, synthetic rubber (butadiene or buna), a wide variety of plastics, synthesized explosive molecules, ersatz food ingredients and preservatives, synthetic blood plasma, and the development of biotechnology methods to produce industrial and food products.

Ulrich Wengenroth, a scientific historian at the Deutsches Museum in Munich, described those conditions and the resulting German achievements [Landes et al. 2010, pp. 290–291, 295–296]:

> The showcase of German science-based industry was undoubtedly organic chemistry. From the 1880s until well after World War II German companies held a commanding position in most products based on carbon hydrates, especially when it came to high-value products like pharmaceuticals. [...] The main strategy was always the same: analyze a natural product and then find ways to synthesize it cheaply from the tar derivatives the heavy industries and gasworks would abundantly supply. The overabundant supply of first-rate human capital for industrial research, plus the additional incentive of not having access to natural resources for colonies, created a situation that proved to be immensely fortunate. Only the Swiss chemical industry, also with a good supply of academically trained scientists and no colonies, could match the progress of German organic chemistry. It was one of the first examples after the Industrial Revolution when the absence of natural resources proved to be beneficial. Apart from the availability of highly qualified human capital, the German dyestuffs industry benefited from having hit a treasure trove of potential products, and the most innovative entrepreneurs were smart enough to see and fully utilize that potential. [...]
>
> Germany, which was in no position to safeguard its raw material supplies from a vastly superior British navy, during conflict and in preparing for war turned to processing poor raw materials from its own territory and producing *Ersatz* to overcome supply shortages by second-rate material. Enormous ingeniousness and innovativeness were invested in autarchy technologies[...]
>
> The strength of the German chemical industry in synthesizing chemical compounds that were found in nature or compounds close to them was greatly in demand when the country went into World War I. Just before the war, Fritz Haber had created a process to synthesize ammonia, by this being able to produce nitrogen, which had mostly been imported from South America before the war and, more important, before the blockade by the British navy. Nitrogen was indispensable for both ammunition and fertilizers. [...]

> More on the autarchy line like ammonia synthesis were developments of coal hydrogenation that were begun during World War I and completed with the advent of World War II to produce both gasoline and rubber from domestic coal. The R & D strategy was not so different from chemical synthesis in the prewar years, but it steered away from international markets and considerations of competitiveness of the new production lines. What was quite rational, given the resource poverty of Germany and its inability to break a British naval blockade, slowly turned into a new paradigm of a self-sufficient Germany that would not have to negotiate its way on international markets but could retreat into some self-designed cage. While before World War I chemical synthesis was a way to beat prices and quality of products based on natural resources, after the war and very much in the Nazi years it became a gospel of independence for conducting wars.

A lengthy 1946 *Harper's* magazine article [Charles Walker 1946] listed a number of examples of synthetic materials and processes that had been developed in Germany during World War II and eagerly adopted by the United States after the war; see pp. 75 and 427. Tom Bower summarized the importance of those synthetic materials for Germany during the war, and for the United States after the war [Bower 1987, p. 5]:

> The proof of German technical prowess is overwhelmingly established in the hundreds of reports written by Allied investigators who did not shy from describing the Germans' "astonishing achievement" and "superb invention." It was also established by the very survival of Germany during four years of total war despite the prediction during the first two years of war by British intelligence that the German economy and German industry faced imminent and total collapse. The blockade on essential minerals, chemicals, and petroleum products, it was argued, would cripple weapons production. But the very opposite happened, because German scientists developed an astonishing range of substitutes that not only humiliatingly neutralized the Allied blockade but heralded the dawn of a new scientific era. [...] German scientists had pioneered so many inventions that many Allied experts would complain that their plunder could do no more than scratch the surface.

In contrast, the global system in general and the United States in particular have not felt especially resource-limited over the last several decades, and hence have lacked strong incentives to develop new synthetic materials and processes beyond those that were previously imported from the German-speaking world. With rising concerns about climate change, pollution, overuse of natural resources, and related problems, hopefully that attitude will change, and nations worldwide will have strong incentives to develop revolutionary new materials and processes to minimize the impact on the environment.

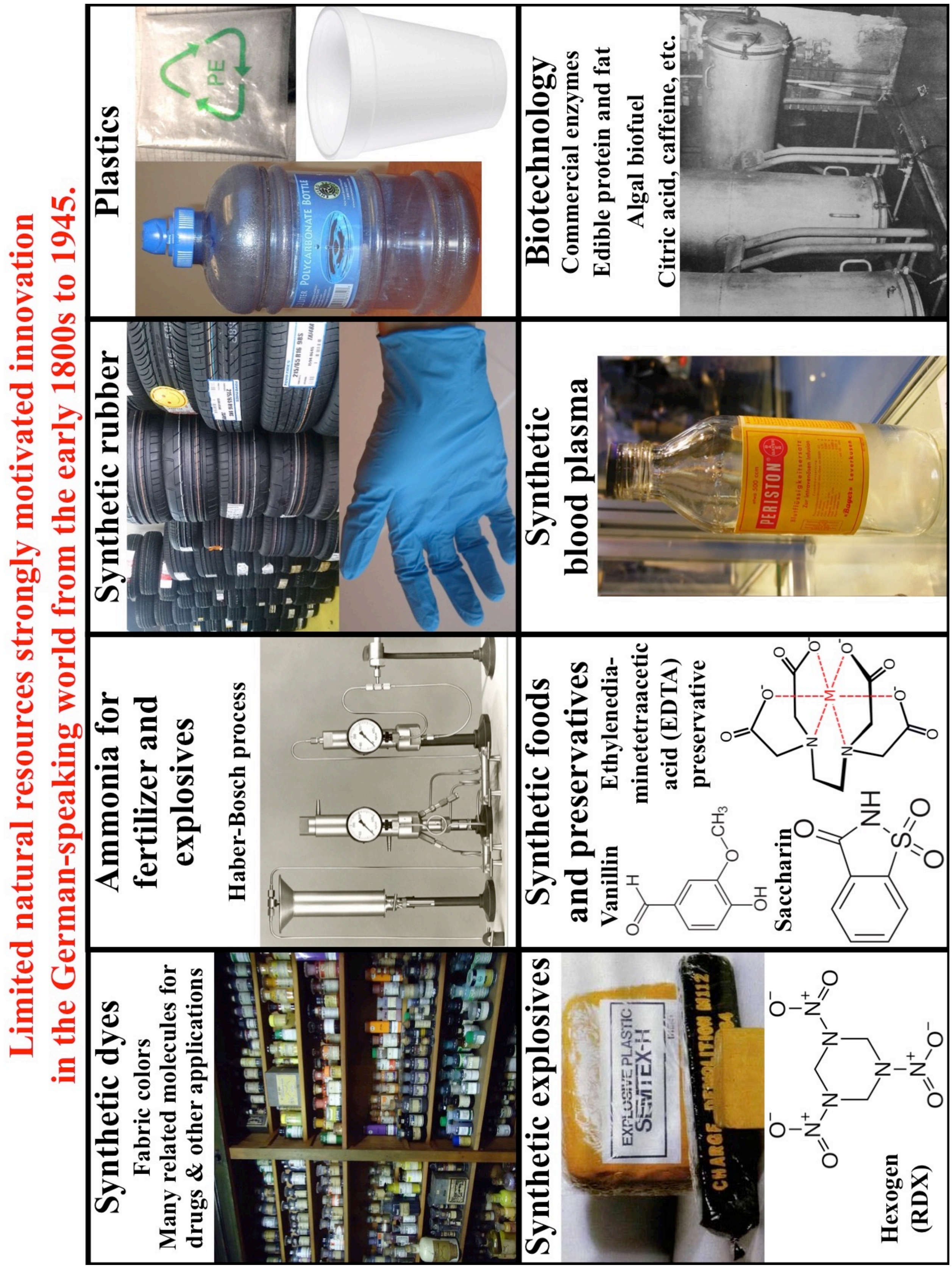

Figure 10.14: Limited natural resources strongly motivated innovation in the German-speaking world from the early 1800s to 1945.

10.2.9 International Rivalry

Strong competition can forestall a sense of complacency and can therefore spur innovation. From the early 1800s through 1945, the German-speaking world was highly motivated by both fierce military competition and fierce economic competition with several other countries (Fig. 10.15):

- The United Kingdom was a strong scientific rival and industrial competitor throughout that entire time period, and a staunch foe in World War I (1914–1918) and World War II (1939–1945).

- The United States became a strong industrial competitor from the late nineteenth century onward, and was a vigorous and ultimately victorious opponent in World Wars I and II.

- France was a waning scientific powerhouse in the nineteenth and early twentieth centuries, and a military opponent during the Napoleonic Wars (1803–1815), the Franco-Prussian War (1870–1871), and World Wars I and II.

- Russia was a ferocious military opponent during World Wars I and II.

- There was also significant military and economic rivalry among German-speaking states until German unification in 1871, with some rivalry among Germany, Austria, and Switzerland continuing even after that time.

The international rivalries over industrial products and market share were strong drivers for innovations in the German-speaking world, especially in areas such as the chemical industry, electrical machinery, engines and engine-powered vehicles, and optics. Likewise, the military conflicts and active planning during peacetime for the next military conflict emphasized the development and use of new technologies for military purposes—trains to rapidly move troops and supplies, submarines to attack enemy shipping, poison gases to employ against entrenched opponents, aircraft and rockets to reach other countries, and so forth.

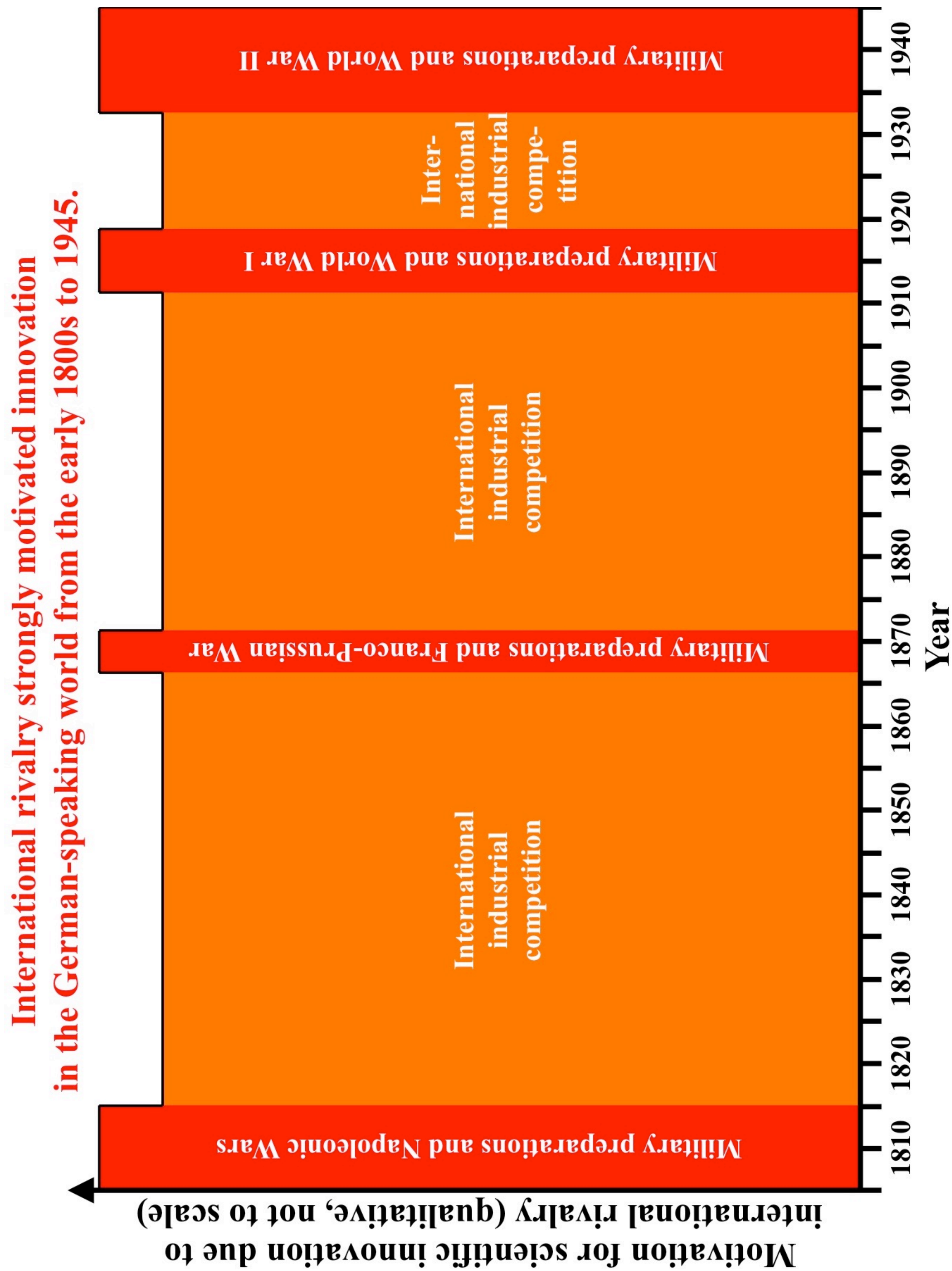

Figure 10.15: International rivalry strongly motivated innovation in the German-speaking world from the early 1800s to 1945.

10.2.10 Industrial Unity of Purpose

Nowadays companies are afraid to create any innovations that they cannot immediately capitalize on themselves, lest any research that they have funded end up benefiting other companies more than their own. In contrast, throughout the late nineteenth and early twentieth centuries, German industry was willing to invest very large sums of money in revolutionary R&D projects. The companies were much more afraid of the possibility that Germany might lose to foreign companies and nations than they were of the possibility that their own company-funded innovations might benefit another German company. Leaders of different German companies were united by a strong sense of common purpose (Fig. 10.16). Ultimately this strong nationalism moved them toward the extreme of massive monopolies like I.G. Farben and the fascist ideology intertwining government and industry.

Ulrich Wengenroth, a scientific historian at the Deutsches Museum in Munich, summarized the history of this German tendency toward "cooperative capitalism" [Landes 2010, pp. 279–280]:

> Cartels mushroomed after the protectionist reversal of the 1870s. They were defended as freedom of contract, and the highest court of the empire in 1897 decided that cartel arrangements were not only legal but binding on all partners and could be enforced. To Alfred Chandler, Jr., this was a watershed setting Germany firmly on the path of cooperative rather than competitive capitalism. By 1897, however, big industry in Germany had already twenty years of intensive cartelization behind it. The climax of cartelization came with the Nazis and their *Zwangskartellgesetz* of 1933, which made cartels mandatory in the interest of Nazi economic planning. After World War II, under pressure from the United States, the cartelization of German industry was largely made illegal if not completely abolished. [...]
>
> Intellectual property rights were hardly protected before 1877 when the German patent law was passed. Before that year, governments of German states, and particularly of Prussia, were reluctant to grant patent protection in an effort to ease transfer of knowledge from abroad. [...] All this changed when Prussia believed that German industry had successfully caught up and was in a position to turn from imitator to bona-fide innovator. The German patent law protected the process rather than the product, thus stimulating research for alternative ways to turn out the same product. This proved to have a highly stimulating effect on corporate research and development.

Wengenroth also gave several examples of how the German propensity for cooperative capitalism greatly benefited the innovation and international competitiveness of German industry in the fields of chemicals, electrical equipment, and machinery [Landes 2010, pp. 290–293]:

> Charts of tar-based products show a wide spectrum from explosives to anesthesia, Bakelite, and a number of synthetic dyestuffs and their intermediates. In protecting processes rather than products the German patent law further stimulated the research drive into ever more fields. It took the German chemical industry's competitors decades and the scrapping of all property rights in the wake of the wars slowly to erode the position it had built by the turn of the century. Only with two paradigm shifts in the industry, from coal to oil and from chemical synthesis to biotechnology, did foreign—mostly

> American—companies draw even with and eventually surpass the “big three,” only two of which are still German with BASF being number one globally, while Hoechst has become part of the French Aventis.
>
> —
>
> An industry that was almost as successful in making the most of the great pool of talent at the many polytechnics was electrical engineering. This industry was governed by two very different titans of German enterprise, Werner Siemens, who had introduced the telegraph to Germany, and Emil Rathenau, the founder of AEG (Allgemeine Electrizitätgesellschaft = General Electric Company). [...]
>
> The outcome on the German market was a duopoly of AEG and Siemens and remained that until the decline of AEG in the 1980s. [...] Although it has been debated whether electrical manufacturing was a science-based industry or an industry-based science in Germany, there is agreement that the close and extensive cooperation of manufacturers and polytechnics greatly helped to solve innumerable problems occurring on the way to innovations that eventually created the high reputation for equipment “made in Germany.”
>
> —
>
> Ludwig Loewe [...] let one of his directors, the twenty-five-year-old Walter Schlesinger, go to the Berlin polytechnic to conduct research in metal cutting using heavy grinding machines. [...] The result was the first ever German dissertation in mechanical engineering, the establishment of a “norm factory” on the premises of Loewe, and the beginning of what was to become the greatest export success of German mechanical industry ever, the DIN (Deutsche Industrie Normen)—German industrial norms used by countries around the world, among them more recently the People’s Republic of China. In creating norms for fits, Schlesinger and his comrades-in-arms—literally, because most breakthroughs happened through World War I—established national norms rather than proprietary factory norms. With national norms, all German industry could participate in decentralized mass production. Products and components designed meeting these norms would always fit together. The test run was arms production in World War I, when a highly decentralized German industry had to turn out components for uniform mass products. [...]
>
> And as Germany moved ahead in creating a system of norms, other countries did not bother to invent something new but adopted DIN norms and later also their electrical counterparts, VDE norms (VDE = German Association of Electrical Manufacturers). There were very few innovations, if any, that helped German industry better to conquer export markets for mechanical and electrical products. Schlesinger and Loewe together had established this path, and others were quick to follow, seeing that agreeing on a common norm helped German business more than going proprietary. It is no surprise that German industry’s tradition of collective action and cooperation was further strengthened by that strategy.

As discussed in Section 11.2.10, many companies in the United States experienced (and greatly benefitted from) a similar unity of purpose during World War II, the Cold War, and the space race, but unfortunately that no longer seems to be true today.

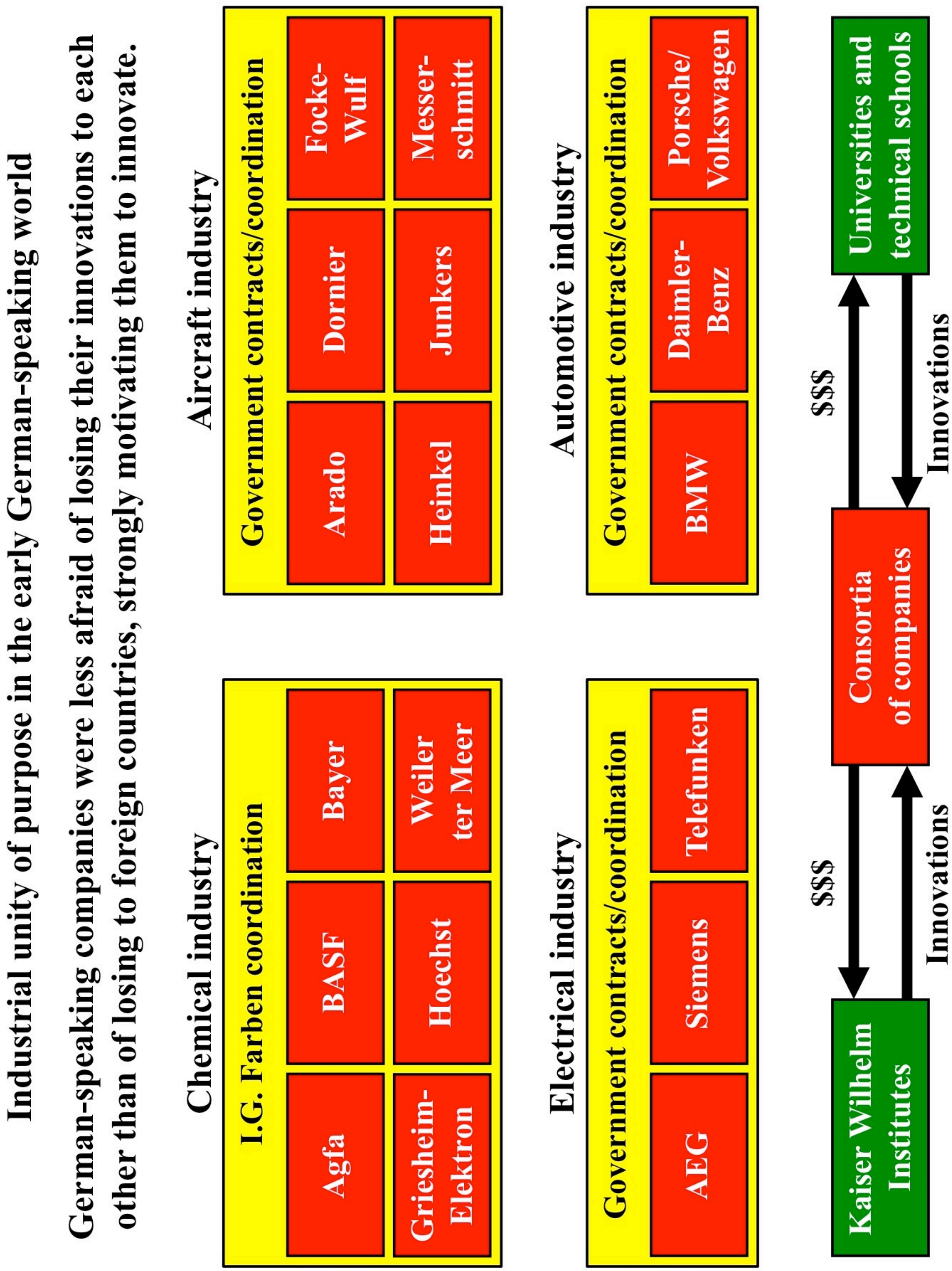

Figure 10.16: In the early German-speaking world, companies were less afraid of losing their innovations to each other than of losing to foreign countries, strongly motivating them to innovate.

10.2.11 Other Factors

Among the creators from the German-speaking world, there was a disproportionate percentage of scientists and engineers who were Jewish or who at least had some sort of Jewish family background [Ash and Söllner 1996; Fraser 2012; Gerstl 2014; István Hargittai 2006; Lebrecht 2019; Leff 2019; Medawar and Pyke 2000; Nachmansohn 1979].

Country	**Number of Jews**	**% of local population**
Austria	191,000	2.8%
Germany	525,000	0.75%
Czechoslovakia	357,000	2.4%
Hungary	445,000	5.1%
Netherlands	156,000	1.8%
Poland	3,000,000	9.5%
Switzerland	18,000	0.4%
German-speaking world total	4,700,000	3.2%
Albania	200	0.02%
Belgium	60,000	0.7%
Bulgaria	48,500	0.8%
Denmark	5,700	0.15%
Estonia	4,560	0.4%
Finland	1,800	0.05%
France	250,000	0.6%
Greece	73,000	1.2%
Italy	48,000	0.11%
Latvia	95,600	4.9%
Lithuania	155,000	7.6%
Norway	1,400	0.05%
Portugal	1,200	0.02%
Romania	756,000	4.2%
Soviet Union (western)	2,525,000	3.4%
Spain	4,000	0.02%
Sweden	6,700	0.11%
United Kingdom	300,000	0.65%
Yugoslavia	68,000	0.49%
European total	9,500,000	1.7%
United States	4,300,000	3.4%
Other countries	1,500,000	0.1%
Worldwide total	15,300,000	0.73%

Table 10.11: Jewish population in selected countries in 1933.

Table 10.11 shows the Jewish population in various countries in 1933 [https://www.jewishvirtuallibrary.org; https://encyclopedia.ushmm.org/content/en/article/jewish-population-of-europe-in-1933-population-data-by-country]. People of Jewish background made up only 0.75% of the population of Germany, 3.2% of the population of the greater German-speaking world, 1.7% of the total European population, and 0.73% of the total world population.

Despite being such a small percentage of the total population, people of Jewish background composed 15–33% of the German scientific research system, according to various estimates [Ash and Söllner 1996, p. 7].

Prior to the Third Reich (before 1933), 17% (17 out of 99) of scientific Nobel Prize winners were of Jewish background, as shown in Table 10.12. As of 2013, 25% of scientific Nobel Prize winners were of Jewish background (144 of the 566 winners for 1901–2013 [Gerstl 2014, pp. 82–96]); many of those were from the German-speaking world, were immigrants from the German-speaking world, or were the children of immigrants from the German-speaking world.

By these metrics, people of Jewish family background were ∼10–30 times more likely to be scientific creators than one would expect from overall demographic figures alone.

Nobel Prize	**Year**	**Name**
Medicine	1908	Paul Ehrlich
Medicine	1908	Élie Metchnikoff
Medicine	1914	Róbert Bárány
Medicine	1922	Otto Meyerhof
Medicine	1930	Karl Landsteiner
Medicine	1931	Otto Warburg
Chemistry	1905	Adolf von Baeyer
Chemistry	1906	Henri Moissan
Chemistry	1910	Otto Wallach
Chemistry	1915	Richard Willstätter
Chemistry	1918	Fritz Haber
Physics	1907	Albert Michelson
Physics	1908	Gabriel Lippmann
Physics	1921	Albert Einstein
Physics	1922	Niels Bohr
Physics	1925	James Franck
Physics	1925	Gustav Hertz

Table 10.12: Jewish Nobel Laureates in science prior to the Third Reich (1901–1932).

In his analysis of why such a disproportionately large percentage of Nobel-Prize-winning scientists have been Jewish, Ronald Gerstl proposed that a number of factors were responsible [Gerstl 2014, pp. 70–74]:

> The Jewish family has traditionally been a secure and nurturing unit. The incidences of family violence, abandonment, failure to provide support for wife and children, alcoholism, unwed mothers and other social ills are relatively rare. [...]
>
> Overall, Jewish families in modern times have considerably fewer children than the average birthrate. Consequently Jewish parents have been able to dedicate more time and money to each child's welfare, education and cultural development. [...]
>
> The Jews have a long history of dedication to learning going back to ancient times. Judaism required every Jewish man to study the Torah and the Talmud, which necessitated literacy. [...]
>
> Whereas most other parents in poor or modest circumstances were anxious for their offspring to join the workforce, Jewish parents, including the poor, were willing to make sacrifices so that their children could remain in school as long as possible. [...]
>
> Children of immigrant parents felt the need to succeed to recompense parents for their sacrifices. Beyond the first generation, parents continued to instill high expectations in their offspring. [...]
>
> Centuries of persecution may actually have strengthened Jews' resolve and tenacity. Jews felt like outsiders in many countries in which they dwelled, which may have given them an incentive to prove their worth rather than complacently accept their lot. Often differing from the general culture, Jews have been less likely to cling to conventional wisdom and preconceptions. This allowed them to be more open to change, to adapt more quickly to new circumstances and to perceive new opportunities. [...]
>
> That said, cultural factors and values alone cannot fully explain the extent of Jewish achievements. Some genetic predisposition has to be considered as well, realizing that both are inextricably linked.

Whereas Ronald Gerstl only listed genetic factors as one possible cause among many others, Charles Murray focused on the genetic theory in several publications [Herrnstein and Murray 1996; Murray 2007, 2020]. Other scholars have also argued for and against the genetic theory [e.g., Cochran et al. 2006; Ferguson 2007; Pinker 2006].

Historian of science Noah Efron criticized both the theories about Jewish educational background and those about Jewish genetics, and proposed that Jewish prominence in science was only a transient historical phenomenon caused by the career opportunities that were and were not open to students of Jewish background in certain countries in the late nineteenth and early twentieth centuries [Efron 2006, 2013, 2014]. Efron summarized his arguments [Efron 2013]:

> Elsewhere, rabbis and pundits tried to puzzle out what it is about Jews that make them so super at science.

> Broadly, two sorts of theories have been floated. One is that Jews have primo genes. Charles Murray, the Enterprise Institute scholar and co-author of *The Bell Curve*, set out the case for this a few years ago in an essay in *Commentary* called "Jewish Genius," writing bluntly that "something in the genes explains elevated Jewish IQ." Another theory is that Jews love hitting the books, as Israeli economics laureate Robert Aumann told the army radio station Galei Tzahal: Jewish homes have overflowing bookshelves. Throughout the generations we have given great honor to this intellectual pursuit.
>
> There are good reasons to doubt both sorts of theories. For one thing, Jewish excellence in science is a new thing. When the great Jewish folklorist Joseph Jacobs set out in 1886 to compare the talents of Jews with the talents of other Westerners, he found their performance mediocre in every science save medicine. In the first decades of the 20th century, Princeton psychologist Carl Brigham tested the intelligence of Jews in America, and concluded they "had an average intelligence below those from all other countries except Poland and Italy." Jewish excellence in science is a phenomenon that flowered in the decades before and, especially, after the Second World War; it is too recent a phenomenon to be explained by natural selection, or even by putative ancient cultural traditions.
>
> The real explanation of Jewish success in science lies elsewhere. The 20th century began with massive migrations of Jews, to the United States, to the cities of Russia (and then the Soviet Union), and to Palestine. In each of these new lands, Jews turned to science in great numbers because it promised a way to transcend the old world orders that had for so long excluded most Jews from power, wealth and society. Science, based as it is on values of universality, impartiality and meritocracy, appealed powerfully for Jews seeking to succeed in their new homes. It is not so much what Jews were (smart, bookish) that explains their success in science, as what we wanted to be (equal, accepted, esteemed), and in what sorts of places we wanted to live (liberal and meritocratic societies). [...]
>
> What bugs me about attributing the remarkable prominence of Jews among Nobel laureates to genes or enduring cultural traditions is that doing so suggests that Jewish success in science will inevitably continue as a matter of course. Most likely it won't. The percentages of Jews among new American Ph.D.s in the sciences has declined greatly over the past generation. In Israel, spending on higher education has continued to decline during most of the same period; to many of the growing numbers in Israel who embrace religion, the appeal of science has nearly vanished. The passions that drew Jews to sciences in such great numbers have dissipated.

Whatever the explanation for the large numbers of Jewish creators, family background appears to help but is not sufficient by itself. For example, the modern United States has roughly six million people of Jewish background [Gerstl 2014, pp. 37–38], and millions of people from each of many other family backgrounds. If any one or more of those family backgrounds were automatically the key to producing revolutionary scientific creators, the modern United States would have produced far more revolutionary innovators and innovations than it appears to have. Although the United States has vast numbers of scientists and engineers, very few of those appear to be producing the sorts of truly revolutionary creations that were much more common in the earlier German-speaking world. Thus the most critical factors appear to be systemic approaches, such as those considered in previous sections, that cultivate, support, and reward revolutionary creators and creations.

In addition to the factors already considered in this chapter, it is possible that other factors helped or hindered scientific innovation in the former German-speaking world. In the future, scholars who examine this problem further should evaluate factors such as (but not limited to) the following for the older German-speaking world, the U.S. research system, and other innovation systems, and determine how much if any effect each factor has had on innovation:

- Being an immigrant, or the descendant of people who recently immigrated to that country or region [Hathaway 2017].
  - For immigrants or the children of immigrants who initially have little wealth or status in their new country, a scientific education and career may be one of the few available paths offering the greatest opportunity for elevation in society. In theory (although not always in practice), someone could go from disregarded poverty to social elite by learning enough and working hard enough. Due to discrimination, upfront financial costs, or other societal barriers or prerequisites, there may be few other career paths that are open and that have so much potential. (This was essentially Noah Efron's explanation for the success of Jewish scientists [Efron 2013], but it could apply to scientists coming from other family backgrounds as well.)
  - Perhaps immigrants are a self-selected group with more independent initiative, greater creativity, and more willingness to work hard in order to leave one country and settle in another.
  - Maybe immigrants, or the children of immigrants, feel that they have more to prove or further to rise in their new country, and therefore on average dream bigger and work harder than those whose families have lived in that country for many generations.
  - Perhaps immigrant families, feeling more alone in a foreign country, are more closely knit and more supportive, which could promote more positive personality characteristics and greater success in life.
- Other family backgrounds that are disproportionately frequent or infrequent among innovators (number of siblings, birth order, parental education and careers, religion and religiosity, wealth, geographical location, etc.).
- The ease with which students could transfer among courses, majors, and schools within the educational system.
- The average total cost required to obtain a doctoral (or other final) degree.
- The annual ratio of the number of available good jobs to the number of students graduating with a final science or engineering degree.
- The average age at which children who ultimately became scientists or engineers first decided that they wanted to pursue that educational and career path.
- The average age at which scientists or engineers first obtained a job that gave them the freedom and resources to pursue their own ideas.

- The average age at which scientists or engineers came up with their first major innovation.
- The average age at which scientists or engineers came up with their last major innovation.
- The average number of innovations per year per person in the innovation system. (Exactly how would an innovation be defined?)
- The average number of publications per year per person in the innovation system (although greater quantity does not necessarily mean greater quality, and might in fact be achieved at the expense of quality).
- The average number of patents per year per person in the innovation system (again, quantity may not be indicative of quality).
- The average number of technology startup companies or laboratories per year per person in the innovation system (although widespread, formal startup companies may be a more modern concept, and it may be difficult to find analogous data for older innovation systems).
- The average amount of total research funding per year per person in the innovation system.
- The average salaries for various categories of science, engineering, and medical professionals.
- The average salaries for teachers at different levels and in different fields.
- The average duration of a research project (from conception to viable demonstration).
- The average duration of a research job.
- The average duration of a research career.
- The average number of hours per year that a person in the system spent on research (actual research, not paperwork related to research).
- The average number of hours per year that a person spent on teaching (actual teaching, not paperwork related to teaching).
- The average number of hours per year that a person spent on scientifically directly productive work other than research and teaching (such as reading).
- The average number of hours per year that a person spent on sponsor proposals and reporting requirements. (Even though many would deem these necessary, they can siphon enormous amounts of time and energy away from actual research.)
- The average number of hours per year that a person spent preparing and submitting journal articles, books, etc. for publication. (Although publications are an essential part of a healthy scientific system, when publications are emphasized to an extreme, they can also divert vast amounts of time and energy away from actual research.)

- The average number of hours per year that a person spent on other work that is less directly productive scientifically, such as required meetings, personnel training, human-resources-related tasks, contract administration, ordering, inventory, approvals, evaluations, other paperwork, etc.

- The ease with which researchers could access all the relevant scientific literature (due to financial, physical, or online restrictions).

- The ease with which researchers could access relevant facilities for laboratory experiments or engineering construction.

- The ease with which researchers could exchange ideas with other relevant researchers in technical conferences, seminars, formal organizations, informal or after-hours organizations, etc.

- The average number of technical supporting personnel (e.g., research assistants) per researcher.

- The average number of nontechnical supporting personnel (e.g., clerical and logistics assistants) per researcher.

- How assistants, researchers, managers, and sponsors were evaluated, selected, and promoted (based on good work and talent vs. politics and favoritism, etc.).

- How major decisions on research programs were made by individuals, organizations, and sponsors (short-term vs. long-term gain, logical reasoning vs. hype and hope, etc.).

- The average sizes and compositions of research groups in different fields and research sectors (academic, corporate, and government laboratories).

- The average probability that a research proposal will be funded.

- The fractions of funding awarded by peer review or other processes, and how those processes work.

- The fraction of research projects that led to a viable demonstration. (Even though it may be bad if the fraction is too low, if the fraction is too high, that could indicate that higher-risk, more innovative projects are being avoided instead of pursued.)

- The fraction of viable demonstrations that ultimately led to a final product.

- How innovative research projects were on average, on a scale from evolutionary (straightforward extensions of what is already known) to revolutionary. (Are there objective, quantifiable, reproducible ways in which the innovativeness of projects can be evaluated?)

Ideally, data such as that described above should be plotted versus time to see how things changed over many decades within a given innovation system, as well as how things appear to be similar or different for different innovation systems.

Chapter 11

Immortalizing the Creations and Forgetting the Creators

Was man nicht aufgibt, hat man nie verloren.	What is not abandoned is never completely lost.

Friedrich Schiller. 1800. *Maria Stuart*, Act II, Scene 5.

As discussed in Chapter 10, the German-speaking research world had several systemic practices that allowed it to produce a huge number of revolutionary scientific creators and creations. As covered in this chapter, the global research system eagerly adopted the creations of the earlier German-speaking world, yet ultimately largely forgot both the creators and the systemic approaches that had made those creations possible.

Section 11.1 outlines the many ways in which creations and creators were transferred to the global research system, especially the United States, before, during, and after the Third Reich.

Section 11.2 analyzes the general innovation-promoting approaches that the U.S. research system borrowed from the earlier German-speaking world and used with relative success during the 1940s–1960s.

Section 11.3 examines how the modern innovation system began a long, slow decline starting in the 1970s. By that time, most of the German-speaking creators had retired or died, their creations had been refined to the point of diminishing incremental returns, and the research system had abandoned most of the German-like practices it had adopted, greatly reducing its efficiency at producing entirely new revolutionary innovators and innovations.

11.1 Creations and Creators Transferred from the German-Speaking World

Before, during, and after the Third Reich, virtually all of the creations, most of the creators, and a number of the underlying general practices were transferred from the German-speaking world to the global research system, especially the early U.S. research system. The United States and the rest of the global research system spent many decades copying, optimizing, and mass-producing the innovations that had been created by the earlier German-speaking world, resulting in our modern world of jet aircraft, electronics, and pharmaceuticals. Most of the creators who had already died or who remained in German-speaking areas were forgotten by the non-German-speaking world, which often mistakenly attributed their creations to whichever non-German-speaking individuals or organizations had acquired their technical information. Most of the creators who emigrated out of German-speaking areas led well-funded but very quiet lives perfecting their creations and were also ultimately forgotten; only a few, such as Albert Einstein, Edward Teller, and Wernher von Braun, sought or received lasting fame.

11.1.1 Before the Third Reich

Even well before the Third Reich, the German-speaking world had significant influences on the development of research systems in the United States and elsewhere. In particular, some German-speaking scientists left their own world in search of opportunities elsewhere, a number of U.S. scientists were educated in the German-speaking world, universities in the United States and other countries were consciously designed or redesigned to mimic the successful model of universities in the German-speaking world, and many technological patents and factories were forcibly transferred during and after World War I.

Émigrés before the Third Reich

Long before the Third Reich came to power and triggered a mass exodus, a steady stream of German-speaking émigrés moved to the United States (or other countries) to seek new business opportunities. Just a few of the better-known examples of German-speaking creators who moved to the United States before the Third Reich are listed in Table 11.1.

U.S. scientists and engineers educated in the German-speaking world

In addition to German-speaking creators who moved to the United States, there were a large number of Americans who travelled to the German-speaking world for education and training and then returned to the United States. Over 9000 Americans attended German universities (especially Berlin, Göttingen, Halle, and Heidelberg) between 1820 and 1920 [Röhrs 1995, p. 11]. Including Americans who attended before that time or up to the Third Reich, as well as those who went to German-speaking universities in countries other than Germany, probably well over 10,000 Americans studied in the German-speaking world (in science, math, engineering, and other areas) and brought what they had learned back to the United States.

A few examples of prominent U.S.-born scientists and scholars who received at least part of their education in the German-speaking world are listed in Table 11.2.

Name	Nationality	Scientific contributions
Louis Agassiz	Swiss	Paleontology
Walter Baade	German	Astronomy
John Jacob Bausch Henry Lomb Ernst Grundlach	German German German	Bausch & Lomb lenses, eyeglasses, microscopes, telescopes, etc.
Emil(e) Berliner	German	Microphone, record player, helicopter
Herman Frasch	German	Oil refining, sulfur
Beno Gutenberg	German	Seismology, earthquake magnitudes, etc.
Karl Herzfeld	Austrian	Quantum and statistical physics
Hermann Lemp	Swiss	Diesel-electric locomotives
Julius Edgar Lilienfeld	Austrian	Field effect transistor
Maria Goeppert Mayer	German	Nuclear shell model
Georg(e) Merck	German	Pharmaceuticals
Ottmar Mergenthaler	German	Linotype
Karl Friedrich Meyer	Swiss	Infectious disease prevention
John Roebling	German	Suspension bridges
Charles (Karl) Steinmetz	German	AC electrical devices
Levi Strauss	German	Blue jeans
Nikola Tesla	Serbian	AC electrical devices
Robert Trümpler	Swiss	Astronomy
Gustave Whitehead/Weisskopf	German	First airplane?

Table 11.1: Examples of creators who emigrated to the United States before the Third Reich.

Name	German education	Scientific contributions
James M. Crafts	Studied with Robert Bunsen	Organic chemistry
William Duane	Ph.D. (Berlin, 1897) under Max Planck	X-rays and radioactive elements
Josiah Gibbs	Studied math and physics under Gustav Kirchhoff and Hermann von Helmholtz	Statistical and thermal physics
Percy Lavon Julian	Ph.D. (Vienna, 1931) with Ernst Späth	Organic chemistry
Irving Langmuir	Ph.D. (Göttingen, 1906) under Walther Nernst	Physical chemistry, General Electric R&D
Arthur Michael	Research assistant for Hofmann, Bunsen	Organic chemistry
J. Robert Oppenheimer	Ph.D. (Göttingen, 1927) under Max Born	Nuclear physics, Manhattan Project
Linus Pauling	Studied quantum theory under Arnold Sommerfeld, Erwin Schrödinger	Chemistry
Ira Remsen	Ph.D. (Göttingen, 1870) with Wilhelm Fittig	Organic chemistry
Howard Robertson	Studied physics under Hermann Weyl, Max Born, and Arnold Sommerfeld	Applied mathematics, cosmology
Edmund Beecher Wilson	Studied developmental biology under Rudolf Leuckart, Carl Ludwig, Theodor Boveri	Developmental biology

Table 11.2: Examples of U.S.-born scientists and scholars who received at least part of their education in the German-speaking world.

Influence on the structure of the U.S. research system before the Third Reich

Up through the nineteenth century, university education in the United States was largely rote learning, with little freedom to choose among courses or to conduct research. Many of the Americans who had been educated in the German-speaking world and returned home wanted to instill U.S. universities with much more freedom, originality, and academic research like what they had witnessed in Europe. This motivation led to the founding of universities such as:

- Massachusetts Institute of Technology in 1861 in Boston (it moved to Cambridge in 1916) [Stratton and Mannix 2005].
- Johns Hopkins University in 1876 in Baltimore, Maryland [Thelin 2019].
- Stanford University in 1891 in Stanford, California [Wels 1999].
- California Institute of Technology in 1891 in Pasadena [Goodstein 1991].

These new schools were intentionally designed to emulate German universities by having faculty and students participate in both courses and original research. Following the success of such schools, older U.S. universities gradually reformed, and by the post-World-War-II era, most major U.S. universities were generally following the same German model [Ben-David 1992; Röhrs 1995; Schwinges 2007; Tanaka 2005].

Just as U.S. universities were deliberately transformed to be more German-like, U.S. companies were also transformed to be more like science- and engineering-based companies in the German-speaking world, by forcibly seizing technological patents and even entire factories from the German-speaking world, as discussed below.

Transferred companies, patents, and other resources

The U.S. Trading with the Enemy Act of 1917 resulted in the large-scale appropriation of resources from German speakers (both those living in Europe and those living in the United States) to the United States government and to certain non-German-speaking U.S. citizens and companies that were politically well connected [Coben 1963; Gross 2014, 2015]. By invoking this and other laws during and after World War I, the U.S. Office of Alien Property Custodian put thousands of German-speaking U.S. residents (both recent immigrants and longtime U.S. residents who had come from Germany, Austro-Hungary, and even Switzerland, which was not a party to World War I) in concentration camps and held them in the camps until 1920, long after the war (Fig. 11.1). From those and countless other German-speaking individuals in the United States and overseas, the Office of the Alien Property Custodian seized over $500 million dollars (as valued then, which would be far more in modern dollars) worth of patents, property, businesses, and possessions. Those permanent seizures included large numbers of patented inventions and processes, as well as the U.S. branches of German and Austro-Hungarian scientific and engineering companies such as Bayer and Merck (p. 2229).

Senior staff of the U.S. Alien Property Custodian's office (1918), which seized over $500 million dollars (as valued then) worth of patents, property, businesses, and possessions from German speakers living in Europe and in the United States

One of the concentration camps for German-speaking residents of the United States during World War I

Figure 11.1: During and after World War I, the U.S. Office of the Alien Property Custodian (run by A. Mitchell Palmer, foremost in the upper photograph) put thousands of German-speaking residents of the United States in concentration camps and seized over $500 million dollars (as valued then) worth of patents, property, businesses, and possessions from German speakers living in Europe and in the United States.

The details and impact of these World War I seizures warrant a detailed study, yet unfortunately there does not appear to be a comprehensive modern account. However, the journalist Daniel Gross wrote two articles that gave insights into this history. Gross described the concentration camps and property seizures [Gross 2014]:

> Posselt was a young editor and translator who emigrated from Austria-Hungary in 1914. His nationality—like that of millions of German-speaking immigrants in the United States during World War I—attracted suspicion and anger from nationalistic Americans. In the course of the war, the federal government registered around half a million "enemy alien" civilians, spied on many of them, and sent approximately 6,000 men and a few women to internment camps. Perhaps more strikingly, it seized huge troves of private property with dubious relevance to the war effort, ultimately amassing assets worth more than half a billion dollars—close to the entire federal budget of pre-war America. [...]
>
> [A]t Fort Oglethorpe, Posselt described an odd collection of imprisoned intellectuals. They were allowed to organize courses taught by interned professors of biology, mathematics, literature, and languages. Several dozen musicians, many of whom had been recruited from Europe to join American orchestras, regularly performed to help keep up morale. [...]
>
> In retrospect, American internment policies are troubling, but they're dwarfed by a quieter and more sweeping practice of property seizure. Under the Trading with the Enemy Act, President Wilson appointed an "Alien Property Custodian" named A. Mitchell Palmer to take control of property that might hinder the war effort. Among other things, this meant all property belonging to interned immigrants, regardless of the charges (or lack thereof). "All aliens interned by the government are regarded as enemies," wrote Palmer, "and their property is treated accordingly."
>
> The basic argument was that property seizure prevented immigrants from financially or materially supporting enemies of America. Under Palmer's direction, the Office of the Alien Property Custodian grew to employ hundreds of officials and used several high-profile cases of espionage and industrial sabotage to defend its work. German chemical companies in the United States were particularly vulnerable to seizure: not only did dye and pharmaceutical companies divert raw materials from the war effort, they could also in theory produce explosives.
>
> The agency's powers were remarkably broad, however. In *Munsey's Magazine*, Palmer described the Alien Property Custodian as "the biggest general store in the country," noting that some of the companies seized were involved in "pencil-making in New Jersey, chocolate manufacture in Connecticut, [and] beer-brewing in Chicago." There were small holdings seized from individuals, too. "Among them," he continued with an odd hint of pride, "are some rugs in New York; three horses near Joplin, Mississippi; [and] a carload of cedar logs in the South." (Historians will probably never figure out why Palmer wanted those rugs in New York.) The historian Adam Hodges found that even women who were American citizens, if married to German and Austro-Hungarian immigrants, were classified as enemy aliens— and they alone lost a combined $25 million in property to the government.

> The war ended in November 1918, just a year after the passage of the Trading with the Enemy Act. In that time, the Alien Property Custodian had acquired hundreds of millions of dollars in private property. In a move that was later widely criticized—and that political allies of the Alien Property Custodian likely profited from directly—Palmer announced that all of the seized property would be "Americanized," or sold to U.S. citizens, partly in the hopes of crippling German industries. (His attitude echoed a wider sentiment that the Central Powers deserved to pay dearly for the vast destruction of the war.) In one high-profile example, the chemical company Bayer was auctioned on the steps of its factory in New York. Bayer lost its U.S. patent for aspirin, one of the most valuable drugs ever produced.
>
> "The same peace which frees the world from the menace of autocratic militarism of the German Empire," Palmer argued, "should free it from the menace of its autocratic industrialism as well." Immigrant property, in his view, was just an extension of German and Austro-Hungarian property—which gave America the right to take it. Several lawsuits later disputed his authority to do so, including one that reached the Supreme Court, but his actions were found to be legal under wartime laws. In fact, the agency's reputation was sufficiently intact that President Franklin Roosevelt re-established it during World War II. [...]
>
> The last prisoner wasn't released until April 1920, a full year and a half after the end of the war. As Glidden described it: "When the camps did close scarcely anyone cared or noticed."

As mentioned by Gross, the Alien Property Custodian during the period 1917–1919 was Alexander Mitchell Palmer (1872–1936, closest to the camera in the upper half of Fig. 11.1). Using the over $500 million of property that his office seized, Palmer acquired power and wealth for himself and his political and business associates. His actions while Alien Property Custodian were so highly regarded by the federal government that he was then elevated to the position of Attorney General of the United States 1919–1921, during which time he led the "Palmer raids" that widely terrorized American communities of immigrants from Europe [Coben 1963].

Daniel Gross added more details about this history in another article [Gross 2015]:

> Ties between German and American chemistry were even tighter in the industrial sphere. Many of the United States' prewar dyestuff and pharmaceutical suppliers were actually branches of German corporations. Americans who wanted a competitive education often traveled to German universities to study chemistry, while German chemists who sought new opportunities came to America. During the war, however, the United States subverted and harnessed the resources of its German competition. [...]
>
> Six months after war was declared, suspicious American authorities gained the legal power to act against German companies. Congress passed the Trading with the Enemy Act, and a man named Mitchell Palmer was appointed Alien Property Custodian. Palmer's office began receiving thousands of reports of enemy-held property. Factories and businesses owned by German nationals were seized by the government, along with thousands of valuable chemical patents. Beckers's former employer, the American branch

> of Bayer, was seized. Many of its employees were even imprisoned at Fort Oglethorpe, Georgia, an internment camp that today has been largely forgotten.
>
> World War I helped erode the advantages of German chemistry. When hostilities in Europe finally ended in 1918, the United States was producing four times as much poison gas as Germany. Palmer, perhaps recognizing that his wartime powers would soon wane, quickly disposed of confiscated holdings worth millions of dollars. Bayer was sold at a public auction on the company steps.

After World War I, the U.S. Office of Alien Property Custodian was viewed as so successful that it was revived and extensively used during and after World War II as well (p. 2120).

In addition to the over half-billion 1918 dollars worth of property seized by the Alien Property Custodian, billions of dollars of reparations (in both property and money) were taken from Germany, Austria, and Hungary after the war. The total reparations paid by Germany amounted to at least 67.7 billion marks or 17 billion 1918-era dollars, equivalent to many years worth of spending by the U.S. federal government at that time. In fact, German reparations obligations for World War I continued even long after World War II, and the final payment from Germany to the United States was not made until 3 October 2010 [https://www.deutschlandfunk.de/das-ende-der-reparationszahlungen-vom-1-weltkrieg.795.de.html?dram:article_id=119010]. Separate reparations of property and money were extracted from Austria and Hungary.

Thus during and after World War I, the German-speaking world transferred to the United States and other countries not only technological patents and factories, but also enough money to fund their continued development and operation for decades.

11.1.2 During the Third Reich

There was a great deal of innovation transfer out of the German-speaking world during the Third Reich, 1933–1945. This transfer took the form of large numbers of émigré scientists and engineers, critical knowledge transferred by them or via other routes, and influence on the wartime structure of the U.S. research system.

Émigrés during the Third Reich

The Third Reich's vicious persecution of people who were of Jewish descent and/or who were perceived as political opponents drove roughly 25% of scientists and engineers to leave the German-speaking world. Over half of those moved to the United States, most of the rest moved to the United Kingdom, and a smaller number went to other countries. This mass exodus was the beginning of the end of the German-speaking scientific world, but a great boon for the countries receiving these talented creators [Ash and Söllner 1996; Fraser 2012; István Hargittai 2006; Leff 2019; Medawar and Pyke 2000; Nachmansohn 1979].

Some examples (though by no means an exhaustive list) of German-speaking creators who moved to the United States during this time are listed in Table 11.3. Note that for thoroughness, this list includes Theodore von Kármán, who came to the United States just before the Third Reich (in 1930) but is generally grouped with the Hungarian refugees from the Third Reich dubbed the "Martians," as well as some younger scientists who completed their education in the United States.

Name	**Nationality**	**Scientific contributions**
Robert Adler	Austrian	Ultrasonic signals
Valentine Bargmann	German	Relativistic physics
Peter Bergmann	German	Relativistic physics
Max Bergmann	German	Proteins
Hans Bethe	German	Solar fusion, Manhattan Project
Erwin Biel	Austrian	Climatology
Marietta Blau	Austrian	Particle detectors
Felix Bloch	Swiss	Solid state physics, NMR, Manhattan Project, radar
Konrad Bloch	German	Cholesterol metabolism/hormones, fatty acid metabolism
Richard Brauer	German	Applied mathematics
Richard Courant	German	Applied mathematics
Max Dehn	German	Applied mathematics
Peter Debye	Dutch	Solid state physics, quantum theory, electrolytes
Max Delbrück	German	Gene structure and mutation, phage genetics
Albert Einstein	German	Relativity, statistical physics, quantum physics
Walter Elsasser	German	Earth's magnetic field
Paul Erdös	Hungarian	Applied mathematics
Kasimir Fajans	Polish	Radioactive elements, inorganic chemistry
James Franck	German	Atomic energy levels, photosynthesis, Manhattan Project
George Gamow	Russian	Nuclear physics

Table 11.3: Examples of German-speaking creators who emigrated to the United States during the Third Reich. (Continued on next page.)

Name	**Nationality**	**Scientific contributions**
Kurt Gödel	Austrian	Applied mathematics
Thomas Gold	Austrian	Astrophysics, origin of life
Gerson Goldhaber	German	Particle physics
Gertrude Scharff Goldhaber	German	Nuclear physics, Manhattan Project
Maurice Goldhaber	Austrian	Nuclear and particle physics
Peter Goldmark	Hungarian	Audio/television recording
Victor Hess	Austrian	Discovered cosmic rays
Arthur von Hippel	German	Radar, solid state physics
Theodore von Kármán	Hungarian	Aerodynamics
Walter Kohn	Austrian	Solid state physics
Willy Ley	German	Rockets
Franz Lipmann	German	Coenzyme A
Otto Loewi	Austrian	Neurotransmitters (esp. acetycholine, epinephrine)
Fritz London	German	Superconductivity
Karl Meissner	German	Spectroscopy
Otto Meyerhof	German	Glycolysis and muscle metabolism
Richard von Mises	Austrian	Aerodynamics
Carl Neuberg	German	Biochemistry
John von Neumann	Hungarian	Manhattan Project, computers
Emmy Noether	German	Applied mathematics
Lothar Nordheim	German	Quantum physics, Manhattan Project
Wolfgang Pauli	German	Quantum, exclusion, spin, neutrino
Arno Penzias	German	Big Bang
George Placzek	Czech	Nuclear physics, Manhattan Project
William Prager	German	Applied mathematics
Eugene Rabinowitch	Russian	Photosynthesis, Manhattan Project
Charlotte Riefenstahl	German	Physics
Joseph Rotblat	Polish	Nuclear physics
Erich Rothe	German	Applied mathematics
Rudolf Schoenheimer	German	Biomolecule isotope labels, cholesterol/atherosclerosis
Roman Smoluchowski	Polish	Solid state physics, astrophysics
Jack Steinberger	Germany	Particle physics
Otto Stern	German	Quantum theory, molecular beam epitaxy
Gabor Szego	Hungarian	Applied mathematics
Leo Szilard	Hungarian	Manhattan Project, molecular biology
Edward Teller	Hungarian	Manhattan Project, H bomb
Victor Weisskopf	Austrian	Relativistic quantum theory, Manhattan Project
Hermann Weyl	German	Relativistic quantum theory
Eugene Wigner	Hungarian	Manhattan Project, quantum physics
Fritz Zwicky	Swiss	Jet propulsion, astrophysics

Table 11.3 (continued): Examples of German-speaking creators who emigrated to the United States during the Third Reich.

Likewise, some examples of German-speaking creators who moved to the United Kingdom during this time are listed in Table 11.4, and examples of German-speaking creators who moved to other countries are listed in Table 11.5.

Name	**Nationality**	**Scientific contributions**
Hermann Blaschko	German	Neurotransmitters
Hermann Bondi	Austrian	Cosmology
Max Born	German	Quantum probability and statistical physics
Egon Bretscher	Swiss	Nuclear Physics, Manhattan Project
Edith Bülbring	German	Smooth muscle, neurotransmitters
Ernst Chain	German	Penicillin, fermentation technologies
Robert Eisenschitz	Austrian	Chemistry
Paul Eisler	Austrian	Printed circuit boards, electric window defroster, etc.
Wilhelm Feldberg	German	Neurotransmitters
Erwin Freundlich	German	Astronomy, general relativity tests
Sigmund Freud	Austrian	Psychology
Otto Frisch	German	Nuclear physics, Manhattan Project, laser scanning
Herbert Fröhlich	German	Solid state physics, biophysics
Dennis Gabor	Hungarian	Holography
Ludwig Guttmann	German	Treating spinal injuries
Fritz Haber	German	Ammonia production, chemical warfare (Died in Switzerland en route to Palestine)
Walter Heitler	German	Quantum physics, particle physics
Bernard Katz	German	Neurotransmitters
Nicholas Kemmer	Russian	Particle physics, Manhattan Project
Hans Krebs	German	Biochemical citric acid and urea cycles
Nicholas Kurti	Hungarian	Micro-Kelvin refrigeration and physics
Heinz London	German	Superconductivity
Hermann Lehmann	German	Hemoglobin, pharmacokinetics
Kurt Mendelssohn	German	Nuclear physics, cryogenics
Rudolf Peierls	German	Solid state physics, Manhattan Project
Max Perutz	Austrian	Hemoglobin protein structure
Michael Polanyi	Hungarian	Physical chemistry
Erwin Schrödinger	Austrian	Lots of quantum; color vision, theoretical biology
Francis (Franz) Simon	German	Low temperature physics, Manhattan Project
Rudolf Strauss	German	Automated soldering for printed circuit boards

Table 11.4: Examples of German-speaking creators who emigrated to the United Kingdom during the Third Reich.

Name	Nationality	Moved to	Scientific contributions
Paul Bernays	Swiss/German	Switzerland	Applied mathematics
György Bíró, László Bíró	Hungarian	Argentina	Ballpoint pen
Walter Gordon	German	Sweden	Relativistic quantum physics
Hans von Halban	German	Canada	Nuclear physics
Gerhard Herzberg	German	Canada	Molecular spectroscopy and structures, free radicals
George de Hevesy	Hungarian	Denmark, then Sweden	Radiolabelled molecules
Rudi Lemberg	German	Australia	Porphyrins
Lise Meitner	Austrian	Sweden	Nuclear fission
Karl Przibram	Austrian	Belgium	Nuclear physics
Richard Willstätter	German	Switzerland	Chlorophyll, chromatography, gas mask filters, enzymes

Table 11.5: Examples of German-speaking creators who emigrated to other countries during the Third Reich.

Kurt Mendelssohn, a German scientist who moved to the United Kingdom, described the whole wave of German-speaking creators who emigrated during the Third Reich, as well as their enormous impact on the countries that received them [Mendelssohn 1973, pp. 175–176]:

> Oxford may have been the first place where German refugee scientists found an opportunity to continue their work; it did not remain the only one. The new Diaspora covered the world. From England to Australia, from America to India, there was hardly a university which did not give shelter and a place of work to the displaced scholars. They, in turn, did all they could by teaching and research to repay the hospitality they were receiving. Around groups of them, or even individuals, there sprang up new schools, recruited from the local students who, in turn, carried forward the heritage of all that had been good and useful in German academic life. Far from destroying the spirit of German scholarship, the Nazis had spread it all over the world. Only Germany was to be the loser.

Scientific knowledge transferred during the Third Reich

A large amount of scientific knowledge was transferred out of the German-speaking world during this time via several routes:

- Émigré scientists and engineers.
- Captured and interrogated scientists, engineers, and military personnel [for example those interrogated at Fort Hunt, Virginia (pp. 2057, 4929) and Wright Field, Ohio (p. 2058)].
- Published scientific literature and patents.

This transferred scientific knowledge was employed by well-funded wartime programs in the United States and United Kingdom.

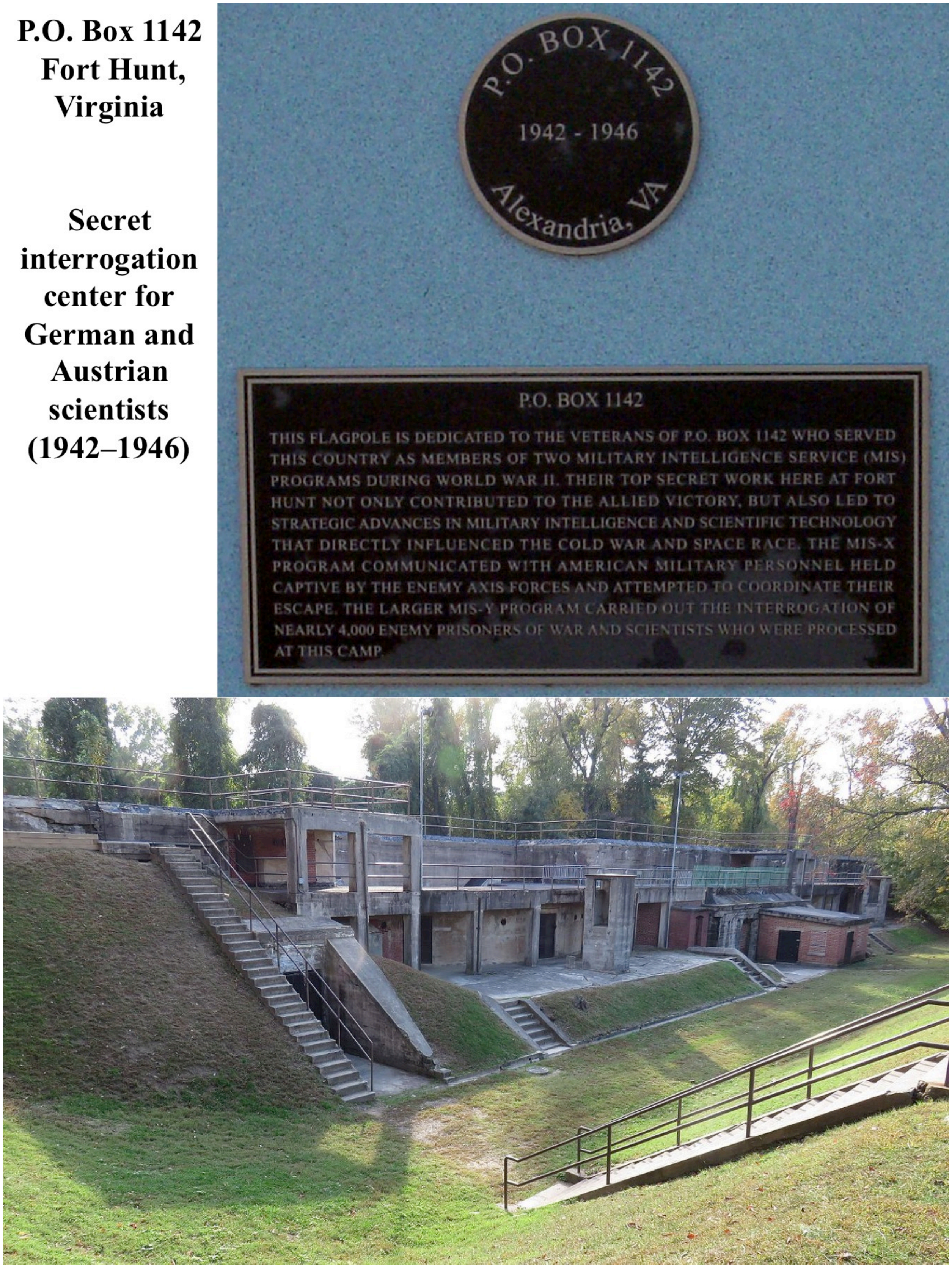

Figure 11.2: From 1942 until 1946, the United States operated "P.O. Box 1142," a highly secret interrogation camp for thousands of captured German and Austrian scientists, engineers, and military personnel at Fort Hunt, Virginia. See p. 4929.

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AFHRA A2055 Frame 1062

14 December 1944

MEMORANDUM FOR RECORD:

SUBJECT: Classification of Reports Prepared by German Scientists

1. Mr. Graishen, A-4, advised by phone that Colonel Brown of CPM, G-2, stated that to his knowledge there were no written instructions to the effect that all reports written by German Scientists at Wright Field must be classified as secret. He therefore advised that T-2 should declassify those reports previously written and classified as secret in accordance with subject matter contained in each report. Col. Brown further advised that reports may be classified lower than confidential if subject matter so permitted even though the report was signed as being prepared by a German scientist so long as nothing in the report identified the author as a German Scientist or his association with the German Scientist Project, or no use is made of the code word for the foreign exploitation project.

D. L. P.

Figure 11.3: Beginning in 1944 (or earlier), captured German and Austrian scientists were put to work at Wright Field to transfer their detailed technical knowledge to the United States, as demonstrated by this 14 December 1944 memo from Colonel Donald L. Putt [AFHRA A2055 Frame 1062].

As has already been quoted in Chapter 1, a 1946 U.S. Senate report on the establishment of the National Science Foundation noted that the greatest scientific accomplishments of the United States during World War II were directly derived from earlier German innovations [NSF 1946, p. 6]:

> It should be somewhat humiliating to us to realize that the revolutionary sulfa drugs had their beginning in German research laboratories; that atom splitting was discovered in Berlin; that the basic pioneer work that has led to radio and radar and the enormous American electronic industries was that of a German professor. Penicillin came from England [where it was purified by Ernst Chain, a German refugee]; DDT from Germany and Switzerland.

In October 1945, Howland Sargeant and James Markham from the U.S. Office of the Alien Property Custodian testified before the U.S. Senate and provided much more detail on how extensively the United States used scientific knowledge from German patents, journals, and books during the war [Sargeant and Markham 1945, pp. 675–676, 692–695]:

> Testimony of Howland H. Sargeant, Chief, Division of Patent Administration, Office of the Alien Property Custodian
>
> Since March 1942 the Office of Alien Property Custodian has been administering thousands of patents and patent applications and other forms of industrial property vested from nationals of enemy and enemy-occupied countries. One of the first problems which confronted the Custodian after the entry of this country into World War II was the seizure and administration of patent property owned by the enemy. At that time we knew very little about the problem. We knew only that the enemy, particularly the Germans, owned great numbers of United States patents and that the inventions covered by these patents should be brought into full use in our war program. [...]
>
> Our primary objective in the administration of industrial property has been to make it available readily and immediately to serve all American industry and science. We intended to foster the active use of the store of technical knowledge represented by these patents and applications for patent; and we wanted to encourage further research on these inventions. [...]
>
> The figures we have show, Mr. Chairman, that about 33,000 of the patents that we took over were enemy-owned. [...]
>
> James E. Markham, Alien Property Custodian.
>
> Report on Alien Property Custodian Program of Reproduction of Foreign Scientific Periodicals
>
> [...] The Office of Alien Property Custodian was created to seize enemy property in this country and to administer it for the benefit of the United States. One valuable property of enemies was the right to control, through copyrights and otherwise, the distribution of much enemy-originated scientific literature. Acting under the authority given him, the Custodian has seized these rights and, through a program of periodical republication, has made available to American scientists throughout the war much of the results of

the results of German technical research, both that published just before the war and that published during it. [...]

During the war it was necessary to obtain and use information regarding activities of the enemy along scientific lines just as it was necessary to know what his military activities were. Scientific research in Germany was far advanced; recently a group of eminent American scientists stated:

"If Hitler had prevented the publication in 1939 of the first papers on atomic fission, Germany might have remained for a certain period of time in exclusive possession of a true fundamental secret of atomic power."[1]

[1]Statement of Drs. David L. Hill, Eugene Rabinowitch, and John A. Simpson, Jr., prepared at the direction of the executive committee of the Atomic Scientists of Chicago and quoted in Life magazine October 29, 1945.

American experts in the scientific field needed ready access to foreign scientific information to buttress scientific research in this country and to keep informed of the results of such research in enemy countries. Scientific literature from enemy countries was in such demand before the war that industrial and research organizations, scientific societies, and libraries annually spent approximately one and one-half million dollars for foreign books and journals. Most of this was spent for German publications. [...]

It was, of course, reasonable to expect that the enemy journals would not reveal exact specifications for the latest antiaircraft equipment or give detailed descriptions of such weapons as the V-1 or V-2 bomb. It is clear, however, from the nature and quality of the materials printed that the German Government throughout the war continued and in some cases even intensified its peacetime policy of encouraging publication of scientific information. The advantages of this kind of dissemination, within Germany and territory occupied by the German Government, as a means of expanding scientific frontiers were obviously considered by the German Government to outweigh the possibility that such information would become generally available to scientific personnel among the enemies of the Reich. The benefits of basic German research in many fields were thus made available to American science. In some cases materials in enemy journals have been of direct and immediate use in military operations. For example, an article in VDI Zeitschrift, concerning engineering problems in constructing German camps was directly utilized in construction of Army barracks.

More frequently, however, the subject matter in the articles served primarily to reveal the trend of enemy research and basic facts which confirmed previously held theories, thus saving thousands of man hours of painstaking investigation. Moreover, such materials presented theories and concepts which were tested on the basis of American experience, and thus became valuable in the war effort. To illustrate, frequent articles in Die Naturwissenschaften and Zeitschrift fuer Physik concerning atomic fission and uranium 238 were effectively utilized by scientists engaged in the Manhattan district project. The editor of Chemical Abstracts, Dr. E. J. Crane, has informed us "There is not the least doubt in my mind of the fact that your republication program was one of the factors which made the atomic bomb possible." Iowa State College reports "This college has received an E [Excellent rating] for its research on the atomic bomb . . . The men working on this splitting of the atom used, to a considerable extent, the periodicals which you have reprinted."

The journals reproduced dealt with almost every phase of scientific development of interest to a nation at war. Included among the journals were the leading periodicals in the following fields:

Acoustics	Geophysics	Paper chemistry
Aluminum	Infectious diseases	Parasitology
Aviation	Immunology	Pathology
Biochemistry	Instruments	Petroleum
Ceramics	Magnesium	Pharmacology
Chemistry	Mathematics	Physics
Crystallography	Mechanical engineering	Plant pathology
Electronics	Metallurgy	Plastics
Engineering	Microscopy	Rubber
Enzymology	Mineralogy	Spectrochemistry
Explosives	Mycology	Steel and iron
Fermentation	Nutrition	Textiles
Geology	Oils and fats	Virus research

[...] No report concerning reproduction of scientific materials originating in enemy countries after 1941 would be complete without reference to books as well as journals. Scientific books published in Germany in 1941, 1942, 1943, and 1944 were surreptitiously obtained by the Office of Strategic Services. Reproduction of the books was licensed to commercial publishers on a basis calculated to encourage the most extensive publication and dissemination. Nearly 700 works were licensed for republication. The books concerned subjects of direct interest to those engaged in war activities, including analysis of gases, analysis of metals, atomic fission, ballistics, electric amplifiers, electrolytes, electron emission, food analysis, magnesium, magnetic measurement, optics, organic chemistry, sound waves and measurement, synthetics and many others. A list of all books licensed, including those of recent date, is attached as an exhibit. It is noted that the prices charged are substantially less than prewar prices. For example, volumes of Beilstein's Handbuch der Organischen Chemie, which would normally have sold for $60 before the war, are currently sold for $12. The books were sold principally to industrial concerns, government agencies and research institutions throughout almost all the allied nations.

Influence on the structure of the U.S. research system during the Third Reich

Many of the general practices that had made the German-speaking world so effective at producing revolutionary creations were at least temporarily adopted by the United States research system, and played a vital role in the successes of its wartime R&D programs. For example, prior to 1940 the United States had little government funding for research, and any government-run laboratories were both small and rare. Beginning in 1940, the United States adopted the German model of large-scale government funding for innovative projects that could be carried out by a combination of new government labs, close ties to industry, and scientists in university laboratories. These general practices are discussed in much more detail in Section 11.2.

11.1.3 After the Third Reich

The largest and yet probably the least well understood (from the modern public's perspective) innovation transfer occurred at the end of the Third Reich. Many thousands of German-speaking scientists and engineers, well over 111,000 tons of German research documentation, more than 750,000 patents, many hundreds of complete factories and laboratories, and untold amounts of supplies, equipment, and prototypes were appropriated by the United States, the Soviet Union, the United Kingdom, France, and other countries after the war, seeding the modern world with a vast array of creations, even as it forgot the names of most of their creators.

Although this massive technology transfer has been nearly forgotten, it was loudly announced and praised by Allied governments and journalists at the time. As just one example among many, *The American Magazine* described "The World's Greatest Treasure Hunt" in its February 1946 issue [Josephs 1946]:

> Those assigned to comb Germany for hidden secrets of weapons, oil production, raw materials, synthetics, engineering, and chemical processes had the same kind of top-priority search orders as the financial treasure hunters, with the added drama of realizing they were taking part in a neck-and-neck race for secrets such as that of the atomic bomb and radar.
>
> One group, in fact, discovered a highly important German system of radar camouflage, consisting of anti-radar coverings and coatings to be employed on submarines and other weapons. When they reached the manufacturing plant they found it practically destroyed. Uncertain whether the device was already in use or had been given to the Japs, the searchers feared they were too late. Then one man came across a file of incoming shipments. That was the clue they needed. By going to the sub-assembly plants and obtaining samples, they were able to piece together the vital data and, within 24 hours, break the secret.
>
> Scientific information sleuths, like Col. Ernest L. McClendon, uncovered vital information, as when he shrewdly tracked down the files of the Berlin Patent Office secreted in a small provincial town. Others also located Nazi plans hidden in the beds of rivers and lakes, on mountaintops, and interspersed within the leaves of poetry books in the library of the University of Munich, which had been moved and hidden in the farming village of Kirchdorf.
>
> In more than 2,000 visits to captured laboratories, factories, and other key spots, our men have so far been able to obtain data showing how the Germans, among other things:
>
> — Had contemplated a piloted missile with a possible range of 3,000 miles which envisaged commercial applications for 17-minute transatlantic passenger crossings.
>
> — Were working on a formula for new war gases they hoped would prove more deadly than any chemical agent yet developed.

— Had perfected a highly advanced jet engine and plans for rocket-assisted plane take-offs. Planes with ceilings higher than our best and V-type weapons far more powerful than those used against England were in their final stages. So were designs for various secret types of guns, gunsights, novel gear and transmission construction, and air-cooled Diesel engines.

— Had specifications and construction details for naval vessels exceeding our largest, and for one-man submarines with high under-water speeds and apparatus for sustained under-water work.

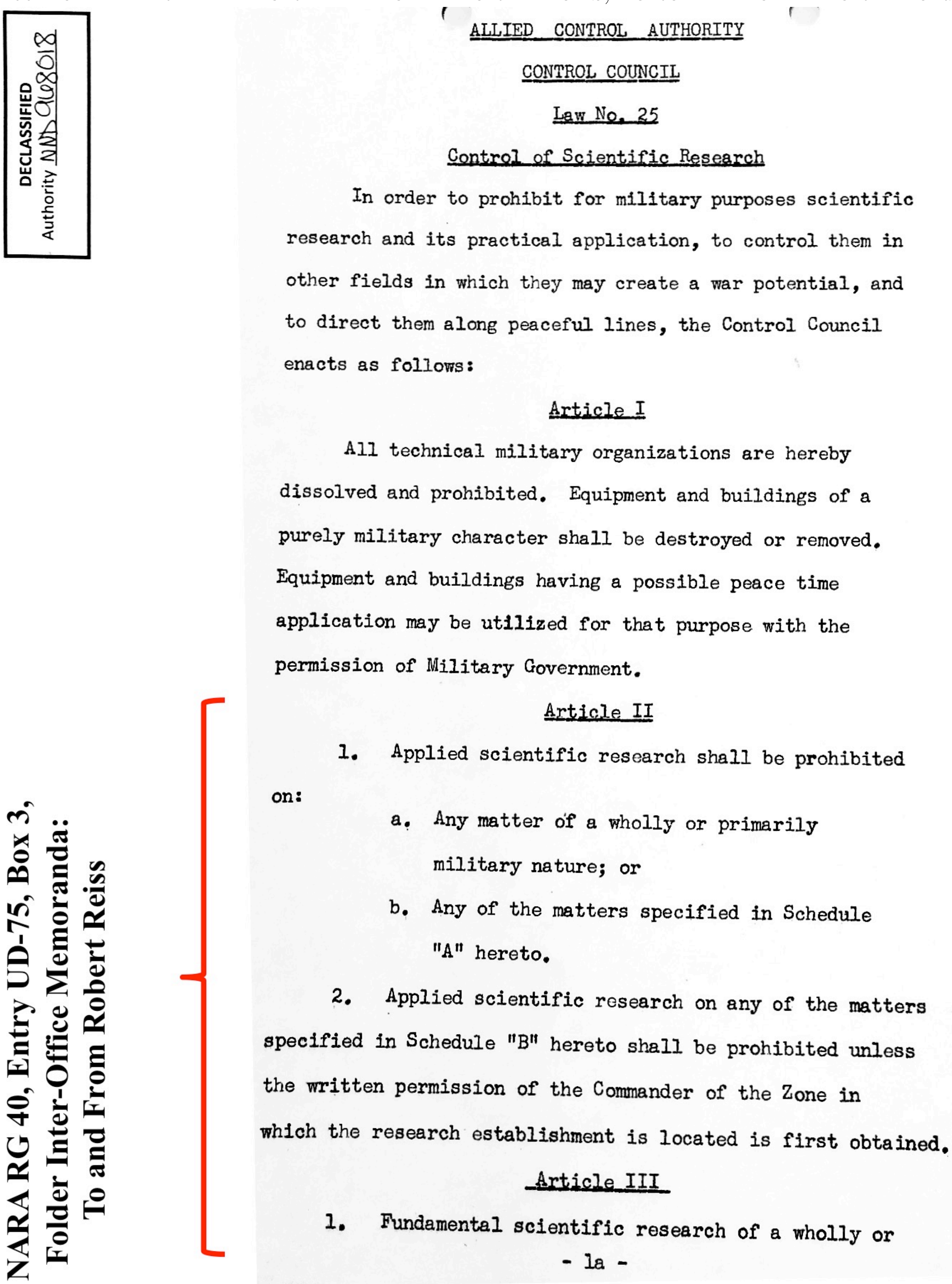
— Had found new uses for many staples. For example, coal. From it they were making synthetic butter, beverage and industrial alcohol, aviation lubricants, soap, and gasoline. And they had improved techniques for the production of synthetic petroleum products and high-grade nitrocellulose from lower-grade wood pulp.

Postwar émigrés

After the war, thousands of scientists in Germany were legally forbidden from continuing to work in their previous research fields, with penalties of imprisonment with hard labor or even execution [NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss]. See pp. 2064–2072. In most cases, their only options were to work for Allied countries or to do menial labor in unrelated areas.

The majority of important German-speaking scientists went to work for the United States, the Soviet Union, France, the United Kingdom, or other countries. Each of those categories is discussed in this section.

Even those scientists who remained in Germany or Austria generally had to give up their innovations when Allied countries interrogated them, seized their papers, and appropriated their scientific equipment, as also covered in this section. Their innovations were then copied in Allied countries while the scientists themselves often sank into poverty and obscurity, without the ability to continue their research careers.



ALLIED CONTROL AUTHORITY

CONTROL COUNCIL

Law No. 25

Control of Scientific Research

In order to prohibit for military purposes scientific research and its practical application, to control them in other fields in which they may create a war potential, and to direct them along peaceful lines, the Control Council enacts as follows:

Article I

All technical military organizations are hereby dissolved and prohibited. Equipment and buildings of a purely military character shall be destroyed or removed. Equipment and buildings having a possible peace time application may be utilized for that purpose with the permission of Military Government.

Article II

1. Applied scientific research shall be prohibited on:

   a. Any matter of a wholly or primarily military nature; or

   b. Any of the matters specified in Schedule "A" hereto.

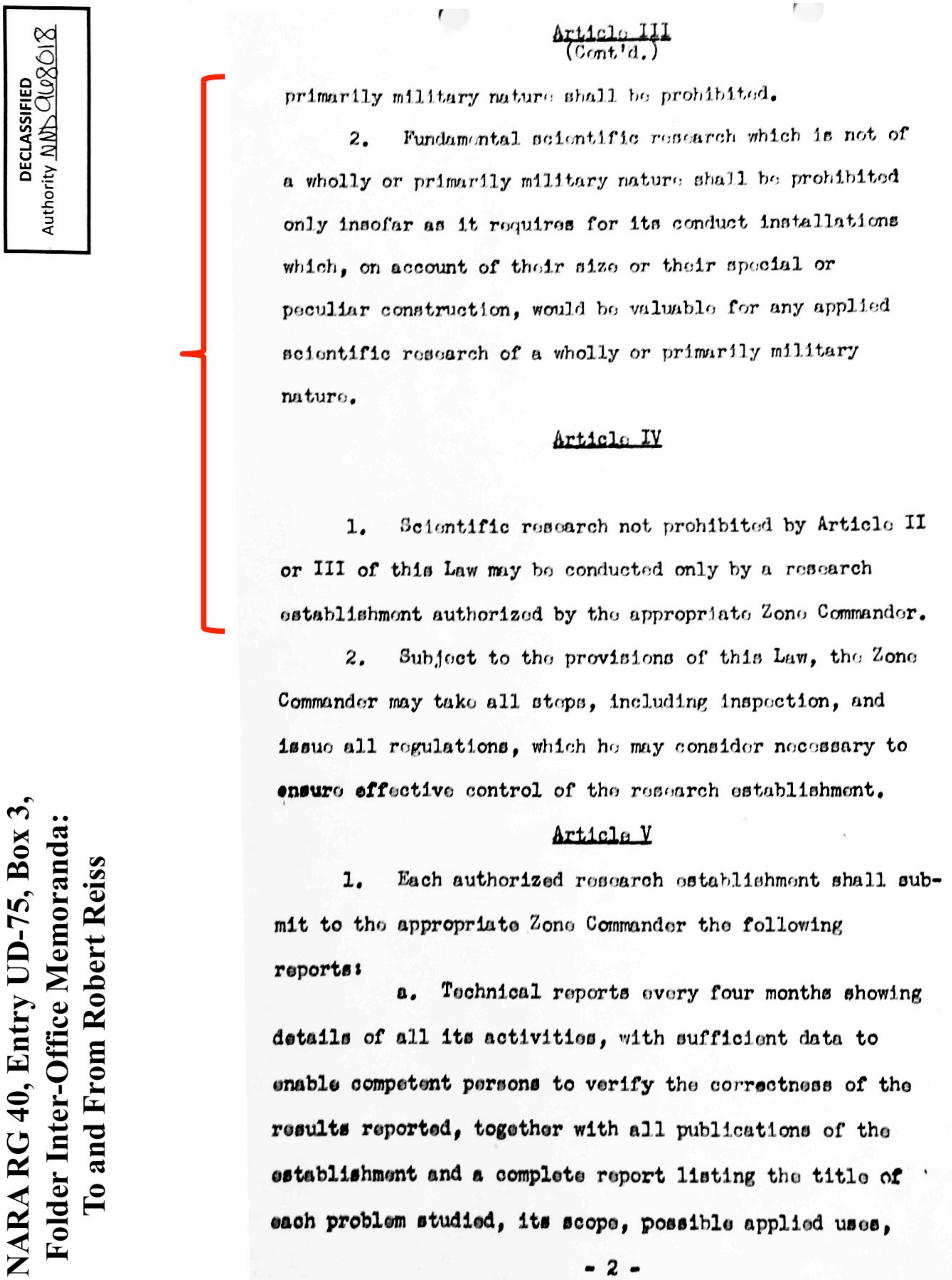
2. Applied scientific research on any of the matters specified in Schedule "B" hereto shall be prohibited unless the written permission of the Commander of the Zone in which the research establishment is located is first obtained.

Article III

1. Fundamental scientific research of a wholly or

- 1a -

Figure 11.4: After the war, thousands of scientists in Germany were legally forbidden from continuing to work in their previous research fields, with penalties of imprisonment with hard labor or even execution. In most cases, their only options were to work for Allied countries or to do menial labor in unrelated areas [NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss].



Article III
(Cont'd.)

primarily military nature shall be prohibited.

2. Fundamental scientific research which is not of a wholly or primarily military nature shall be prohibited only insofar as it requires for its conduct installations which, on account of their size or their special or peculiar construction, would be valuable for any applied scientific research of a wholly or primarily military nature.

Article IV

1. Scientific research not prohibited by Article II or III of this Law may be conducted only by a research establishment authorized by the appropriate Zone Commander.

2. Subject to the provisions of this Law, the Zone Commander may take all steps, including inspection, and issue all regulations, which he may consider necessary to ensure effective control of the research establishment.

Article V

1. Each authorized research establishment shall submit to the appropriate Zone Commander the following reports:

a. Technical reports every four months showing details of all its activities, with sufficient data to enable competent persons to verify the correctness of the results reported, together with all publications of the establishment and a complete report listing the title of each problem studied, its scope, possible applied uses,

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Figure 11.5: After the war, thousands of scientists in Germany were legally forbidden from continuing to work in their previous research fields, with penalties of imprisonment with hard labor or even execution. In most cases, their only options were to work for Allied countries or to do menial labor in unrelated areas [NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss].

Article V
(Cont'd.)

sources of funds, amount of funds expended, and the person in charge, and any other matter required from time to time by the Zone Commander.

b. Annual reports in as non-technical language as possible covering all work done in the year.

c. A complete statement of the plant, apparatus and equipment existing in the research establishment, as may be required by the Zone Commander.

2. A research establishment shall file with the Zone Commander a written notification, including a description of the proposed work and its potentialities, before instituting permitted research of the following types:

a. Fundamental scientific research on matters specified in Schedule "A" or "B".

Article VI

1. All research and technical personnel employed in a research establishment shall be registered with the appropriate Zone Commander in accordance with regulations issued by him.

2. Senior officials or scientists who were members of the National Socialist German Workers' Party (N.S.D.A.P.) or members of other Nazi organizations with more than nominal participation in its activities shall be removed and their replacement effected only by persons with suitable political records. Scientific work in general or on the development of weapons in the past shall not, in itself, be regarded as ground for dismissal or other punishment.

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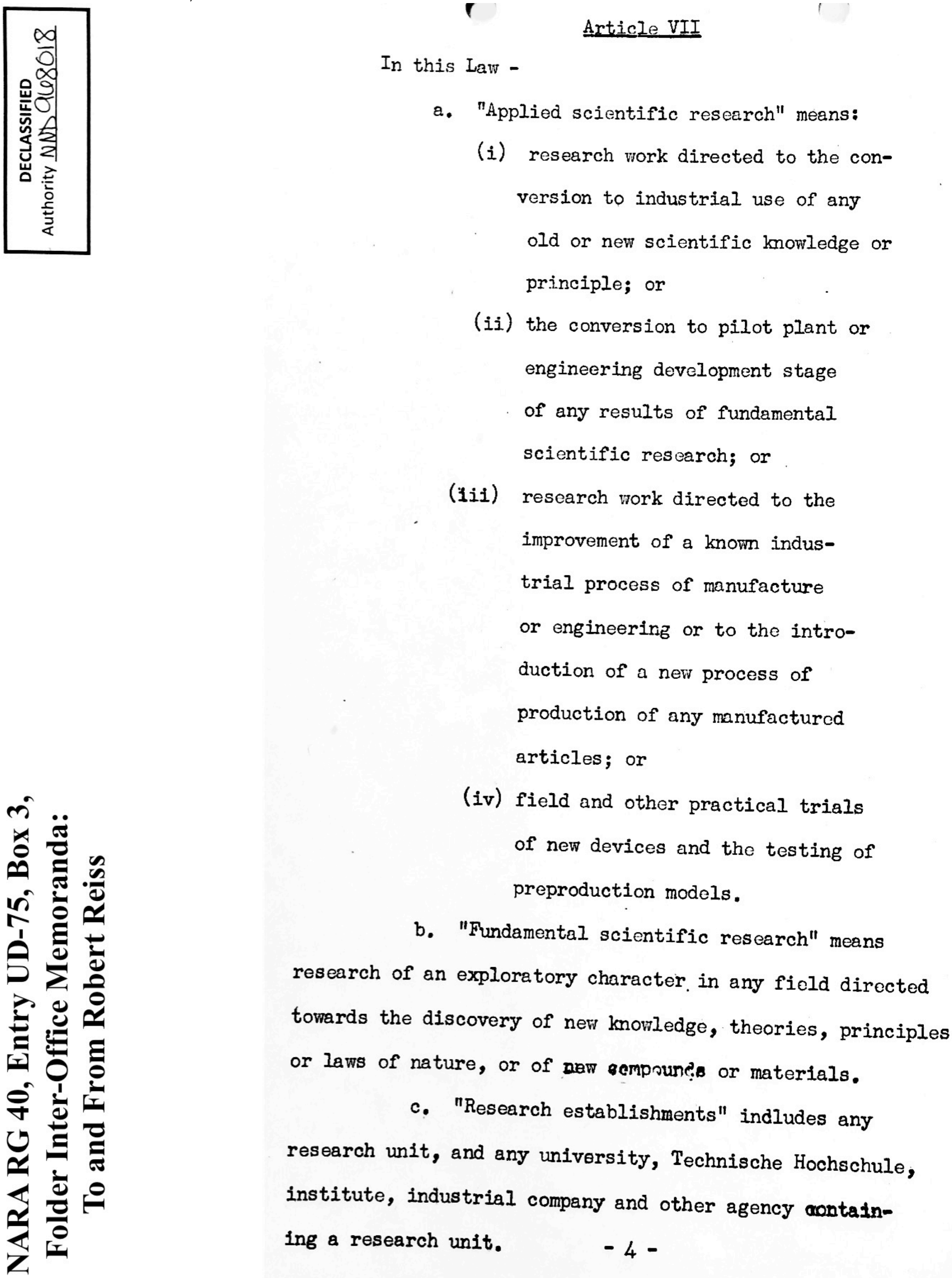
NARA RG 40, Entry UD-75, Box 3,
Folder Inter-Office Memoranda:
To and From Robert Reiss

Figure 11.6: After the war, thousands of scientists in Germany were legally forbidden from continuing to work in their previous research fields, with penalties of imprisonment with hard labor or even execution. In most cases, their only options were to work for Allied countries or to do menial labor in unrelated areas [NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss].



DECLASSIFIED
Authority NND 968018

Article VII

In this Law -

a. "Applied scientific research" means:

(i) research work directed to the conversion to industrial use of any old or new scientific knowledge or principle; or

(ii) the conversion to pilot plant or engineering development stage of any results of fundamental scientific research; or

(iii) research work directed to the improvement of a known industrial process of manufacture or engineering or to the introduction of a new process of production of any manufactured articles; or

(iv) field and other practical trials of new devices and the testing of preproduction models.

b. "Fundamental scientific research" means research of an exploratory character in any field directed towards the discovery of new knowledge, theories, principles or laws of nature, or of new compounds or materials.

c. "Research establishments" indludes any research unit, and any university, Technische Hochschule, institute, industrial company and other agency containing a research unit.

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NARA RG 40, Entry UD-75, Box 3,
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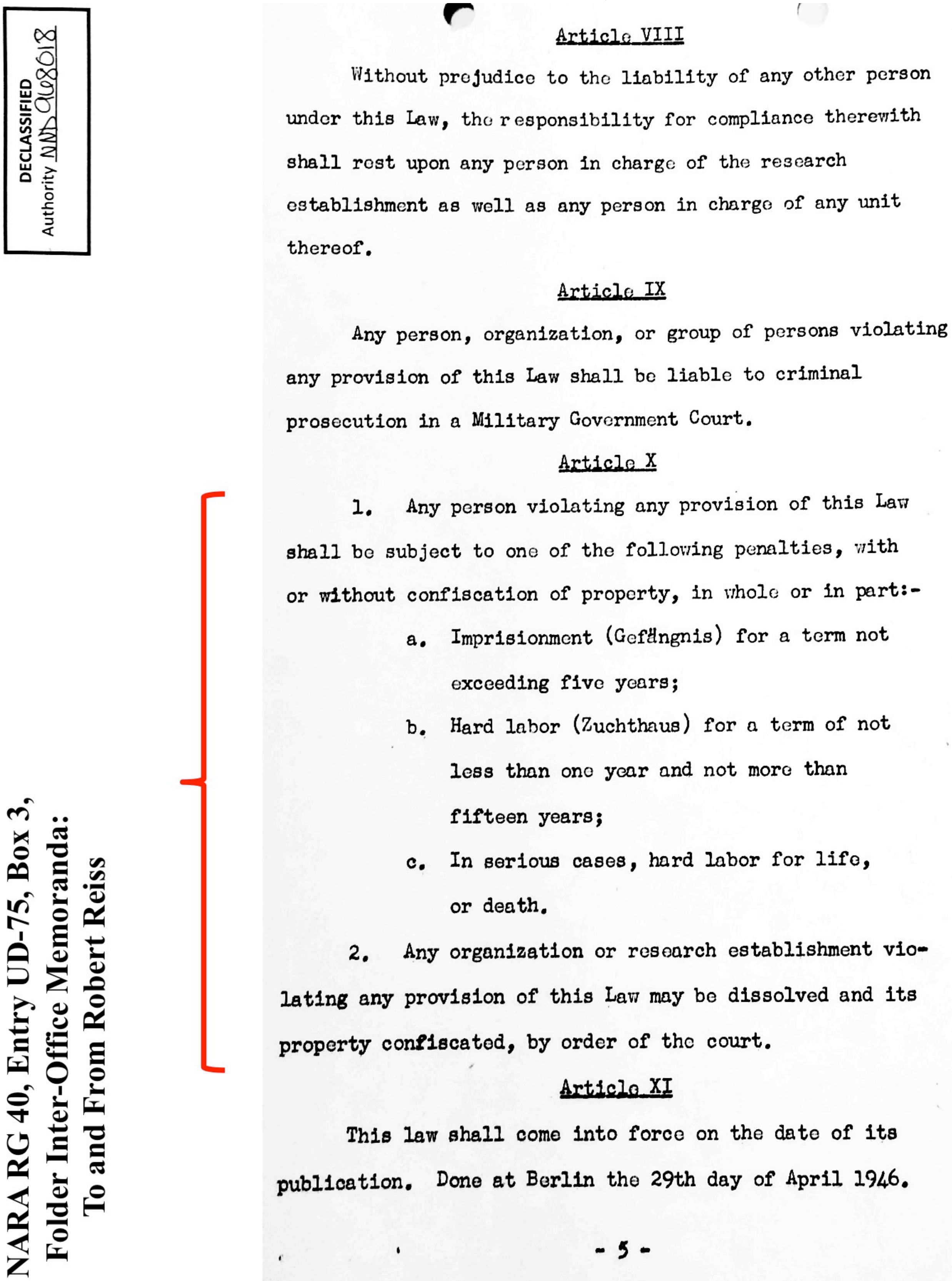
To and From Robert Reiss

Figure 11.7: After the war, thousands of scientists in Germany were legally forbidden from continuing to work in their previous research fields, with penalties of imprisonment with hard labor or even execution. In most cases, their only options were to work for Allied countries or to do menial labor in unrelated areas [NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss].



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Authority NND 968018

Article VIII

Without prejudice to the liability of any other person under this Law, the responsibility for compliance therewith shall rest upon any person in charge of the research establishment as well as any person in charge of any unit thereof.

Article IX

Any person, organization, or group of persons violating any provision of this Law shall be liable to criminal prosecution in a Military Government Court.

Article X

1. Any person violating any provision of this Law shall be subject to one of the following penalties, with or without confiscation of property, in whole or in part:-

    a. Imprisionment (Gefängnis) for a term not exceeding five years;

    b. Hard labor (Zuchthaus) for a term of not less than one year and not more than fifteen years;

    c. In serious cases, hard labor for life, or death.

2. Any organization or research establishment violating any provision of this Law may be dissolved and its property confiscated, by order of the court.

Article XI

This law shall come into force on the date of its publication. Done at Berlin the 29th day of April 1946.

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NARA RG 40, Entry UD-75, Box 3,
Folder Inter-Office Memoranda:
To and From Robert Reiss

Figure 11.8: After the war, thousands of scientists in Germany were legally forbidden from continuing to work in their previous research fields, with penalties of imprisonment with hard labor or even execution. In most cases, their only options were to work for Allied countries or to do menial labor in unrelated areas [NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss].

Article XI
(Cont'd.)

/s/ Joseph T. McNarney
/t/ JOSEPH T. MCNARNEY
General

/s/ Montgomery of Alamein
MONTGOMERY OF ALAMEIN
Field Marshall

/s/ P. Koenig
P. KOENIG
General de Corps d'Armee

/s/ V. Sokolovsky
/t/ V. SOKOLOVSKY
Army General

CONTROL COUNCIL LAW NO. 25

SCHEDULE "A"

Prohibited Applied Scientific Research

(i) Applied nuclear physics.

(ii) Applied aerodynamics, aeronautical structural engineering and aircraft power plants.

(iii) Rocket propulsion, jet propulsion and gas turbines.

(iv) Applied hydro-dynamics, particularly underwater acoustics and marine propulsion.

(v) Ship construction and the behavior of ships.

(vi) Electromagnetic, infra-red and accoustic radiation which has as its purpose:

(a) the detection of objects or obstacles; or

(b) the determination of the position of vehicles, aircraft, ships, submarines or missiles; or

(c) the remote and the automatic control of vehicles, aircraft, ships, submarines or missiles; or

(d) the destruction of living matter, except for specifically medicinal and public

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NARA RG 40, Entry UD-75, Box 3,
Folder Inter-Office Memoranda:
To and From Robert Reiss

Figure 11.9: After the war, thousands of scientists in Germany were legally forbidden from continuing to work in their previous research fields, with penalties of imprisonment with hard labor or even execution. In most cases, their only options were to work for Allied countries or to do menial labor in unrelated areas [NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss].

health purposes.

(vii) All electronic methods of coding and the achievement of speech security.

(viii) The chemicals specified in Schedule C.

(ix) The methods of manufacture (but not the methods of utilization) of the chemicals specified in Schedule D.

CONTROL COUNCIL LAW NO. 25

SCHEDULE "B"

Applied Scientific Research Requiring Prior Permission

(i) Electromagnetic, infra-red and accoustic radiation which has as its purpose:

(a) communication of intelligence by telephony or telegraphy; or

(b) provision of public broadcast or television services; or

(c) location of fixed transmitters by direction finding methods; or

(d) other applications not banned under Schedule "A".

(ii) Valves, tubes or other devices which employ emission of electrons, either thermionic or from cold surfaces.

(iii) Industrial explosives.

(iv) Ball and roller bearings.

(v) Ammonia and methanol produced by high pressure hydrogenation.

(vi) Synthetic oil.

(vii) Radioactivity other than for medical purposes.

(viii) Synthetic rubber.

(ix) The methods of utilization of the chemicals specified in Schedule "D".

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NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss

Figure 11.10: After the war, thousands of scientists in Germany were legally forbidden from continuing to work in their previous research fields, with penalties of imprisonment with hard labor or even execution. In most cases, their only options were to work for Allied countries or to do menial labor in unrelated areas [NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss].

CONTROL COUNCIL LAW NO. 25

SCHEDULE "C"

Chemicals on Which Applied Scientific Research is Prohibited

High explosives.

NOTE: By "high explosives" is meant organic explosives used as fillings for shells, bombs, etc.

Double-base propellants (i.e. nitrocellulose propellants containing nitro-glycerine, diethyleneglycol dinitrate or analogous substances).

Single-base propellants

Nitroguanidine

Nitroglycerine

Initiating explosives

Dinitrotoluene

Poison war gases (including liquids and solids customarily included in this term) with the exception of:

Chlorine
Phosgene
Hydrocyanic acid
Chlorinated ketones
Halogenated carboxylic acids and their esters
Cyanogen halides
Lachrymatory halogen derivatives of hydrocarbons

Rockets fuels: - Hydrogen peroxide of above 50% concentration
Hydrazine hydrate
Methyl nitrate

Highly toxic products from bacteriological or plant sources (with the exception of those bacteriological and plant products which are used for therapautic purposes).

CONTROL COUNCIL LAW NO. 25

SCHEDULE "D"

Chemicals on Which Applied Scientific Research is Prohibited in

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NARA RG 40, Entry UD-75, Box 3,
Folder Inter-Office Memoranda:
To and From Robert Reiss

Figure 11.11: After the war, thousands of scientists in Germany were legally forbidden from continuing to work in their previous research fields, with penalties of imprisonment with hard labor or even execution. In most cases, their only options were to work for Allied countries or to do menial labor in unrelated areas [NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss].

SCHEDULE "D" (Cont'd.)

Respect to Methods of Manufacture, and Require Prior Permission in Respect to Methods of Utilization

Nitrocellulose
Potential poison war gases: - Chlorine
Phosgene
Hydrocyanic acid
Chlorinated ketones
Halogenated carboxylic acids and their esters
Cyanogen halides
Lachrymatory halogen derivatives of hydrocarbons

Hydrogen peroxide having a concentration of 50% or less.

Liquid oxygen
Activated carbons
White phosphorus
Incendiary compositions, e.g. Thermites
Smoke-producing substances, e.g. titanium tetrachloride and silicon tetrachloride

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NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss

Figure 11.12: After the war, thousands of scientists in Germany were legally forbidden from continuing to work in their previous research fields, with penalties of imprisonment with hard labor or even execution. In most cases, their only options were to work for Allied countries or to do menial labor in unrelated areas [NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss].

Beginning in 1945, more than 1600 German-speaking scientists and engineers were brought to the United States by Operation Paperclip, which in its earliest phases was also called Operation Overcast [Linda Hunt 1991, p. 1]. Many hundreds more were brought by at least two other Paperclip-related programs, Project 63 and National Interest [Linda Hunt 1991, pp. 1, 200], so the total number of German-speaking specialists bought to the United States in the late 1940s was well over 2000 people. In 1956, U.S. Ambassador to West Germany (and former Harvard president) James Conant described Paperclip as “a continuing U.S. recruitment program which has no parallel in any other Allied country” [NARA RG 59]. By 1966, at least 6000 German-speaking scientists and engineers had moved to the United States [Mick 2000, p. 316]. U.S. recruitment of German-speaking scientists and engineers through these programs continued until at least 1973, nearly three decades after the end of World War II, despite official protests from West Germany and official denials from the United States [Linda Hunt 1991, pp. 141, 221–222].

Tom Bower, who wrote a detailed exposé of the Paperclip program, described the origins of the program and the technological superiority of the German-speaking scientists it brought to the United States [Bower 1987, pp. 3–6]:

> During the cataclysmic life span of the Third Reich, [Wernher] von Braun, [Hubertus] Strughold, and twenty thousand German scientists had revolutionized the weapons of warfare. Twenty-five years later [in the manned moon landings], the Americans were reaping the benefit of their former enemies’ youthful genius. [...]
>
> Their recruitment after the war had followed interrogation by American officers. After selection, the chosen German scientists were identified simply with an ordinary paperclip on their personal file. [...]
>
> The fact that all the four Allies—the Americans, the British, the Russians, and the French—became involved in the frantic and at times ruthless competition for German scientists is particularly surprising when one realizes that the use of the Germans was simply not contemplated until as late as 1945. [...]
>
> The answer to the riddle starts in the prewar years, when European engineering students learned German as a second language so that they could read the important scientific literature published by one of the world’s industrial giants and its leading technical innovator. It was no coincidence that many of the scientists developing the American atomic bomb in Los Alamos had Teutonic names. Von Braun’s rockets were the symbol of Germanic superiority. The substance was considerably broader—in engineering, chemical processes, and industrial design—but, before 1940, this was not appreciated by either the American or British military.
>
> At the outbreak of war, complacent military chiefs and politicians in Washington and London misunderstood the nature of the conflict into which they had been cast. In Berlin, scientists and engineers were the welcome allies of politicians and military chiefs. But in London and Washington the government, the civil service, and the military chiefs largely ignored or even disdained the purveyors of technical information. Allied officers, startled by Hitler’s momentous conquests, only gradually stumbled to the realization that their Achilles heel was the technical inferiority of many of their guns, planes, tanks,

and submarines. On the eve of Hitler's final defeat, Allied scientists had narrowed the lead and occasionally overtaken their enemy, but in crucial areas Germany's superiority, even in the last year of the war, had actually increased. Acknowledgment of that reality bred a conviction—some would say a legend—of German scientific supremacy that was not far from the truth. [...] The proof of German technical prowess is overwhelmingly established in the hundreds of reports written by Allied investigators who did not shy from describing the Germans' "astonishing achievement" and "superb invention." It was also established by the very survival of Germany during four years of total war despite the prediction during the first two years of war by British intelligence that the German economy and German industry faced imminent and total collapse. The blockade on essential minerals, chemicals, and petroleum products, it was argued, would cripple weapons production. But the very opposite happened, because German scientists developed an astonishing range of substitutes that not only humiliatingly neutralized the Allied blockade but heralded the dawn of a new scientific era. [...] German scientists had pioneered so many inventions that many Allied experts would complain that their plunder could do no more than scratch the surface.

Since 1945, the genesis of weapons by all four Allies has been dominated by the inheritance of Germany's wartime inventions. Indeed, the Korean War can be viewed, on the technical level, as a trial of strength between two different teams of Germans: those hired by America and those hired by the Soviet Union. The aerial dogfights between Soviet MiG-15s and American F-86 Sabres—both designed by German engineers—dispelled for many their doubts about the expediency of plundering Germany's scientific expertise.

As the war ended, Allied investigators, plunged into the hectic race to find their German competitors, were in turn shocked, excited, and then bewildered as they began to appreciate their own technical ignorance. For them, a haphazard series of interrogations conducted in the turmoil of a distraught and defeated nation was tantalizing and frustrating. The obvious solution was to transport the German experts to America and Britain, following the example of the French and Russians. The American haul, enthusiastically hailed as an Aladdin's cave, was worth alone, according to some American military estimates, "thousands of millions of dollars."

Figure 11.13: Examples of German-speaking creators who emigrated to the United States after the Third Reich.

John Gimbel, who wrote the definitive book on postwar technology transfer, further described the widespread impact that the Paperclip scientists ultimately had in the United States [Gimbel 1990a, pp. 171–172]:

> As we have also seen, the armed services shared their Paperclip specialists with their contractors, on occasion permitting them to shuttle from military installations to private firms and in many instances ultimately releasing them entirely for employment in the private sector. A Joint Intelligence Objectives Agency (JIOA) statistical report of 1951, for example, shows Paperclip specialists working in a variety of private firms and agencies, among them Bendix Aviation Corporation, Grumman Aircraft Company, Packard Motor Company, Hydropress, Incorporated, of New York, Phillips Petroleum Company, Dow Chemical Company, Hydrocarbon Research, and the Universities of Indiana, Chicago, Minnesota, Illinois, Missouri, and others. Clarence G. Lasby, in his pioneering study of Project Paperclip, published in 1971, listed numerous universities (Yale, Wisconsin, Kansas, Ohio State, and others) and corporations (Boeing, Raytheon, General Electric, Bell, Westinghouse, and others) to which Paperclip specialists had gone in the 1950's and 1960's, "frequently in executive positions."

For additional examples of the contributions of Paperclip scientists, see pp. 4936–4938.

Figure 11.13 shows one group of Paperclip scientists (aerospace engineers including Wernher von Braun right of center in the front row) at Fort Bliss, Texas, in 1946.

In addition to thousands of scientists and engineers, the United States and other countries also acquired many of the administrators who had selected, funded, and managed the science and engineering programs. One of the most spectacular examples is that Dr. Ing. Hans Kammler, an SS general who ended up controlling almost all of Germany's advanced weapons programs by the end of the war, was captured by the United States and interrogated at great length after the war; see pp. 4977–5005.

The Soviet Union forcibly removed and held thousands of German-speaking skilled scientific workers (the exact numbers are even murkier than the corresponding figures for the United States), and millions of German-speaking unskilled workers.[1]

The German historian Christoph Mick was able to access some relevant files in Moscow archives for the first time in the 1990s. He reported that he had found documentation for at least 3000 German and Austrian scientists and engineers who had been transferred to the Soviet Union during the period 1945–1947 [Mick 2000, pp. 15–17]:

[1] Albrecht et al. 1992; von Ardenne 1990, 1997; Barkleit 2008; Barwich and Barwich 1970; Boch and Karlsch 2011; Fengler 2014; Fengler and Sachse 2012; Graham 1993; Heinemann-Gruder 1992; Holloway 1994; Karlsch and Laufer 2002; Kozyrev 2005; Kruglov 2002; Jürgen Michels 1997; Mick 2000; Nagel 2016; Naimark 1995; Oleynikov 2000; Pondrom 2018; Przybilski 1999, 2002a, 2002b; Riabev 2002a; Riehl and Seitz 1993; Siddiqi 2009; Sokolov 1955; Uhl 2001; Zeman and Karlsch 2008; *News Chronicle* 1945-10-15 p. 1; NYT 1945-10-15 p. 4, 1945-10-31 p. 6, 1946-01-29 p. 1, 1946-11-28 p. 16, 1946-12-06 p. 17, 1947-02-24 p. 1, 1948-05-26 p. 3, 1948-12-28 p. 10b; *Spokane Daily Chronicle* 1948-03-16 p. 6; *Sydney Morning Herald* 1946-04-20 p. 2; *Times* 1945-05-15, 1945-05-18.

Zwischen 1945 und 1947 wurden deutsche und österreichische Wissenschaftler, Techniker und Facharbeiter in die Sowjetunion gebracht, um in Werken, Konstruktionsbüros und Forschungseinrichtungen qualifizierte Arbeit zu verrichten. [...]

Es handelte sich um etwa 3.000 Wissenschaftler, Ingenieure, Techniker und Facharbeiter, zusammen Angehörigen nicht mehr als 8,000 Personen. [...]

Nach Art und Zeitpunkt der Rekrutierung können fünf Typen von Spezialisten unterschieden werden.

1. Die erste Gruppe wurde zusammen mit ihren Familien bereits im Sommer 1945 per Flugzeug in die Sowjetunion gebracht. Angesichts der Zeitumstände kann von einer freiwilligen Wahl keine Rede sein, doch ist kein Fall bekannt, in dem physische Gewalt angewandt wurde. Diese erste Welle betraf vor allem die Atomforscher, es handelt sich um weniger als 100 Personen. Darunter fallen der Privatforscher Manfred von Ardenne, der Physiknobelpreisträger Gustav Hertz, der ehemalige Leiter der Forschungsabteilung der Auer-Gesellschaft, Nikolaus Riehl, und der Direktor des Kaiser-Wilhelm-Instituts für physikalische Chemie in Berlin, Peter Adolf Thiessen.

2. Die zweite und mit Abstand größte Gruppe wurde am 22. Oktober 1946 zwangsweise in die Sowjetunion gebracht. Davon betroffen waren etwa 2.200–2.300 Familien, insgesamt 6.700–7.000 Personen. Die Fachleute stammten vor allem aus den Bereichen Flugzeugzellen- und Flugzeugtriebwerksbau, Optik, ballistische und Lenkraketen, Chemie, Elektrotechnik und Marinewaffen.

Between 1945 and 1947 German and Austrian scientists, technicians and skilled workers were brought to the Soviet Union to carry out qualified work in factories, design offices and research facilities. [...]

There were about 3,000 scientists, engineers, technicians and skilled workers, together with relatives no more than 8,000 persons. [...]

Five types of specialists can be distinguished according to the type and time of recruitment.

1. The first group and their families were brought to the Soviet Union by plane as early as summer 1945. Given the circumstances, there was no voluntary choice, but there was no known case of physical violence. This first wave mainly affected nuclear researchers, fewer than 100 people. These include the private researcher Manfred von Ardenne, the Nobel Prize winner in physics Gustav Hertz, the former head of the research department of the Auergesellschaft Nikolaus Riehl, and the director of the Kaiser Wilhelm Institute for Physical Chemistry in Berlin, Peter Adolf Thiessen.

2. The second and by far the largest group was forcibly brought to the Soviet Union on 22 October 1946. About 2,200–2,300 families were affected, a total of 6,700–7,000 people. The experts came mainly from the fields of airframe and aircraft engine construction, optics, ballistic and guided missiles, chemistry, electrical engineering and naval weapons.

3. Die dritte Gruppe kam zwischen 1946 und 1947 ausgestattet mit Zeitverträgen in die Sowjetunion. Etwa 200–250 Fachkräfte halfen beim Wiederaufbau demontierter Betriebe und wiesen die einheimischen Arbeiter in die Funktionsweise der Maschinen ein. Diese Spezialisten waren meist in der Textil- und Chemieindustrie tätig. Dazu kamen zehn Fachleute für Marinewaffen und einzelne Chemiker und Physiker, die im Atomprojekt eingesetzt wurden.

3. The third group came to the Soviet Union between 1946 and 1947 with temporary contracts. Some 200–250 skilled workers helped rebuild dismantled factories and trained local workers in the operation of the machines. These specialists were mostly employed in the textile and chemical industries. There were also ten specialists for naval weapons and individual chemists and physicists who were employed in the nuclear project.

Diese drei Gruppen waren zwar in ihrer Bewegungsfreiheit stark eingeschränkt, galten aber nicht als Gefangene.

Although these three groups were severely restricted in their freedom of movement, they were not considered prisoners.

4. Davon unterschied sich die vierte Gruppe. Sie bestand aus Häftlingen der sowjetischen Speziallager in der SBZ, die wegen echter oder angeblicher Verstrickung in die Verbrechen des NS-Regimes interniert worden waren. Etwa 50–60 Häftlinge mit technischem Spezialwissen wurden 1946 und 1947 zur Arbeit in Konstruktionsbüros des NKVD/MVD in die Sowjetunion deportiert. Sie arbeiten zunächst im elektrotechnischen Bereich, später wurden sie bei der Entwicklung von lenkbaren Flugabwehrraketen eingesetzt.

4. The fourth group was different from those. It consisted of prisoners from the Soviet special camps in the Soviet Zone who had been interned because of real or alleged involvement in the crimes of the Nazi regime. In 1946 and 1947, about 50–60 prisoners with specialized technical knowledge were deported to the Soviet Union to work in construction offices of the NKVD/MVD. At first they worked in the electrotechnical field; later they were used in the development of guided anti-aircraft missiles.

5. Die fünfte Gruppe wurde aus Kriegsgefangenenlagern rekrutiert. Etwa 200–250 Kriegsgefangene, in der Regel Handwerker, aber auch einzelne Wissenschaftler und Ingenieure, wurden in Einrichtungen des Atomsektors gebracht, in denen bereits deutsche Wissenschaftler tätig waren.

5. The fifth group was recruited from prisoner-of-war camps. Some 200–250 prisoners of war, usually craftsmen, but also individual scientists and engineers, were brought to nuclear facilities where German scientists were already working.

It is important to note that Mick's estimate of 3000 German-speaking scientists is a minimum number. That estimate did not include specialists who were transferred to the Soviet Union after 1947, scientists and engineers who remained in Soviet-controlled East Germany and labored on behalf of the Soviet Union there, and German-speaking scientists from other areas of the former Third Reich (Poland, Czechoslovakia, etc.) who worked for the Soviet Union in those regions or were transferred to the Soviet Union. Thus the total number of German-speaking scientists recruited by the Soviet Union would have been many thousands.

For example, after German reunification, the Stanford University historian Norman Naimark studied some former East German records that described over 6000 specialists who remained in East Germany to work there on behalf of the Soviet Union [Naimark 1995, pp. 230–232]:

> The Soviets removed most of the scientists and technicians important to their armaments industry in the October 22 [1946] operation, and they took others periodically by a variety of means from Western and Eastern zones. [...] But Soviet technical experts understood that they still had a lot to gain in the way of knowledge and expertise from the high level of German technological achievements, industrial infrastructure, and production methods in the Eastern zone. [...] An Administration for the Study of Science and Technology in Germany was attached to SVAG headquarters in Karlshorst. This central administration was to supervise a network of Science and Technology Offices (NTOs) in each of the provinces and many of the large cities in the Eastern zone. [...]
>
> Altogether in the NTOs, 611 Soviet specialists oversaw the work of 6,014 German scientists and technicians, plus 7,067 German workers. Between 1946 and 1948, the NTOs supervised the completion of 7,069 projects, some of which had great practical value for Soviet industry. From German specialists the Soviets learned how to make high-octane gas and carbon fuels. They learned how to produce liquid fuels and build turbines that could be run on liquid fuels. They created a Soviet nylon industry from German accomplishments in that field, and adapted the Buna chemical factories' advancements for the creation of synthetic rubber. Similarly, the technology of the German coal briquette industry was adapted for Soviet use[...] Other Soviet industries that benefited in particular from German technologies developed by the NTOs included ceramics, metal finishing, film developing, and metal plating. Almost 4,000 prototypes of a variety of machines, production stations, and technologies were transferred to the Soviet Union in this period, through the NTOs.

In 1946 in just one Soviet-occupied former German underground factory alone, 2000–3000 German scientists were reported to currently be working for the Soviet Union, continuing wartime German work on nuclear weapons and rockets (p. 3731).

For examples of contemporary articles documenting the transfer of German and Austrian scientists to the Soviet Union, see:

> Russian Seizures [of Austrians] in Austria Aired [NYT 1945-11-22 p. 16].
>
> Russians Said to Use German War Experts [NYT 1946-05-22 p. 4].
>
> Seizure of 3,000 Laid to Russians: Human Reparations [NYT 1946-10-24 p. 14].
>
> 3,000,000 Axis POW on Siberian Projects [NYT 1946-12-17 p. 18].
>
> Former German Officers Reported Sent to Russia [NYT 1946-12-21 p. 4].
>
> Soviet Seen Ready to Shift Workers: Technicians Are Needed in the East [NYT 1946-12-28 p. 7].
>
> Austrians Attack Russian Seizures [of Austrians] [NYT 1948-11-07 p. 13].
>
> Russia Keeps Prisoners [1,000,000 POWs for labor] [NYT 1948-02-01 p. 25].
>
> The Kremlin Picks a German Brain [Littell 1958].

Similarly, large numbers of German-speaking scientists and engineers were recruited by France.[2] Writing for *L'Express*, investigative journalists Vincent Nouzille and Olivier Huwart sifted through government records and described the recruitment and ultimate technological impact of over 1000 German and Austrian scientists and engineers in France after the war [Nouzille and Huwart 1999]:

> Entre 1945 et 1950, plus de 1 000 chercheurs allemands, dont certains nazis, ont été "embauchés" par les autorités françaises. Un apport très secret à la reconstruction de l'industrie militaire et aéronautique du pays. [...]
>
> Plus étonnant: le LRBA n'est pas le seul organisme français à avoir bénéficié, après guerre, de ces "transferts de technologie" très particuliers. Les faits ont longtemps été masqués aux yeux de l'opinion pour cause d'orgueil national et de secret défense. Mais, depuis quelques années, une poignée d'historiens et d'initiés ont commencé de découvrir une réalité insoupçonnée: entre 1945 et 1950, la France a massivement recruté des "cerveaux du IIIe Reich". Combien? En recoupant ces études avec les archives accessibles et des témoignages directs, L'Express peut avancer qu'ils furent plus d'un millier. Soit nettement moins que les 5 000 savants allemands enrôlés par l'URSS ou les 3 000 recrutés par les Etats-Unis dans le cadre de leur opération "Paperclip". Mais plus que les quelques dizaines embauchés en Grande-Bretagne. Des nazis? Nombre de ces savants n'étaient, semble-t-il, ni des fanatiques ni des militants. "J'étais un simple ingénieur, sans engagement politique", dit Kraehe. Toutefois la France, on le verra, ferma les yeux pour attirer quelques figures au passé chargé. Ces recrues avaient-elles un bon niveau de connaissances? "Oui, estime Jacques Villain, historien de la SEP, spécialiste du sujet. La France, principalement dans le domaine aéronautique et militaire, a su attirer des personnalités de premier plan."

> Between 1945 and 1950, more than 1,000 German researchers, including some Nazis, were "hired" by the French authorities. A highly secret contribution to the reconstruction of the country's military and aviation industry. [...]
>
> More surprisingly, the LRBA is not the only French organization to have benefited after the war from these very specific "technology transfers." For a long time, the facts were hidden from the eyes of the public because of national pride and military secrecy. But in recent years, a handful of historians and insiders have begun to discover an unsuspected reality: between 1945 and 1950, France massively recruited the "brains of the Third Reich." How many? By cross-checking these studies with accessible archives and direct testimonies, L'Express can state that there were more than a thousand of them. This is considerably less than the 5,000 German scientists recruited by the USSR or the 3,000 recruited by the United States as part of their "Paperclip" operation. But more than the few dozen hired in Great Britain. Nazis? Many of these scientists were, it seems, neither fanatics nor militants. "I was a simple engineer, without political commitment," Kraehe says. However, France, as we will see, closed its eyes to attract some figures with a busy past. Did these recruits have a good level of knowledge? "Yes," says Jacques Villain, SEP historian and specialist in the subject. France, mainly in the aeronautics and military sectors, has been able to attract leading personalities."

[2] Defrance 2001; Ludmann-Obier 1986, 1988, 1989; Hans-Ulrich Meier 2010; Nouzille and Huwart 1999; O'Reagan 2019; Teyssier and Hautefeuille 1989; Trichet 2009.

Les noms de ces têtes de file sont inconnus du grand public: Jauernick, Müller, Bringer, Habermann pour les fusées (LRBA et SEP); Oestrich pour les moteurs à réaction à la Snecma [...]; Sänger pour les engins spéciaux à l'arsenal de Châtillon (aujourd'hui Aerospatiale); Schardin et Schall pour les explosifs à l'institut Saint-Louis (ministère de la Défense). A ces leaders il faut ajouter des apports d'équipes allemandes chevronnées—réparties sur tout le territoire [...]—dans le domaine des hélicoptères, des sous-marins, des torpilles, des radars, des moteurs de char, des obus, des souffleries aéronautiques. Et même de la force de frappe[...]

The names of these leaders are unknown to the general public: Jauernick, Müller, Bringer, Habermann for rockets (LRBA and SEP); Oestrich for Snecma jet engines [...]; Sänger for special vehicles at the Châtillon arsenal (now Aerospatiale); Schardin and Schall for explosives at the Saint-Louis Institute (Ministry of Defense). To these leaders must be added the contributions from experienced German teams—spread throughout the country [...]—in the field of helicopters, submarines, torpedoes, radar, tank engines, shells, and aeronautical wind tunnels. And even the strike force[...]

La liste est loin d'être close: "La dispersion des archives et leur fréquente classification militaire empêchent encore d'avoir une vision complète du phénomène, estime Gérard Bossuat, professeur d'histoire à l'université de Cergy-Pontoise, spécialiste des relations franco-allemandes d'après-guerre [3]. Mais une chose est sûre: ce recrutement de savants a été assumé politiquement par le gouvernement et organisé administrativement." Même si la plupart sont repartis en Allemagne dans les années 50, Emmanuel Chadeau, professeur d'histoire à l'université Lille III, estime que "leur présence a permis à certains secteurs de l'industrie française de rattraper au moins cinq ans de retard, voire de réaliser de belles percées". De quoi réviser quelques vérités... [...]

The list is far from over: "The dispersion of archives and their frequent military classification still prevent us from having a complete picture of the situation," says Gérard Bossuat, Professor of History at the University of Cergy-Pontoise, a specialist in Franco-German postwar relations. But one thing is certain: this recruitment of scientists was politically decided by the government and organized administratively." Even though most of them returned to Germany in the 1950s, Emmanuel Chadeau, professor of history at the University of Lille III, believes that "their presence has enabled certain sectors of French industry to catch up at least five years earlier, or even to make significant breakthroughs." Something to revise some truths.... [...]

Pourtant, dans cette chasse souterraine, les Français ne se débrouillent pas mal. Les ordres viennent de très haut. Dès le 16 mai 1945, dans une note classée "très secret"—exhumée des archives de l'armée de terre par l'historienne Marie-France Ludmann-Obier—l'état-major de la Défense nationale alerte le général de Gaulle, chef du gouvernement provisoire, sur l'intérêt des recherches allemandes: "L'activité et l'ampleur des résultats obtenus, dans le domaine des armes secrètes notamment, ont vivement impressionné ceux qui les ont examinés[...]. Certaines personnalités, têtes de file, ont été emmenées en Angleterre, d'autres pressenties pour travailler en Amérique. De notre côté, nous avons emmené temporairement à Paris certaines personnalités [...]". Soucieux de redonner rapidement à la France les moyens d'une grande puissance, le général de Gaulle délivre, le 17 mai 1945, une instruction personnelle et confidentielle: "Il y aura tout lieu de transférer en France les scientifiques ou techniciens allemands de grande valeur pour les interroger à loisir sur leurs travaux et éventuellement les engager à rester à notre disposition."

However, in this underground hunt, the French did not do badly. Orders came from very high places. As early as 16 May 1945, in a note classified as "top secret"—exhumed from the army archives by the historian Marie-France Ludmann-Obier—the National Defense Staff alerted General de Gaulle, Head of the Provisional Government, to the importance of German research: "The activity and scale of the results obtained, particularly in the field of secret weapons, greatly impressed those who examined them[...] Some leading people were taken to England; others were approached to work in America. On our side, we temporarily took some people to Paris..." Eager to quickly give France back the resources of a great power, General de Gaulle issued a personal and confidential instruction on 17 May 1945: "There will be every reason to transfer to France German scientists or technicians of great value to question them at will about their work and possibly urge them to remain at our disposal."

Les consignes sont claires. Le général Pierre Koenig, qui assure, à Baden-Baden, le commandement en chef des forces françaises dans la zone d'occupation en Allemagne (ZFOA), s'en fait l'ardent promoteur. "Mieux vaut la qualité que le nombre", écrira-t-il en octobre 1946 dans une note secrète, conservée aux archives de la ZFOA, à Colmar. Il prône une "immigration éclairée", de savants, mais aussi de techniciens de "valeur honorable". Avec un argument de poids: "Chaque technicien qui vient se fixer à demeure en France correspond à une diminution du potentiel allemand et à une augmentation du potentiel français; il faut en profiter." Dans une autre lettre, il insiste sur cet avantage qu'il sait temporaire: "Soyons sûrs que du jour où un gouvernement allemand [...] sera reconstitué, il fera tout son possible pour arrêter cette véritable hémorragie humaine, se rendant compte du grave préjudice subi..."

The instructions were clear. General Pierre Koenig, who was in charge of the chief command of the French forces in Baden-Baden in the German occupation zone (ZFOA), was the ardent promoter. "Quality is better than number," he wrote in October 1946 in a secret note in the ZFOA archives in Colmar. He advocated "enlightened immigration" of scientists, but also of technicians of "honorable value." With a strong argument: "Each technician who comes to France permanently corresponds to a decrease in German potential and an increase in French potential; we must take advantage of it." In another letter, he insisted on this advantage, which he knew to be temporary: "Let us be sure that from the day a German government is reconstituted, it will do everything possible to stop this real human bleeding, realizing the serious damage suffered..."

> Malgré des moyens limités, la machine administrative française se met en marche. La "section T" laisse la place à la mi-1945 à une "section d'information scientifique" où sont représentées toutes les armes (air, terre, marine), le CNRS et le Centre national des télécoms (Cnet). Cette instance établit des centaines de rapports et rédige plus de 3 500 fiches personnelles sur des savants allemands. Le 19 mars 1946, le ministère de l'Economie nationale détaille la procédure de recrutement, soumise au feu vert de neuf services ministériels (production industrielle, finances, travail, sûreté, consulats, etc.). Une "procédure d'extrême urgence" est tout de même prévue, "dans le cas où un savant ou un technicien serait sur le point de partir à l'étranger et de nous échapper". [...]
>
> Lorsque les cibles valent la peine, tous les arrangements sont possibles. Une liste de souffleurs de verre, très prisés pour l'optique de pointe, est transmise à Paris avec cette précision: "Ces personnes résidant en zone russe [...], il serait recommandable de faire appel aux services du Sdece." Autrement dit: les services secrets français sont chargés des "exfiltrations" des autres zones d'occupation. C'est ainsi qu'en décembre 1945 Ferdinand Porsche est enlevé par des Français dans sa résidence de Zell am See, alors qu'il est surveillé par les Américains. Inventeur de la Coccinelle de Volkswagen et de l'énorme char Maus, Porsche, hitlérien fanatique, est d'abord emprisonné à Dijon, avant d'être affecté quelques mois chez Renault, où il est mal accepté, puis remis en prison.

> Despite limited resources, the French administrative machinery was set in motion. The "T section" gave way in mid-1945 to a "scientific information section" where all military services (air, land, sea), the CNRS and the National Telecommunication Center (Cnet) were represented. This body produced hundreds of reports and more than 3,500 personal files on German scientists. On 19 March 1946, the Ministry of the National Economy detailed the recruitment procedure, subject to the approval of nine ministerial departments (industrial production, finance, labour, security, consulates, etc.). An "extreme urgency procedure" was nevertheless provided for, "in the event that a scientist or technician is about to leave for a foreign country and escape from us." [...]
>
> When the targets were worth it, all arrangements were possible. A list of glassblowers, highly prized for their advanced optics, was sent to Paris with this instruction: "These people residing in the Russian zone [...], it would be advisable to use the services of the Sdece." In other words: the French secret services were responsible for "exfiltrations" from the other occupation zones. Thus in December 1945 Ferdinand Porsche was kidnapped by the French from his residence in Zell am See, while he was under American surveillance. Inventor of the Volkswagen Beetle and the huge Maus tank, Porsche, a Hitlerian fanatic, was first imprisoned in Dijon, before being posted for a few months at Renault, where he was poorly received and then put back in prison.

According to the historians of science Burghard Ciesla and Bernd Krag, the true number of German scientists and engineers working in postwar France was actually much higher than Nouzille and Huwart reported, and was at least several thousand [Hans-Ulrich Meier 2010, p. 678]:

> In 1947 the French authorities selected from the almost 100,000 German prisoners of war about 6700 men as "spécifiquement recrutés." These were mostly members of technical professions and were to work in France in different industrial areas, but also in research and development projects. German experts in the fields of rocket, missile, torpedo, engine, aircraft, helicopter, and tank development as well as experts in material science,

> navy-related fields, ballistics, and handguns were at the same time brought to France after the war. But these were by far not yet all the areas. Regarding the employment of German specialists in France, an order of magnitude of 2000 to 3000 persons may be assumed[...]

Pierre Trichet, a French aerospace engineer retired from the ONERA research center, gave further examples of the contributions of German-speaking scientists and engineers to postwar French programs [Trichet 2009]:

> The four major victorious countries of World War II, the United States, the USSR, Great Britain and France shared, to varying extents, the skills acquired by the Germans in science and technology. These scientists were fewer in number than those who went to the United states or to the Soviet Union, but they nonetheless formed an array that represented a broad spectrum of competencies. German engineers and scientists worked in the years after the war closely and successfully together with their French colleagues. A large German engineering group was initially headed by Fritz Nallinger, developed at the French engine company Turbomeca a number of small gas turbines. The ATAR engine, developed by the group of BMW engineers, headed by Hermann Oestrich, was manufactured by SNECMA in large numbers. Under the technical supervision of Hans Schneider, the newly registered company SEPR started the development of liquid fuel rocket motors. Eugen Sänger contributed as adviser to the design and layout of the French test aircraft Nord 1500 "Griffon" with a combined turbojet-ramjet engine. Under the participation of a German group of engineers, headed by Heinrich Focke, a helicopter development program was started at the SNCASE with the SE3101 which led to the successful French helicopter "Alouette". In continuation of the "Doblhoff-concept" of blade-tip propulsion, the light helicopter SO 1221 "Djinn" was developed at SNCASO under the technical supervision of Theodor Laufer. From a rebuild of the missile Fieseler Fi103 (V1), the homing missile Nord CT10 and CT20 with pulsejet, respectively turbojet engines were realized under participation of German engineers.

Likewise, large numbers of German-speaking scientists and engineers were recruited by the United Kingdom.[3] Over 1000 German-speaking scientists and engineers worked for the U.K. government or companies, either in the United Kingdom or on its behalf in West Germany [Glatt 1994]. They played important roles in postwar British developments in jets, missiles, rockets, submarines, and other areas. The U.K. government was relatively secretive about its use of these German-speaking scientists, quite possibly due to a desire to avoid public questions about employing scientists who had only recently been creating weapons that were bombarding the United Kingdom. Historian Charlie Hall described the U.K. programs for interrogating, recruiting, and exploiting German-speaking scientists [Hall 2019a, pp. 1–2, 4]:

> [...A]fter the war ended, the victorious Allies sought to continue the work of the Third Reich's rocket scientists and bring the technology of the V-2 into their own armories. [...] Under the codename Operation Backfire, this took place through the summer and autumn of early 1945 and culminated in three test-firings in October. All of these took place in the Lower Saxony coastal town of Cuxhaven and were run by the same German troops who had overseen the rocket attacks on London, albeit now under close British

[3] Bud and Gummett 1999; Edgerton 2006; Glatt 1994; Hall 2019a; O'Reagan 2014, 2019; Paneth 1948.

supervision. [...] Britain, through the utilisation of German technology and expertise, had now entered the ballistic missile era.

Backfire was not the only operation of its type which took place at this time, nor was rocketry the only field in which the British (and the other Allies) were interested. For instance, 125 kilometers to the south-east of Cuxhaven, at Raubkammer, near Munster, experts from the British Chemical Defence Experimental Establishment at Porton Down spent three months conducting a wide range of trials and experiments with the newly discovered German nerve agents, primarily Tabun and Sarin. Elsewhere, Operation Surgeon, run by the Ministry of Aircraft Production and the Ministry of Supply, took over several former Luftwaffe installations and set out to explore German progress in all manner of aeronautical topics. These large investigative projects which sprung up in the summer of 1945 were of huge significance, but only represent a small portion of British interest in German science and technology in the post-war period. British officials had entered Paris within a week of its liberation to explore formerly German-occupied laboratories in the French capital. Royal Navy experts were among the first Allied forces into Kiel and moved quickly to examine the submarine design and construction facilities there. After Germany surrendered, British investigators poured into the country and visited every laboratory, research site and factory of even passing interest, in their quest to learn all they could about German science and technology.

The process did not stop there. In January 1946, the first group of 23 German scientists recruited by Britain after the war arrived in Barrow-in-Furness in Cumbria, to work on submarine technology at the Vickers-Armstrong shipyard. Many more followed over the next two or three years, travelling to Britain to work on rockets, aircraft, chemical warfare, and on a huge range of civil-industrial topics as well. When the British and French launched Concorde, the world's first supersonic commercial airliner, in 1976, few knew that much of the aerodynamics work involved in its design had been completed by German experts who came to Britain as part of a government scheme in the immediate post-war period. Other German specialists did not land such significant roles in Britain after the war, but did contribute to the British military or economy in other ways, often through written reports or interrogations which took place during periods of internment at special camps in Germany and Britain after the war. Some of these individuals were not even detained because they were considered of value to Britain, but rather because it was considered important to keep them out of the employ of the Soviet Union. In this way, German science and technology became a source of much competition in the early Cold War period.

[...I]n the minds of Allied strategists, German military technology was far superior to their own and the perceived benefits to be gained by acquiring this equipment, and the expertise behind it, were extremely tempting. Thus exploitation was born. The supposedly more advanced nation had been defeated, and its victorious occupiers could now claim the scientific and technological spoils of war; their own armouries and industries could make huge leaps forward by standing on the shoulders of their newly vanquished foe. [...]

With full British government sanction, German laboratories and factories were inspected and meticulously pillaged, machinery and prototypes were confiscated, and documents

> and blueprints were shipped back to Britain in their thousands. In addition, expert German personnel were detained, interrogated and, in many cases, recruited to work for the British state or for private companies. No area of expertise was left untouched, from the most highly sensitive military project to the most mundane commercial production techniques; all was considered fair game under the terms of the British exploitation initiative.

German-speaking scientists also went to many countries other than the four major Allies. Through the British Commonwealth, at least 150 moved to Australia [Evan Jones 2002] and at least 41 to Canada [Margolian 2000]. At least 108 went to Argentina and at least 27 to Brazil [Stanley 1999]. At least ∼100 went to Spain, ∼100 to Egypt, and ∼50 to India [Neufeld 2012].

Although the numbers of German-speaking scientists working for various countries as given above are only lower bounds, and the corresponding figures for other countries (Switzerland, Sweden, South Africa, etc.) are not readily available, the total number of scientists and engineers who left the German-speaking world in the years immediately after the war was likely well over 10,000, or the majority of the creators who were still in the German-speaking world in 1945.[4]

[4] For more information on the transfer of German-speaking scientists, see Albrecht et al. 1992; Bar-Zohar 1967; Bower 1987; Buyer and Jensen 1948; Byrd 1948; Crim 2018; DOW 1945b, 1946; Gimbel 1986, 1990a, 1990b, 1990c; Goudsmit 1947; Glatt 1994; Hall 2019a; Linda Hunt 1985; Morton Hunt 1949; Jacobsen 2014; Jensen 1948; Jösten 1947; Matthias Judt and Ciesla 1996; Kurowski 1982; Lasby 1971; Nagan 1947; O'Reagan 2014, 2019; Simpson 1988.

Postwar transferred equipment

Despite heavy bombing by Allied forces, a large majority of scientific, engineering, and industrial infrastructure and equipment from the German-speaking world survived the war, due to numerous vast underground installations, camouflage, target dispersal, and continuous rebuilding, as shown for example by the following reports:

The Hydra [*Newsweek* 1945-07-09 p. 52]:

> This job of controlling Germany . . . is no short-term business. The Germans are capable and industrious people. They are fired by their desire for revenge and can rebuild an industrial war machine and reorganize it for war purposes in a few short years, regardless of the damage wrought by bombing.
>
> That was how Leo T. Crowley, Foreign Economic Administrator, described the problem of controlling the Reich last week in testimony before a subcommittee of the Senate Military Affairs Committee. "If we were to leave Germany to its own devices and not to institute a program of economic and industrial disarmament, Germany could be far better prepared for war in five years than she was in 1939," Crowley said.
>
> Crowley cited these examples of Germany's capacity to rearm unless severely supervised:
>
> "Allied bombing and military operations accomplished their mission . . . But such military operations, basically selective in their character, were not and could not be executed so as to eliminate permanently a national industrial war potential."
>
> "As it stands today, Germany, except for the United States, is the outstanding armament machine shop in the world."
>
> "[Germany] has one dye plant that can turn out almost as much dye in one year as all the plants in the United States together" . . .
>
> "Practically all of the great iron and steel furnaces of Germany are ready for operation or can be in operation with minor repairs."
>
> "Germany was producing about 1,000,000 metric tons [of nitrogen] in 1939 . . . A large part of the capacity remains or can be rebuilt in a short time."
>
> "Germany did not lack materials for textiles . . . It would appear that little permanent damage has been done to most of the plants."
>
> "According to the best available estimates, the German synthetic-rubber capacity today is more than 100,000 tons."
>
> "In 1944, Germany was producing about 1,000,000 tons of natural petroleum and about 5,500,000 tons of synthetic oil . . . It is believed that a large part of Germany's 1944 capacity for producing petroleum products can be restored within a brief period."

German Industry Grew under Raids: Many Fields Showed Increase in Production During Last Year of War [NYT 1945-08-08 p. 15]:

> Captured records disclosing that the Germans had been able to rebuild plants and expand war production in the face of intensified bombings during the final year of the European war were made public here today to support a Congressional investigating committee's warning that Germany, even in defeat, remained a major threat to world peace. [...]
>
> The records, cited in detail in an official report of the Ministry for Armaments and War Production that were seized last spring, showed that in 1944 three times as many armored fighting vehicles, more than three times as many fighter-bombers and eight times as many night fighters had been produced [as] in 1942.
>
> In a number of war items there was an increase in the last quarter of the year. While there was a decreased production in some fields, increase of air-raid damage and loss of territory, the Ministry reported, it was "still possible to keep the armament industry continuously supplied with the necessary material, a task that could be fulfilled only by drastic measures of control. [...]
>
> "Additional power plants were made available in 1944. [...]
>
> "At the beginning of 1944 the supply of parts and components was the bottleneck of all forms of German armament production. By the autumn of 1944, sufficient reserves of material had been accumulated, with the result that, in spite of more difficult conditions in the basic industry, and also among subcontractors, the output of armaments could be maintained and in some cases even increased."

75% of Industries in Reich Survived [NYT 1945-10-11 p. 6]:

> Despite the almost incessant heavy bombing and the fierce battles fought on German soil, some 75 per cent of Germany's industry is intact or in a reparable condition, Col. James Boyd, chief of the industry division of the Office of Military Government, said today. [...]
>
> He did say, however, that in his opinion roughly 50 per cent of Germany's steel-producing machinery would have to be removed as reparations or destroyed.

Out of that surviving infrastructure, many hundreds (perhaps well over a thousand) of complete factories and laboratories were removed, as may be seen by more examples from contemporary news articles:

Soviet Said to Get Its Yalta Demand: Moscow's Share Believed Half of Movable Reich Property in Potsdam Reparations [NYT 1945-08-05 p. 6]:

> The Potsdam reparations agreement in effect gives the Russians about 50 per cent of the movable German property covered by the accord, officials familiar with the preliminary negotiations on the subject said today.
>
> [...A]bout 45 per cent of German assets of the capital variety covered by the agreement were situated in the Russian zone [East Germany].
>
> This high percentage surprised some persons familiar with pre-war German economy, who were under the impression that the bulk of German industrial installations were in the west, but it was pointed out that during and just before the war the Germans built up their industrial plant in the east, where they located some of the nation's largest and most efficient units.
>
> Added to the 45 per cent of total movable German plant and equipment said to be situated in the Russian zone, the Soviet Government receives, under the agreement, 10 per cent of certain capital equipment in the western zones [West Germany]. [...]
>
> From the remainder of the movable equipment in the western zone, after the Russians get their 10 per cent, the reparations claims of all the United Nations in the war against Germany, except Russia, must be satisfied.

Allies Confiscate 300 Farben Plants: Part of Reich Trust's Factories to be Dismantled and Used to Pay Reparations: Other Assets Also Taken [NYT 1945-10-13 p. 3]:

> The Allies have confiscated the entire holdings in Germany of the octopus-like I. G. Farbenindustrie, without whose vast industrial output the Germans would have been unable to wage war. General Clay, administrator of civil affairs in American-occupied Germany, announced tonight that a part of the 300 plants owned by the huge trust would be dismantled and taken by the Allies as reparations. [...]
>
> General Clay estimated that about 75 per cent of Farbenindustrie's plants in Germany were intact. [...]
>
> Pre-war assets of the trust were estimated at 5,000,000,000 Reichsmarks—$2,000,000,000.
>
> Construction costs alone for the plants all over Germany and in Czechoslovakia amounted to $762,800,000, Colonel Pillsbury estimated.

Germans Report More Removals: Say 310 Plants in Thuringia Have Been Sent To Russia—Fear Wide Unemployment [NYT 1946-10-27 p. 32]:

> According to a report of the reparations department of the Thuringian Land Bureau for Economics, by the end of June, 1946, 310 plants in Thuringia alone had been fully dismantled by the Russians. The report added that during the third quarter of this year 410 Thuringian plants had worked exclusively on reparations deliveries of goods made from German raw materials[...] As of Oct. 1 the entire production quota of Thuringia has been allocated to Soviet occupation forces, the report added.
>
> Representatives of workers in glass factories and optical works in Jena, in their telegram Friday to the Allied Control Council, especially cited the stripping of that basic industry from the one-industry town[...]
>
> Accordingly the Russians apparently have made plans to drop their efforts to conciliate the Germans and instead drain all possible resources out of the country as quickly as possible.

BIOS 290, *The Viscose Continuous and Rayon Staple Fibre Plants of the British, American and French Occupation Zones of Germany*, pp. 2–3:

> The Team visited Germany with one primary object which was to assess the value of any suitable plant likely to be seized as Reparations, in accordance with the Potsdam Agreement.
>
> A very agreeable and secondary objective was the acquisition of any further technical knowledge, and an additional report has therefore been written to supplement the information gathered by the C.I.O.S. earlier in the year. [...]
>
> It will be appreciated that the report of the C.I.O.S. became a very useful charter and enabled us to investigate thoroughly the obviously new departures in the preparation, spinning and finishing of Viscose Yarn and Rayon Staple. It might be of general interest to say that the impression gathered by the team was that the Viscose industry of Germany has developed rapidly along mass production lines with a high degree of endeavour to eliminate handling and to shorten the Viscose preparation times as much as possible by the introduction of many new shredding and mixing devices. [...]
>
> In the Rayon Staple field the output of yarn per spinning position has reached almost fantastic proportions. 15,000 denier is now quite common with an individual filament denier of 1.5. We learned that some spinners are now contemplating an increase to 22,500 denier, using a jet of 15,000 holes of 0.07 m.m. diameter. Spinning pumps of the order of 75.0 ccs. per rev. are already in use. Rheinische Zellwolle use only 5 combination machines to produce 80 tons per day.
>
> We would specially draw attention to our recommendation on the Zellwolle Lehr Spinnerei Research Station at Denkendorf. It is the opinion of the team that this would be a valuable acquisition to the British Rayon Industry.

BIOS 428. *German Rayon and Staple Fibre Industry and Allied Engineering Industry.* p. 3:

> This work was undertaken following the original reconnaissance of the German Rayon and Staple Fibre Industry (Ref. 1) and had as its primary object the evacuation of a number of machines and processes upon which it was considered detailed investigation and development work should be carried out for the benefit of the British Viscose Rayon Industries. [gives long, detailed list of machines to be taken from Germany]

For many more examples, see:

Allies Will Strip German Economy [NYT 1945-02-02 p. 1].

Russia Said to Strip U.S. [Claimed] Plants in Reich [NYT 1945-07-08 p. 4].

Berlin's Factories Stripped by Soviet [NYT 1945-07-17 p. 2].

Germany Stripped of Industry by Big 3 [NYT 1945-08-03 p. 1].

U.S. Allies to Get 5 Plants In Reich [NYT 1945-09-26 p. 8].

U.S. Will Transfer 11 More Reich Plants [NYT 1945-09-30 p. 25].

Russia Would Take Big Plants in Reich [NYT 1945-10-05 p. 2].

Opel's Equipment Sought by Russians [NYT 1945-10-11 p. 4].

Smash I. G. Farben Empire, Eisenhower Advises Allies [NYT 1945-10-21 p. 1].

26 German Plants Divided by Allies [NYT 1945-12-11 p. 4].

26 German Plants Ready for Delivery [NYT 1945-12-23 p. 7].

Factories on Sale in Germany Listed [NYT 1946-01-06 p. 20].

21 Farben Plants Wiped Out by U.S. [NYT 1946-01-17 p. 14].

Russians to Strip 600 German Mills [NYT 1946-03-24 p. 18].

German Industry Gets Allies' Bill [NYT 1946-03-29 p. 10].

Germany Moving Out Factory Equipment [NYT 1946-04-17 p. 13].

Russians Increase German Industry Reparations in Kind [NYT 1946-07-05 p. 4].

Russia for Seizing 200 German Firms [NYT 1946-07-11 p. 5].

Allies Will Share 11 German Plants [NYT 1946-07-25 p. 6].

Russians Charge Looting of Reparations from Plants in U.S. Zone of Germany [NYT 1946-08-03 p. 7].

200 German Firms Seized by Soviet [NYT 1946-08-26 p. 7].

Transfers of Plants from American Zone to Russia Ahead of Schedule [NYT 1946-08-27 p. 12].

German Plant Ask as U.S. Reparations [NYT 1946-10-09 p. 22].

658 German Plants Listed for Payment [NYT 1946-10-20 p. 30].

Clay Sees End Soon to Occupation Costs [NYT 1946-11-14 p. 18].

10 Soviet Trusts Drain Germany, U.S. Occupation Sources Report [NYT 1946-12-06 p. 1].

Reparation Plan Enters 2 D Phase: U.S. Sends Soviet Equipment from Two German Plants [NYT 1946-12-10 p. 11].

A German Plant Dismantled by the Russians [NYT 1947-07-13 Magazine p. 8].

682 [More] German Plants to be Dismantled [NYT 1947-10-17 p. 8].

28 More Plants in Germany Allotted [to Allies] [NYT 1947-12-23 p. 5].

Marshall Opposes End to Dismantling of German Plants [NYT 1948-02-09 p. 1].

Soviet Dismantles 19 Plants in Zone [NYT 1948-06-02 p. 10].

Farben Liquidation Mapped: New Concerns Are Planned: U.S. and British Officials [NYT 1948-07-25 p. 1].

Britain Clings to Dismantling [of German Factories]: Opposes Change in German Policy [NYT 1948-09-09 p. 10].

French Dismantling 38 [German] Plants [NYT 1948-10-28 p. 10].

Dismantling Feared by French [NYT 1948-11-21 p. 10].

Soviets Hold Up Reparations Debt [NYT 1948-11-28 p. 10].

Dismantling Halt by U.S. Protested [NYT 1948-12-05 p. 9].

Allies Weigh Rift on German Plants [NYT 1948-12-07 p. 9].

For even more examples of transferred equipment, see the thousands of BIOS ER, BIOS, BIOS Misc., BIOS Overall, CIOS ER, CIOS, FIAT, *FIAT Review*, JIOA, NavTecMisEu LR, and NavTecMisEu reports in the Bibliography.

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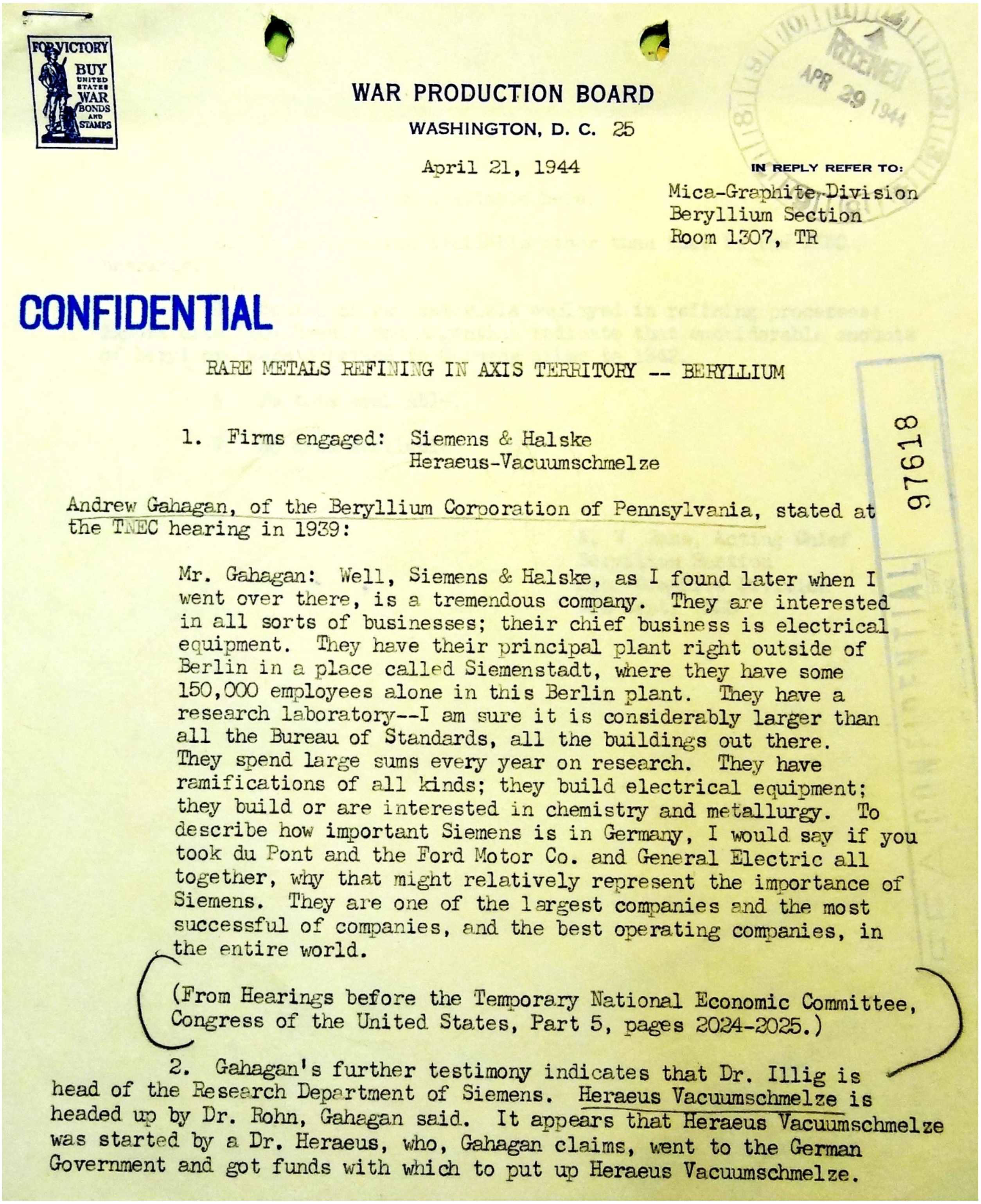
Authority 917017

NARA RG 77, Entry UD-22A, Box 169, Folder 32.32. Germ. Incl. TA



FOR VICTORY BUY UNITED STATES WAR BONDS AND STAMPS

WAR PRODUCTION BOARD
WASHINGTON, D. C. 25

April 21, 1944

RECEIVED APR 29 1944

IN REPLY REFER TO:
Mica-Graphite Division
Beryllium Section
Room 1307, TR

CONFIDENTIAL

RARE METALS REFINING IN AXIS TERRITORY -- BERYLLIUM

1. Firms engaged: Siemens & Halske
Heraeus-Vacuumschmelze

97618

Andrew Gahagan, of the Beryllium Corporation of Pennsylvania, stated at the TNEC hearing in 1939:

> Mr. Gahagan: Well, Siemens & Halske, as I found later when I went over there, is a tremendous company. They are interested in all sorts of businesses; their chief business is electrical equipment. They have their principal plant right outside of Berlin in a place called Siemenstadt, where they have some 150,000 employees alone in this Berlin plant. They have a research laboratory--I am sure it is considerably larger than all the Bureau of Standards, all the buildings out there. They spend large sums every year on research. They have ramifications of all kinds; they build electrical equipment; they build or are interested in chemistry and metallurgy. To describe how important Siemens is in Germany, I would say if you took du Pont and the Ford Motor Co. and General Electric all together, why that might relatively represent the importance of Siemens. They are one of the largest companies and the most successful of companies, and the best operating companies, in the entire world.
>
> (From Hearings before the Temporary National Economic Committee, Congress of the United States, Part 5, pages 2024-2025.)

2. Gahagan's further testimony indicates that Dr. Illig is head of the Research Department of Siemens. Heraeus Vacuumschmelze is headed up by Dr. Rohn, Gahagan said. It appears that Heraeus Vacuumschmelze was started by a Dr. Heraeus, who, Gahagan claims, went to the German Government and got funds with which to put up Heraeus Vacuumschmelze.

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Figure 11.14: An example of the physical size and technological and financial importance of German industrial plants [NARA RG 77, Entry UD-22A, Box 169, Folder 32.32. Germ. Ind. TA].

All four major Allied countries claimed huge amounts of German and Austrian equipment. For example, Vincent Nouzille and Olivier Huwart wrote about some of the factories and other equipment that were acquired by France [Nouzille and Huwart 1999]:

Cette histoire débute au printemps de 1945, alors que les armées alliées resserrent leur étau sur le IIIe Reich. Les troupes de la Ire armée française du général de Lattre avancent dans le sud de l'Allemagne. Parmi les unités de reconnaissance qui les précèdent se trouvent des membres de la "section T". Ces experts du renseignement technique sont chargés de repérer les installations militaires et scientifiques allemandes. Si possible avant les autres vainqueurs. Par chance, le sud de l'Allemagne est truffé de dizaines d'usines et de laboratoires, repliés dans cette région moins exposée aux bombardements alliés.	This story began in the spring of 1945, when the Allied armies tightened their grip on the Third Reich. General de Lattre's troops of the First French Army advanced into southern Germany. Among the reconnaissance units preceding them were members of "Section T." These technical intelligence experts were responsible for identifying German military and scientific installations. If possible before the other winners. Fortunately, southern Germany was full of dozens of factories and laboratories, folded back into this region less exposed to Allied bombardments.
La chasse au butin est ouverte. Une équipe du 2e bureau de l'armée de l'air découvre ainsi près d'Oberammergau une vingtaine de caisses plombées, contenant 2 500 documents ultrasecrets du bureau d'études de l'avionneur Messerschmitt. Des trésors inestimables, ramenés à Paris pour être exploités par les industriels. Les formes d'ailes en flèche des futurs chasseurs français Ouragan et Mystère sont inspirées de ces documents.	The hunt for loot was on. A team from the 2nd office of the French Air Force discovered around twenty sealed boxes near Oberammergau, containing 2,500 top secret documents from the design office of the aircraft manufacturer Messerschmitt. Priceless treasures, brought back to Paris to be exploited by industrialists. The arrow-shaped wings of the future French fighters Ouragan and Mystère were inspired by these documents.
Près de 50 000 tonnes de matériels divers sont également envoyées en France durant l'année 1945. Des centaines d'équipements des usines aéronautiques de Dornier et Zeppelin à Friedrichshafen franchissent la frontière. La soufflerie subsonique d'Ötztal, dans le Tyrol autrichien, est démontée avant d'être réinstallée à Modane-Avrieux sous les auspices de l'Onera (Office national d'études et de recherches aéronautiques).	Nearly 50,000 tons of various materials were also sent to France in 1945. Hundreds of pieces of equipment from the Dornier and Zeppelin aeronautical plants in Friedrichshafen were taken across the border. The Ötztal subsonic wind tunnel in Austrian Tyrol was dismantled before being relocated to Modane-Avrieux under the auspices of Onera (Office national d'études et de recherches aéronautiques) [where it is still in use].

Près de 200 usines "civiles" allemandes—comme le complexe chimique BASF d'IG Farben à Ludwigshafen—sont remises en marche par les Français dans la zone d'occupation qui leur est octroyée par les accords de Potsdam de juillet 1945. Cette zone couvre 10% de l'Allemagne et une partie de l'Autriche. Les installations à vocation militaire sont également rouvertes. Dans la région du lac de Constance, 17 usines et laboratoires travailleront, jusqu'à leur déménagement, en 1948, dans le sud de la France, avec du personnel allemand, pour le compte de la marine française. Le physicien Yves Rocard (père de Michel) supervise une partie de ces récupérations. "On s'en est donné à coeur joie, en ramassant des Allemands eux-mêmes", raconte-t-il dans ses *Mémoires sans concessions* (Grasset, 1988). D'autres scientifiques français viennent évaluer le potentiel scientifique nazi. Le chimiste Henri Moureu, qui a étudié de près les V 2 tombés près de Paris, réussit à visiter en juin 1945 l'usine Mittelwerke-Dora où étaient notamment fabriqués ces engins. Son ami physicien Frédéric Joliot-Curie, directeur du nouveau CNRS, dépêche, quant à lui, plus de 400 missions en Allemagne. Des expéditions parfois risquées: on retrouvera un jour à Vienne le cadavre d'un scientifique français, probablement jugé trop curieux par les Soviétiques...

Nearly 200 German "civilian" factories—such as the BASF chemical complex of IG Farben in Ludwigshafen—were restarted by the French in the zone of occupation granted to them by the Potsdam agreements of July 1945. This area covered 10% of Germany and part of Austria. Military facilities were also being reopened. In the Lake Constance region, 17 factories and laboratories worked with German personnel on behalf of the French navy until they moved to southern France in 1948. The physicist Yves Rocard (Michel's father) supervised some of these recoveries. "We had a great time, picking up Germans themselves," he says in his *Mémoires sans concessions* (Grasset, 1988). Other French scientists came to evaluate the Nazi scientific potential. The chemist Henri Moureu, who had closely studied the V-2s that had fallen near Paris, succeeded in visiting the Mittelwerke-Dora factory in June 1945, where these machines were manufactured. His physicist friend Frédéric Joliot-Curie, director of the new CNRS, sent more than 400 missions to Germany. Sometimes risky expeditions: one day in Vienna we found the body of a French scientist, probably considered too curious by the Soviets...

In addition to whole factories and laboratories, untold amounts of supplies, equipment, and prototypes were appropriated by Allied countries after World War II. A 1945 U.S. Navy document [NARA RG 38, Entry 72] listed examples of equipment transported to the United States in one shipment, including a submarine, 39 aircraft, V-1 and V-2 missiles, and other advanced technology prototypes.

Some newspaper headlines illustrate other examples:

> U.S. Navy to Use German Weapons [NYT 1945-06-30 p. 3].
>
> Use of Armament Seized in Europe Asked in Pacific [NYT 1945-07-07 pp. 1, 3].
>
> Ten U-Boats for Russia to be Yielded in Ulster [NYT 1945-11-22 p. 16].
>
> U.S. Plans to Sell German Machines [NYT 1945-11-22 p. 17].
>
> German Guns to Be Tested [NYT 1946-01-25 p. 4].
>
> U.S. to Get 4,209,000 Tons of Germany's Shipping [NYT 1946-04-24 p. 14].
>
> All German Scrap Is Now Allocated [NYT 1948-09-04 p. 19].

As may be seen from these and other newspaper articles, large-scale removals were still going on over 3½ years after German surrender. So many industrial plants and their supplies and equipment were removed, and for so many years, that Germans began to protest that the continuing removals would hinder their ability to peacefully rebuild and support themselves financially. As reported in these articles, western Allied countries responded by threatening to cut off Germany's food supply if any further protests were made:

> Germans Strike Against Removals [NYT 1946-10-29 p. 10].
>
> Clay Will Force Plant Removals [by Threatening Food] [NYT 1947-10-02 p. 8].
>
> German Charges Allies Loot West [Germany] [NYT 1948-01-07 p. 15].
>
> Germans Warned on Food Supplies [If They Protest] [NYT 1948-01-09 p. 17].
>
> Protests Removal of German Plants [NYT 1948-01-20 p. 2].
>
> Farben Attorney Condemns Allies [NYT 1948-06-11 p. 5].
>
> Baden Chiefs Quit Over Dismantling [NYT 1948-08-27 p. 3].
>
> Germans Protest [Plant Dismantling] Restitution Plans [NYT 1948-09-05 p. 19].
>
> Allied Suggestion Provokes German Ire [NYT 1948-11-28 p. 12].
>
> Germans Boycott British over Plant Dismantling [NYT 1948-12-06 p. 3].

The Soviet occupation and exploitation of areas they controlled was much more brutal and lasted until 1990.[5]

[5] E.g., Albrecht et al. 1992; von Ardenne 1990, 1997; Barkleit 2008; Barwich and Barwich 1970; Boch and Karlsch 2011; Fengler 2014; Fengler and Sachse 2012; Graham 1993; Heinemann-Gruder 1992; Holloway 1994; Karlsch and Laufer 2002; Kozyrev 2005; Kruglov 2002; Jürgen Michels 1997; Mick 2000; Nagel 2016; Naimark 1995; Oleynikov 2000; Pondrom 2018; Przybilski 1999, 2002a, 2002b; Riabev 2002a; Riehl and Seitz 1993; Siddiqi 2009; Sokolov 1955; Uhl 2001; Zeman and Karlsch 2008; *News Chronicle* 1945-10-15 p. 1; NYT 1945-10-15 p. 4, 1945-10-31 p. 6, 1946-01-29 p. 1, 1946-11-28 p. 16, 1946-12-06 p. 17, 1947-02-24 p. 1, 1948-05-26 p. 3, 1948-12-28 p. 10b; *Spokane Daily Chronicle* 1948-03-16 p. 6; *Sydney Morning Herald* 1946-04-20 p. 2; *Times* 1945-05-15, 1945-05-18.

Soviet exploitation of German industry was also far larger than the number of German plants would seem to indicate. The Soviet Union apparently had a systematic policy of shipping half of a German plant and its workforce to the Soviet Union, forcing the remaining German workers to rebuild and restaff the plant until it was functional again, then shipping half of the rebuilt plant and workers to the Soviet Union, and repeating the process many more times. Thus the number of industrial plants that the Soviet Union extracted from Germany was many times the number of original plants. Even in its divided and war-ravaged state, Germany was mass-producing modern industrial plants for the entire Soviet Union, covering everything from aerospace to electronics to chemical technologies.

This Soviet practice was documented for example in the following U.S. intelligence report: Headquarters Berlin Command, Office of Military Goverment for Germany (US). 11 December 1946. Special Intelligence Memorandum No. 48. Subject: V-2 Production in SovZone. Source: Extremely Reliable. D-138175. [NARA RG 319, Entry A1-134A, Box 29, Folder ZA 019293 Soviet Guided Missiles, Rockets and V-Weapons Research, Development and Production Vol. 1, Fldr. 2 of 3. See pp. 2972–2973.]:

> BLEICHERODE in the Harz mountains is still doing fine in the production of V-2 rockets. It was reported from this office that dismantling was going on, but it was stopped as of 1 December. The general procedure for dismantling of installations very dear to the Soviet heart is the following as illustrated best by BLEICHERODE.
>
> As soon as Soviet troops took over the V-2 plants, they did everything in their power to get it reorganized and re-equipped. As soon as this was done, they started production. When they saw that the finished product was satisfactory, they began to dismantle the plant for the first time. The dismantling was not carried through completely, but was halted as soon as about half was taken. Together with the machinery some personnel was taken out, to be shipped to the USSR in order to set up the machinery which was confiscated and complete it with more later.
>
> In the meantime the plant in BLEICHERODE was being rebuilt under supervision of German and Soviet engineers. Once rebuilt, production was started all over again and as soon as satisfactory results were achieved, the dismantling was continued. In this way, Soviet authorities enrich their own country by building up some priceless industries and on the other hand they see to it that the original plant in Germany is reconstructed and re-equipped after each time. Thus, they would be able theoretically to continue an uninterrupted flow of industries from Germany to the Soviet Union.
>
> This procedure is known to have been applied to all V-weapon plants in BLEICHERODE, NORDHAUSEN, GOTHA and BERLIN. In BLEICHERODE the installations were dismantled for the fourth time; in NORDHAUSEN for the sixth time; in Berlin only once; conditions in GOTHA are unknown. [...]

It is helpful to visualize the locations of scientific research, development, and production sites from which various countries removed plants, materials, prototypes, scientists, and information at the end of the war.

Figure 11.15 shows a map of areas controlled directly or indirectly by Germany in 1942. Although much of German research and industry was located within the Greater German Reich (darkest area), there were also major sites in satellite countries from Norway to Bulgaria. At the end of the war, Allied countries seized resources, personnel, and information from sites in the respective regions they regained or occupied.

Figure 11.16 presents a detailed map of the Greater German Reich in 1941, not including satellite countries that were also controlled by Germany. Note that the Greater German Reich covered the territory of not only modern Germany but also modern Austria, Poland, and the Czech Republic, as well as small portions of other countries. At the end of the war, the majority of this territory was occupied by the Soviet Union and therefore was generally not open to inspection by western Allied investigators.

As an example of the distribution of wartime sites that were ultimately seized by Allied countries, Fig. 11.17 shows a map of plants run by or affiliated with I.G. Farben in 1943. The large majority were located within the Greater German Reich (covering modern Germany, Austria, Poland, and the Czech Republic), although a few I.G. Farben plants were located outside that territory (mainly in France). There were also I.G. Farben-associated facilities in Norway that are not shown on this map.

Some (but certainly not all) major sites involved in scientific research, development, and production during World War II are shown in:

- Fig. 11.20 for locations in modern Germany.
- Fig. 11.21 for locations in modern Austria and Hungary.
- Fig. 11.22 for locations in modern Poland and Russia.
- Fig. 11.23 for locations in the modern Czech Republic and Slovakia.

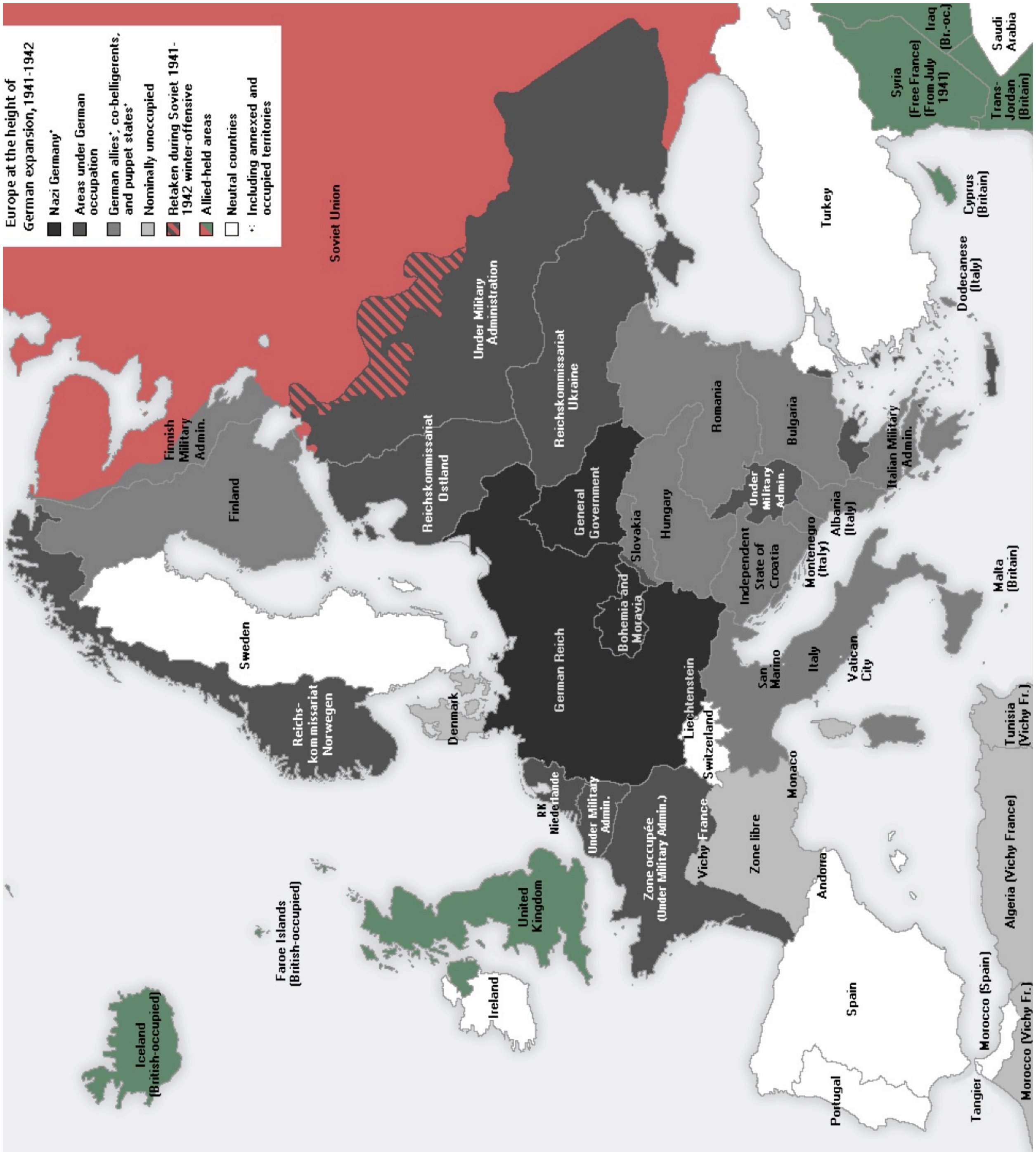


Figure 11.15: Map of areas controlled directly or indirectly by Germany in 1942. Although the majority of German research and industry was located within the Greater German Reich (darkest area), there were also major sites in satellite countries from Norway to Bulgaria. At the end of the war, Allied countries seized materials, scientists, and information from sites in the regions they regained or occupied.

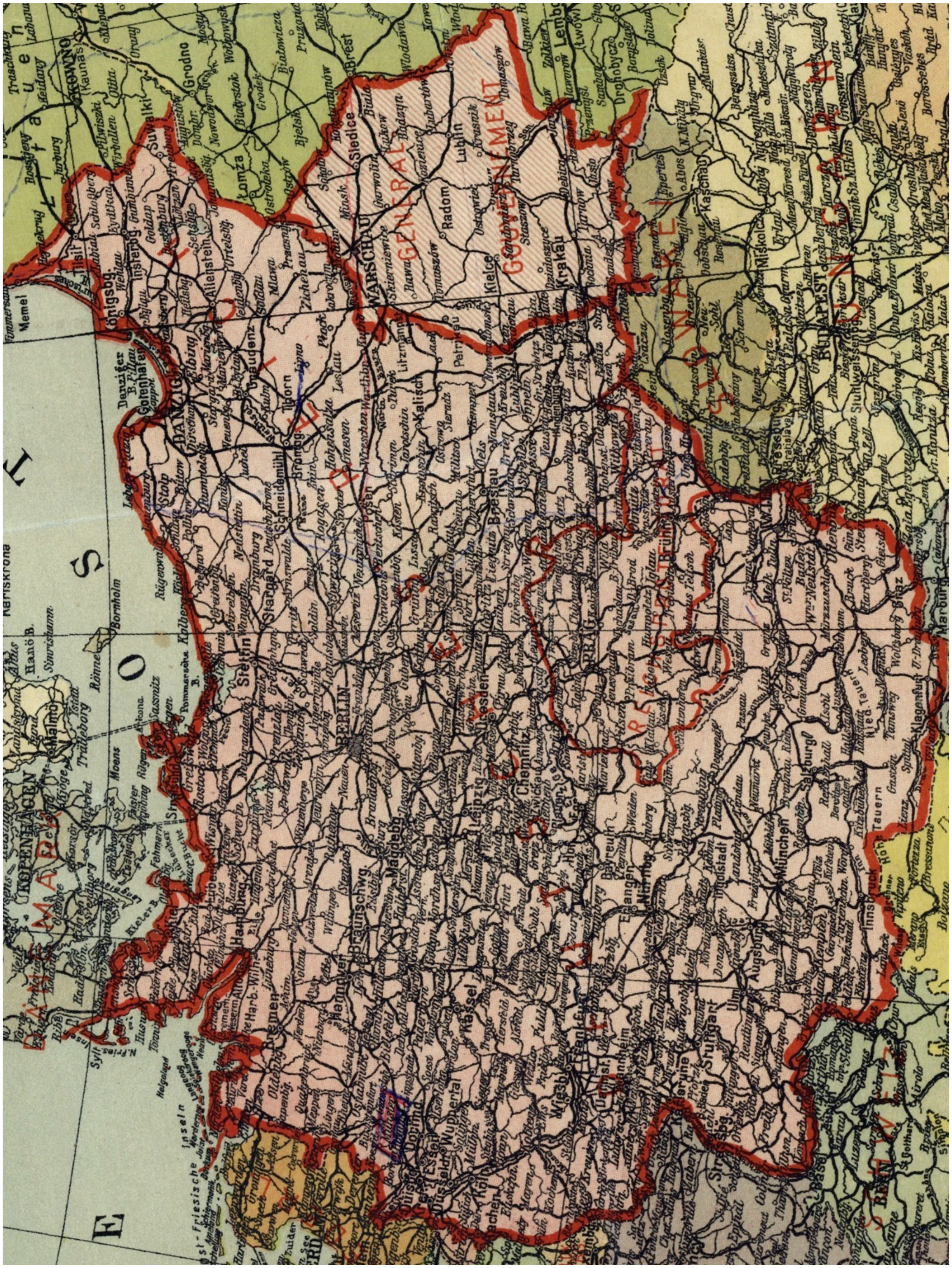


Figure 11.16: Map of the Greater German Reich in 1941, not including satellite countries that were also controlled by Germany. At the end of the war, the Soviet Union, United States, United Kingdom, and France seized materials, scientists, and information from sites in the regions they occupied. Note that the majority of this territory was occupied by the Soviet Union and therefore was generally not open to inspection by western Allied investigators.

Locations of major I.G. Farben-related plants in 1943

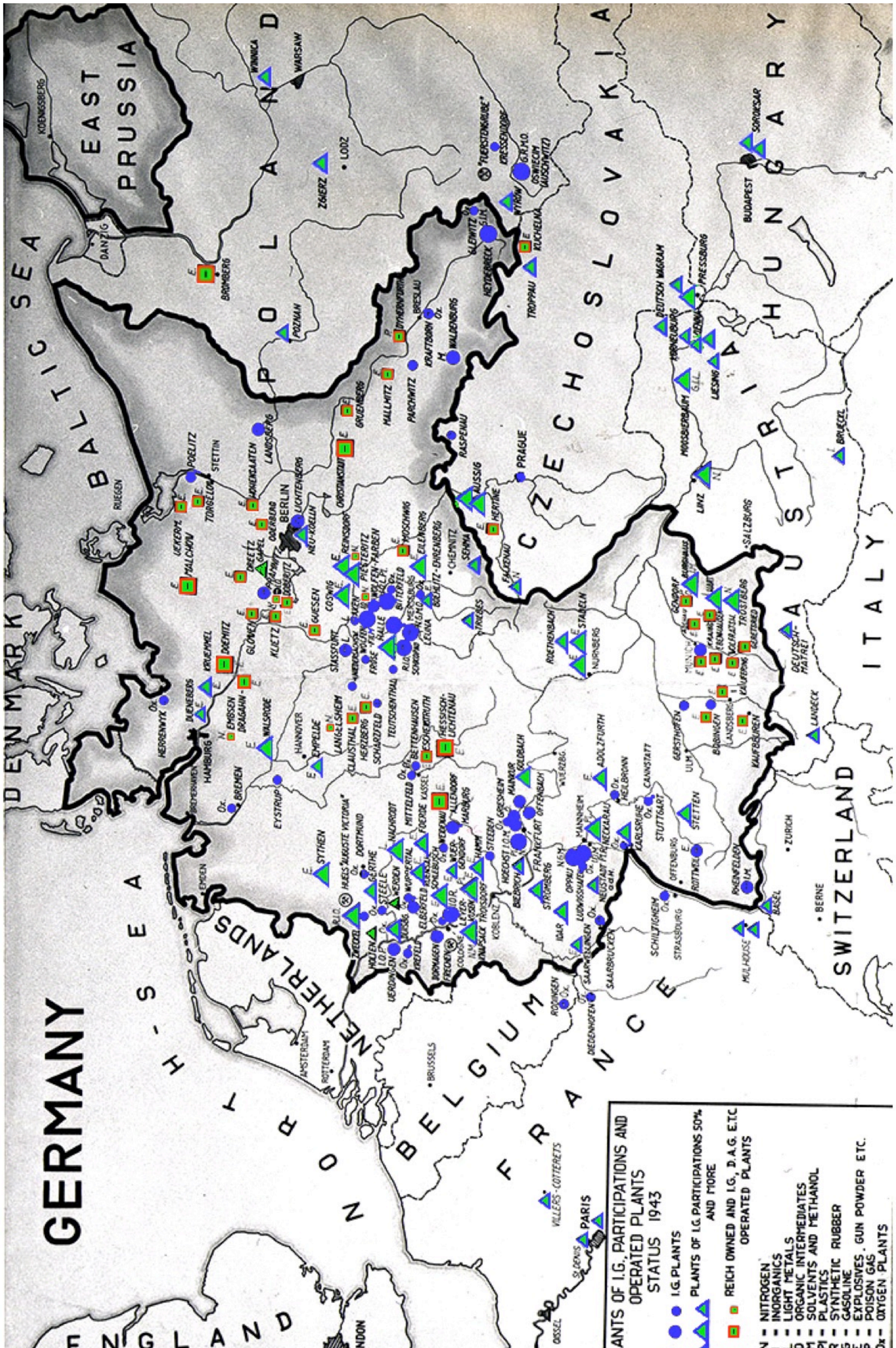


Figure 11.17: Map of plants run by or affiliated with I.G. Farben in 1943. The large majority were located within the Greater German Reich, but that included the territory of modern Austria, Poland, and the Czech Republic in addition to modern Germany. Like other scientific sites, I.G. Farben plants were seized at the end of the war by the countries occupying the corresponding regions.

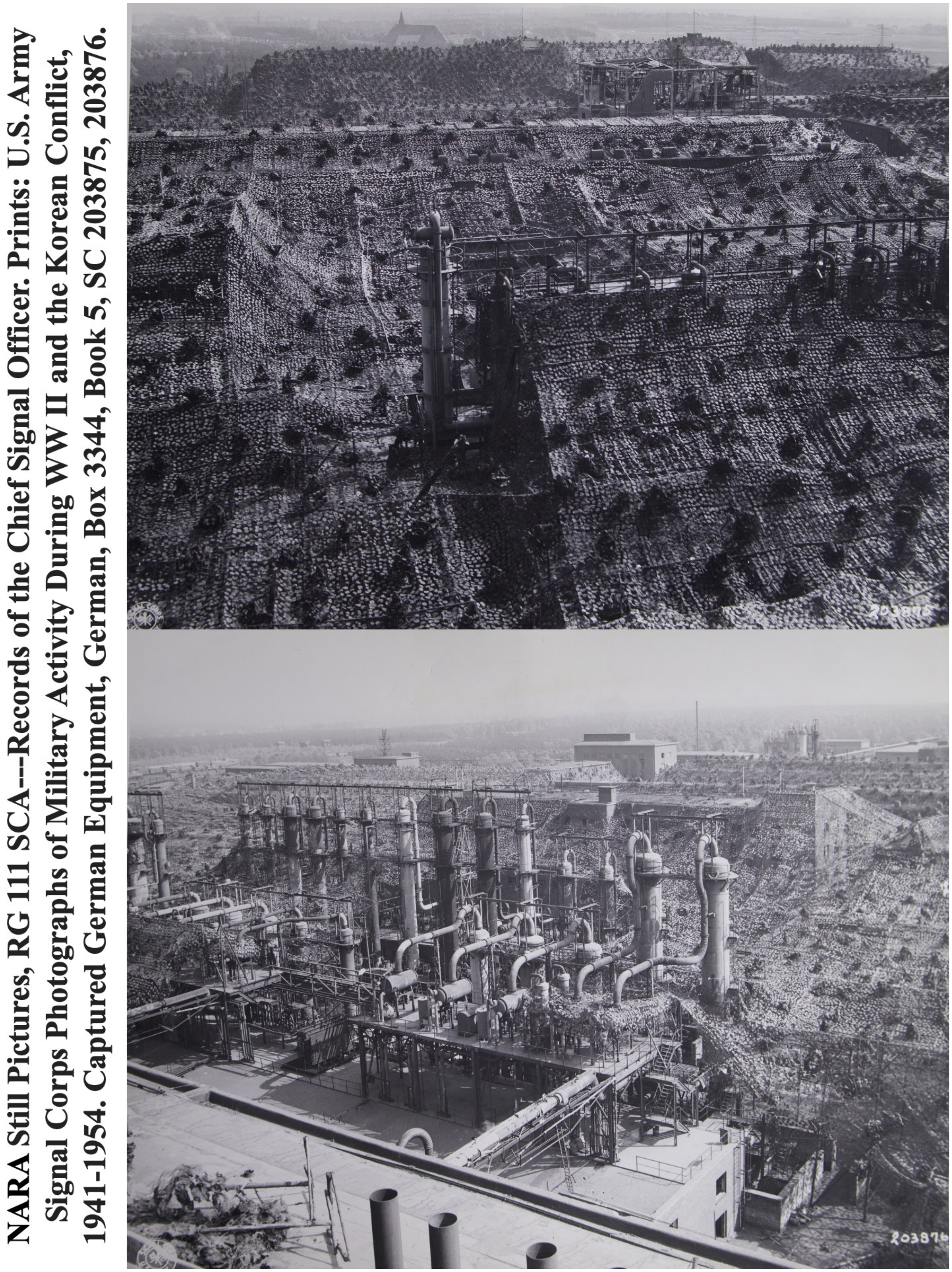


Figure 11.18: Large I.G. Farben buna synthetic rubber plant near Hüls, discovered intact under camouflage netting by the U.S. Army in April 1945 [NARA Still Pictures, RG 111 SCA—Records of the Chief Signal Officer. Prints: U.S. Army Signal Corps Photographs of Military Activity During WW II and the Korean Conflict, 1941–1954. Captured German Equipment, German, Box 3344, Book 5, SC 203875, SC 203876].

NARA Still Pictures, RG 111 SCA--Records of the Chief Signal Officer. Prints: U.S. Army Signal Corps Photographs of Military Activity During WW II and the Korean Conflict, 1941-1954. Captured German Equipment, German, Box 3354, Book 15, SC 282453, 282456.

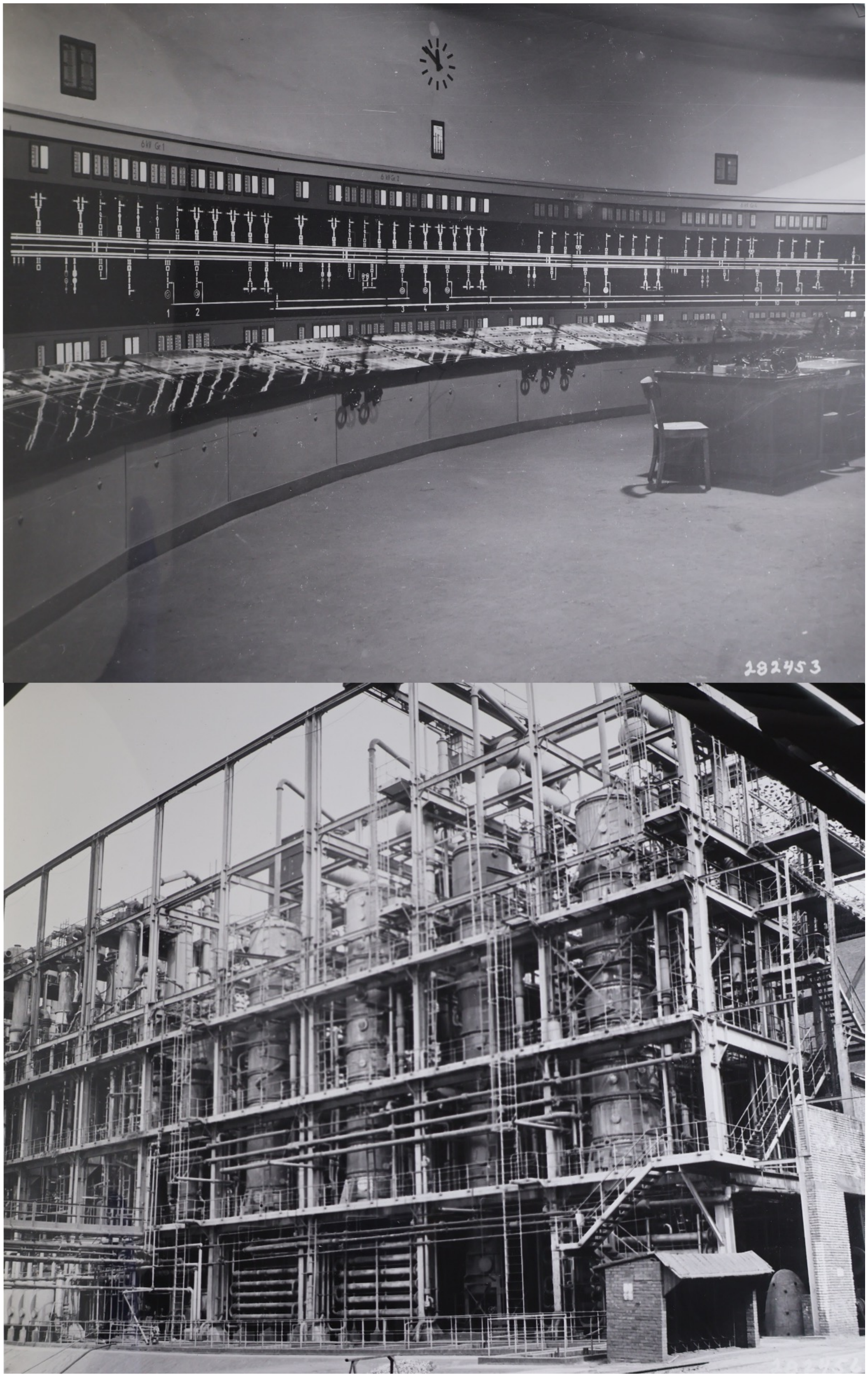


Figure 11.19: Large I.G. Farben buna synthetic rubber plant near Hüls, discovered intact under camouflage netting by the U.S. Army in April 1945 [NARA Still Pictures, RG 111 SCA—Records of the Chief Signal Officer. Prints: U.S. Army Signal Corps Photographs of Military Activity During WW II and the Korean Conflict, 1941–1954. Captured German Equipment, German, Box 3354, Book 15, SC 282453, SC 282456].

Figure 11.20: Some major sites involved in research and development during World War II that are located in modern Germany.

Notes for Fig. 11.20, showing sites located in modern Germany:

Berlin area: universities and technical schools; Kaiser Wilhelm Institutes; Kummersdorf and Spandau army research centers; Oranienburg Auer/SS research center; Reichspost research institutes; AEG, Siemens, Degussa, I.G. Farben, and other industry (e.g., pp. 3642, 3728, 3961, 4218, 4220, 5026) [Hayes 2004; Nagel 2016].

Braunschweig: Luftfahrtforschungsanstalt; Göring Werke; SS facilities; Buchler uranium (p. 5026).

Bremerhaven: naval research and development (e.g., p. 1467).

Dresden: Reichspost, AEG, and other laboratories (pp. 4343, 4552).

Elberfeld/Leverkusen area: I.G. Farben plants, including chemical warfare (e.g., pp. 3968–3969).

Erfurt area: numerous underground facilities (pp. 3742–3743, 4480–4482, 4522–4617) and also uranium deposits [Hayes 2004; Nagel 2016; Zeman and Karlsch 2008].

Frankfurt area: universities, research institutes, and industry [Hayes 2004; Nagel 2016].

Freiburg-im-Breisgau area: nuclear and other sites (pp. 3530–3558, 3730).

Friedrichshafen and Unterraderach (pp. 3955–3956).

Göttingen University.

Hamburg area: universities, research institutes, and industry; chemical and nuclear weapons development in Lüneburger Heide/Munster-Lager/Raubkammer (e.g., pp. 3512–3534, 4214–4220, 4446).

Heidelberg: university and Kaiser Wilhelm Institutes.

Jena: Zeiss (e.g., pp. 1279–1283, 1288, 2090); others in surrounding area.

Johanngeorgenstadt and Schneeberg area: uranium mining and use for nuclear development (pp. 3451–3455, 3474–3434, 3742, 4968) [Zeman and Karlsch 2008] .

Kaufering/Landsberg: installation possibly involved in nuclear work (p. 3726).

Kiel: naval research and development; uranium centrifuges (e.g., pp. 3512–3534).

Lehesten/Saalfeld area: underground rocket/aircraft/nuclear facilities (pp. 3723, 3730).

Leuna/Halle: I.G. Farben (e.g., pp. 4076–4090).

Munich area: universities, research institutes, and industry; Tegernsee facility (p. 3730).

Nordhausen: underground factories for rockets, missiles, and aircraft (e.g., pp. 5349–5354).

Peenemünde area of the Baltic coast: Peenemünde test center for rockets, missiles, and aircraft (e.g., pp. 3730, 5337–5348); Friedrich Löffler Institute for infectious disease research on Riems island (e.g., p. 198); military testing facilities on Rügen island (e.g., pp. 4428–4479); military testing facilities on Bornholm island, Denmark (e.g., pp. 3820, 4625); Lübeck, Dräger Werke (e.g., p. 4098); other facilities to produce and test advanced weapons and aircraft.

Piesteritz: chemical and possible nuclear development work (p. 4496).

Sigmaringen (p. 3730).

Stassfurt vicinity: underground Salzbergwerke facility for rocket and nuclear development (p. 3731).

Tübingen: university and research facilities (p. 3730).

Zellendorf: SS nuclear facility (p. 3728).

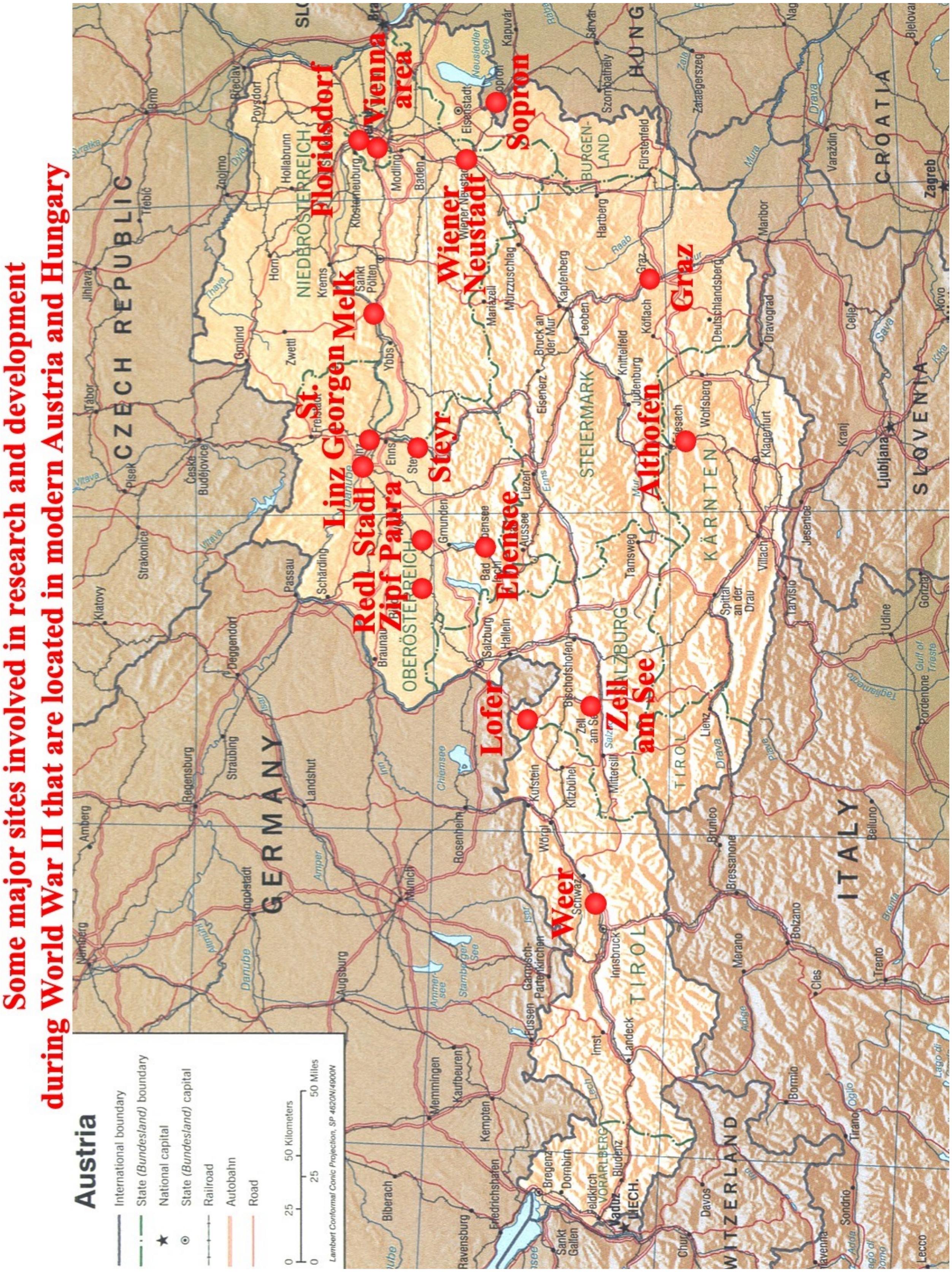


Figure 11.21: Some major sites involved in research and development during World War II that are located in modern Austria and Hungary.

Notes for Fig. 11.21, showing sites located in modern Austria and Hungary:

Althofen: Treibacher Chemische Werke (e.g., pp. 3450–3455, 5026) [Gollmann 1994].

Ebensee: underground facilities for oil production, rocket development, and apparently nuclear-related work (e.g., pp. 3752–3775, 5357–5359).

Floridsdorf (e.g., p. 3730).

Graz (e.g., pp. 4657–4658).

Linz: Reichswerke Hermann Göring and other heavy industries, at least some of which were apparently nuclear-related (e.g., p. 3911).

Lofer (e.g., p. 5020).

Melk vicinity and associated sites: underground facilities that were part of the Quarz development (e.g., p. 3766) [Schmitzberger 2004].

Redl Zipf: underground facility (e.g., pp. 3752–3775).

Sopron, Hungary (e.g., pp. 3780–3781).

Stadl Paura (e.g., pp. 3752–3775).

Steyr.

St. Georgen/Gusen/Langenstein vicinity: underground facilities that were part of the Bergkristall/ Gusen/Esche development (e.g., pp. 3908–3954 and 5008–5016).

Vienna area: universities, research institutes, and industry.

Weer and Brixlegg, Tyrol: heavy water production plants (e.g., pp. 4109–4115).

Wiener Neustadt vicinity (e.g., pp. 3782, 3766).

Zell am See (e.g., p. 4834).

Figure 11.22: Some major sites involved in research and development during World War II that are located in modern Poland and Russia.

Notes for Fig. 11.22, showing sites located in modern Poland and Russia:

Baltic coast/Pomerania: many military test ranges located along most of the coast (e.g., p. 4434, Leba/Rumbke, etc.).

Blizna: SS Truppenübungsplatz Heidelager A-4 (V-2) rocket test/launch site.

Bydgoszcz/Bromberg: underground facility, possibly nuclear-related (e.g., p. 4500).

Choszczno/Arnswalde: secret large underground factory (p. 5642).

Gdansk/Danzig: Anti-radar/anti-sonar; uranium enrichment (pp. 3594, 4446, 4566).

Kaliningrad/Königsberg, Russia: Henschel guided missile development (e.g., p. 3962).

Lubań/Lauban area:

- GEMA-Werke for electronics.
- Leśna/Marklissa: VDM factory for A-4 (V-2) rocket engines.
- Zgorzelec/Görlitz: underground factory for A-4 (V-2) rockets.

Nord test range: Henschel Hs 117 Schmetterling surface-to-air missile development.

Oświęcim/Auschwitz: large I.G. Farben production facility, heavy water production, and possibly other nuclear-related work (e.g., pp. 4487–4521); to the north, Auergesellschaft uranium facility at Katowice/Kattowitz and Messerschmitt Me 163 rocket plane development at Mierzęcice/Udetfeld.

Poznan/Posen:

- Nesselstedt/Reichsinstitut für Krebsforschung biological weapons research (pp. 2574–2587).
- Biological weapons production (e.g., p. 2594).
- Electromagnetic railgun production (e.g., pp. 3263–3264)
- Numerous factories to produce other advanced weapons and aircraft.

Racibórz/Ratibor: Siemens Plania Werke, graphite production for nuclear experiments.

"Riese" area of Lower Silesia (e.g., pp. 4549–4563):

- Ksiaż castle/Schloss Fürstenstein: Jägerstab/SS development.
- Numerous underground facilities, some of which were conducting nuclear work.
- Kowary/Schmiedeberg uranium mine (e.g., p. 3346) and heavy water production plant [Witkowski 2013, p. 224].

Szczecin/Stettin area.

- Mosty/Speck: underground facility, apparently nuclear work [Witkowski 2013, p. 224].
- Stargard and Miedwie Lake/Madüsee: surface-to-air missile development.

Tuchola Forest/Tucheler Heide: military/SS rocket testing and nuclear work (e.g., pp. 4506, 4948–4949) [Dornberger 1958, pp. 227–229].

Wrocław/Breslau area: uranium centrifuges (p. 4567); heavy water (pp. 4106–4107); Rheinmetall missiles; Brzeg Dolny/Dyhernfurth chemical weapons.

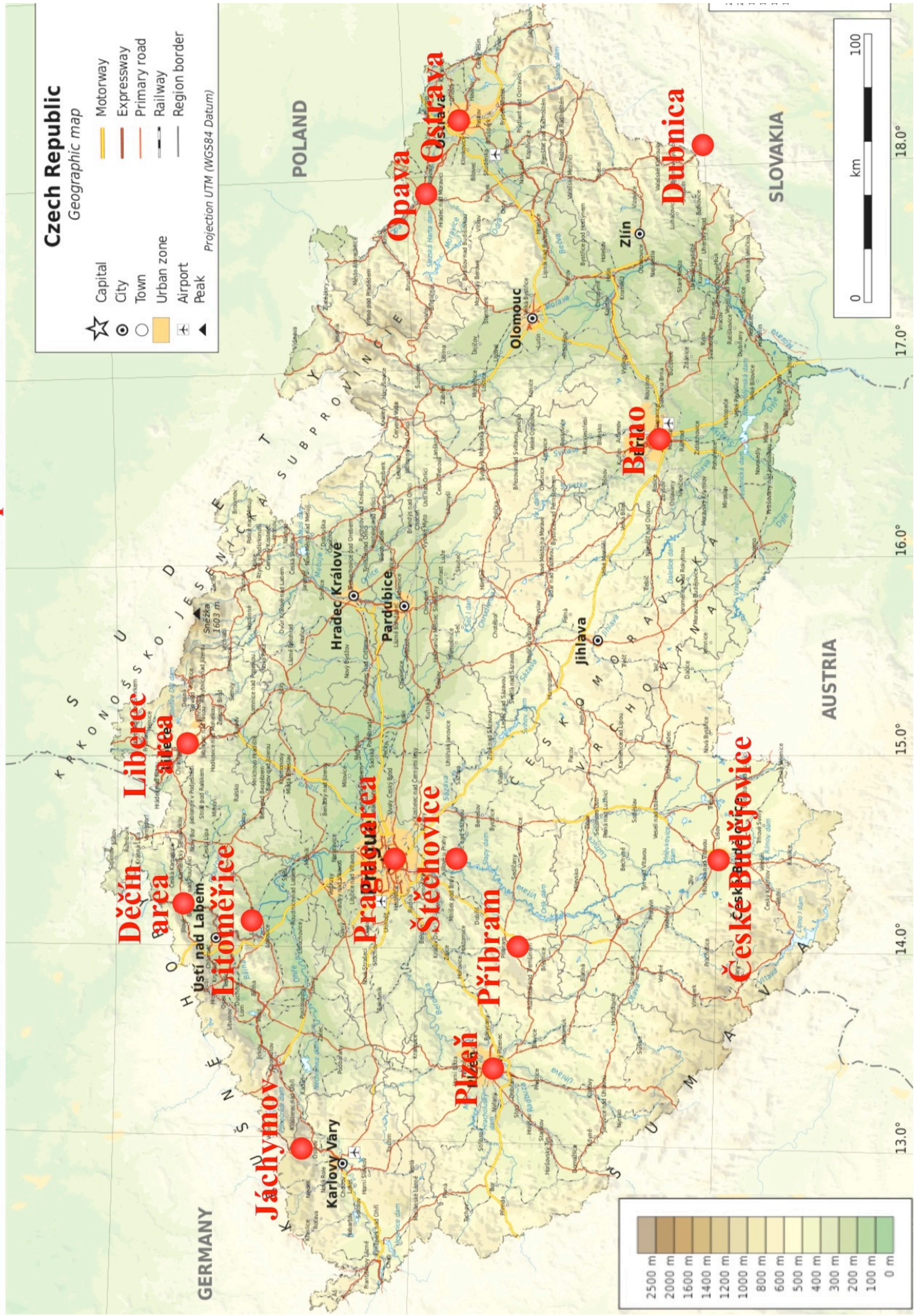


Figure 11.23: Some major sites involved in research and development during World War II that are located in the modern Czech Republic and Slovakia.

Notes for Fig. 11.23, showing sites located in the modern Czech Republic and Slovakia:

Brno/Brünn: Waffenwerke-Brünn, SS academy research institute (pp. 3728, 4031).

České Budějovice/Budweis: several Siemens electronics factories for guidance systems, proximity fuses, etc. (pp. 4013–4056, 5585–5653).

Děčín/Tetschen area (pp. 4013–4056, 5585–5653):

- Podmokly/Bodenbach Krizik Works/Weserwerke underground factory.
- Benesov nad Ploucnici/Beneschau AEG electronics factory.
- Schmidding factory for rockets and missiles.
- Neumann und Slabenow factories for metals and electronics.

Dubnica/Dubnitz, Slovakia: Skoda underground facility (p. 3818).

Jáchymov/St. Joachimsthal: uranium mine (pp. 4032, 5026–5030).

Liberec/Reichenberg and Jablonec/Gablonz area (pp. 4013–4056, 5585–5653):

- Bedrichov/Friedrichsthal/Benesov nad Ploucnici AEG factory for V-3 and V-4 rockets/guidance systems.
- Rychnov/Reichenau GETEWENT (Gesellschaft für Technisch-Wirtschaftliche Entwicklung mbH) SS electronics factory.
- Straz nad Nisou/Habendorf Skoda underground factory (p. 5631).
- Tanvald/Tannwald: multiple electronics and semiconductor research facilities (p. 2769).
- Turnov/Turnau aerospace research facility.

Litoměřice/Leitmeritz: Richard I–IV underground factories (p. 3723).

Opava/Tropau: I.G. Farben production plant, apparently involved in nuclear work (p. 3782).

Ostrava/Ostrau and Vitkovice/Witkowitz: I.G. Farben and other industrial production plants, apparently some of which were involved in nuclear work (pp. 3782, 4013–4056).

Plzeň/Pilsen: Skoda/SS research facilities and administrative headquarters (p. 5020).

Prague/Praha/Prag area (pp. 2769, 3155–3174, 4013–4056, 5585–5653):

- Charles University/Prague German University.
- Bohemian/Czech Technical University in Prague.
- Kbely/Gbel airfield.
- Čelakovice/Tschelakowitz cyclotron factory (northeast of Prague).

Příbram/Przibram/Pibrans: Skoda/SS rocket development facility (pp. 3785–3788, 4967, 5794).

Štěchovice/Stechowitz area: Blaumeise underground facilities, apparently nuclear (pp. 3789–3816).

Most of this section demonstrates the size of the industries controlled by Germany by giving examples of the numbers and types of plants built by Germany, the geographical distribution of plants, and the magnitude of the postwar transfer of plants, products, materials, scientists, documents, and other information to Allied countries.

One can also demonstrate the size of the industries controlled by Germany (and subsequently transferred) by two other measures:

1. Gross domestic product (GDP). Table 11.6 summarizes information from economist Mark Harrison [Harrison 1998, pp. 3–13] regarding the economic output of Germany and countries aiding Germany during the war. Prewar (1938) GDP figures are expressed in billions of 1990 U.S. dollars. The 1938 GDP numbers were 351.4 for Germany alone, 1046.5 for Germany plus other Axis/occupied countries, and 1166.7 for Germany plus other Axis/occupied countries plus nominally "neutral" countries that actually gave considerable material support to Germany. Although the only easily available figures are those 1938 numbers, the totals for German-controlled Europe were probably fairly comparable during the war. (Allied bombing and territorial losses toward the end of the war would tend to reduce the totals, whereas German-initiated industrial construction, relocation to avoid Allied bombing, use of low-wage and forced labor, and other policies would tend to increase the totals.)

For comparison, the U.S. GDP (expressed in billions of 1990 U.S. dollars) was 800 in 1938, rising to 1094 in 1941 and reaching a wartime peak of 1499 in 1944. Thus the economic and industrial resources controlled by Germany were roughly comparable to and perhaps even greater than those of the United States (yet outmatched by the combined resources of the United States plus the complete British Commonwealth plus the Soviet Union).

2. Electrical power production. According to the U.S. Strategic Bombing Survey (USSBS), at the end of 1944 the Greater German Reich had a total known electrical production capacity of 22 GW, with at least 16 GW of that currently then in use despite territorial losses, extensive bombing, and ongoing repair work.[6] See pp. 2114–2116. BIOS 342 estimated a total of 23 GW for 1944 (pp. 2117–2118). Note that that total known production capacity of 22–23 GW does not include secretive or specialized power plants for classified or dedicated projects in the Greater German Reich that were either not known to USSBS and BIOS (especially in areas occupied by the Soviet Union after the war) or known but not publicly revealed by USSBS and BIOS. Note also that that 22–23 GW does not include the electrical production capacities of other countries that were occupied by Germany, allied with Germany, or nominally neutral but exporting aid to Germany. Detailed numbers on those extra production capacities are difficult to find, but a reasonable estimate is that adding secretive production within the Greater German Reich and production outside the Greater German Reich would approximately double that 22–23 GW to ∼44–46 GW of total electrical production capacity to aid the German war effort.

[6] United States Strategic Bombing Survey. 1947. *German Electric Utilities Industry Report.* pp. 1, 4, Exhibit C, Exhibit D. https://books.google.com/books?id=U9Q9TS-FtSgC

Country	**GDP**
Germany	351.4
Other Axis/occupied:	
Austria	24.2
Baltic states	12.9
Belgium	39.6
Bulgaria	10.5
Czechoslovakia	30.3
Denmark	20.9
Finland	12.7
France	185.6
Greece	19.3
Hungary	24.3
Italy	140.8
Netherlands	44.5
Norway	11.6
Poland	76.6
Romania	19.4
Yugoslavia	21.9
Subtotal:	695.1
"Neutrals" supporting Germany:	
Portugal	12.9
Spain	51.1
Sweden	29.8
Switzerland	26.4
Subtotal:	120.2
Total:	1166.7

Table 11.6: Gross domestic product (GDP) figures for Germany and countries that aided Germany during World War II (1938 GDPs, expressed in billions of 1990 U.S. dollars [Harrison 1998, pp. 3–13]. For comparison, the U.S. GDP (expressed in billions of 1990 U.S. dollars) was 800 in 1938.

For comparison, total production of electrical energy in the United States increased from 161,308 GW hr for the year of 1939, or a time-average of 18.4 GW electric power production, to 271,255 GW hr for 1945, or a time-average of 31.0 GW electric power production.[7] Thus the electrical power available to aid Germany was roughly comparable to and possibly even greater than the electrical power production of the United States (though outmatched by the combined electrical power of the United States plus the complete British Commonwealth plus the Soviet Union).

[7] United States Census Bureau. 1949. *Statistical Abstract of the United States.* p. 512.
https://www.census.gov/library/publications/1949/compendia/statab/70ed.html
https://www2.census.gov/library/publications/1949/compendia/statab/70ed/1949-08.pdf

GERMAN ELECTRIC UTILITIES

PART I

GENERAL SUMMARY AND CONCLUSIONS

1. The objective of the Utilities Division was to examine the actual damage done by the bombing of Germany's electric generating plants and transmission networks, to study the effect of the resultant curtailment in suppply of electric energy upon Germany's war industry, and to reach conclusions concerning the desirability of electric utility systems as targets for strategic bombing.

2. German industry derived its electric supply from generating plants having a total nominal or name plate capacity at the end of 1944 of approximately 22,000,000 KW, or an available capacity of probably 16,000,000 KW. Of this nominal or name plate total, 13,300,000 KW formed the so-called "integrated system" (Verbundsnetz), which was under the jurisdiction of a National Load Dispatcher and consisted of all public utility systems and of the larger private industrial generating plants. The remaining 8,700,000 KW of the 22,000,000 KW nominal capacity, consisted of plants of industry, the national railroad system and isolated plants both large and small. The integrated system produced 45 billion kilowatt hours a year, of which probably over 80 per cent was consumed by industry. Of the 13,300,000 KW nominal capacity in the integrated system, 46 per cent was in hard coal burning plants, 33 per cent in brown coal burning plants, and 21 per cent in water power plants.

3. Generating stations were interconnected through substations by a high voltage transmission system which had as its backbone a 220 KV transmission line looping northward from the Swiss border through the Ruhr area, east to the vicinity of Leipzig, and then south to Austria. Radiating and interlacing with this system were a large number of 110 KV circuits partly for the collection of electric energy from off-lying generating stations, and partly for the delivery of electric energy to large industrial consumers and to municipal consuming areas. This transmission system, popularly spoken of as the "grid", was built according to plans originally made in 1926 primarily for the coordination of hydro power with thermal power with a view to economy.

4. Field surveys were made by the Utilities Division of the principal power plants in two great industrial areas of Germany: that around Leipzig where there is installed approximately one-fifth of all German public utility generating capacity; and that area from Essen to Cologne served by the large RWE (Rheinisch-Westfalisches Elektrizitatswerk A.G.) System, which comprises approximately 20 per cent of German capacity. The hydroelectric developments in southwest Germany which tie into and form an operating part of the RWE System were also inspected. Several electric substations and a generating station in northern Italy which had been bombed were also surveyed.

- 1 -

Figure 11.24: United States Strategic Bombing Survey. 1947. *German Electric Utilities Industry Report.* p. 1. https://books.google.com/books?id=U9Q9TS-FtSgC

GERMAN ELECTRIC UTILITIES

PART II

BRIEF REVIEW OF THE ELECTRIC
UTILITY INDUSTRY IN GERMANY

GENERAL.

1. Prewar Germany (including Austria and Sudeten territory) with a population according to 1939 census of 79,400,000 people and occupying an area of about 225,000 square miles, was largely industrial.

2. The principal industrial centers were:

The Ruhr and Saarland, for iron or steel production.
Berlin, for general manufacturing.
Bavaria and Prussia, for chemical manufacturing.
Saxony, for textile manufacturing.

The main centers of power generation were:

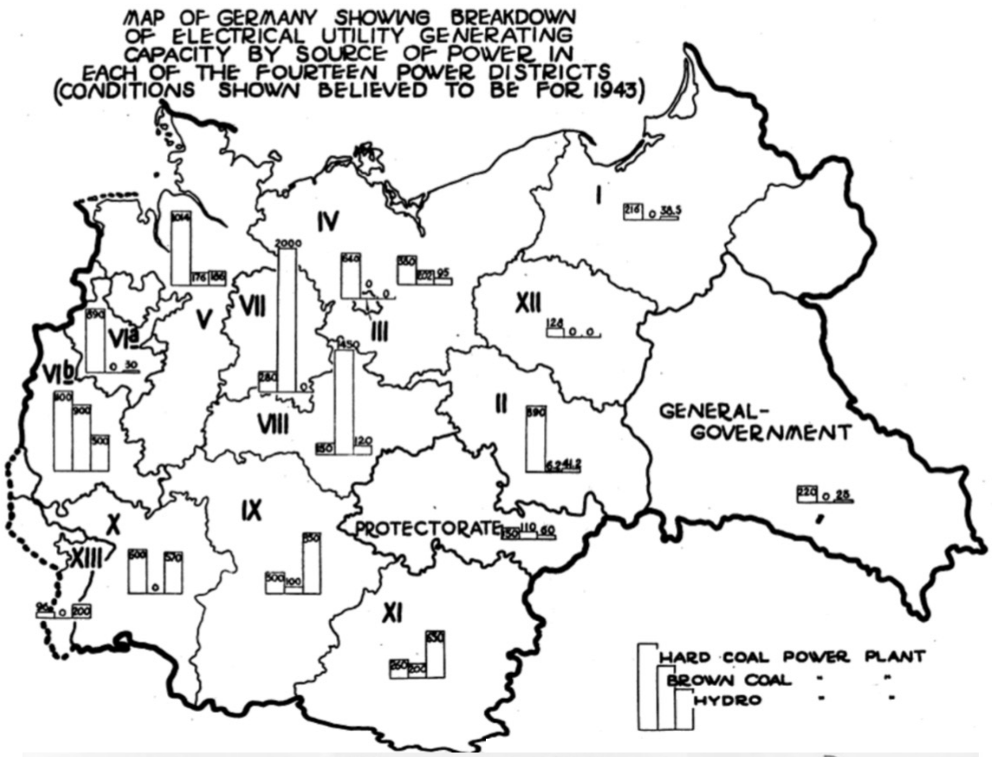
Rhine-Westphalia brown coal and hard coal areas.
Southwestern German water power area (including Austria.)
Central German brown coal area (including Leipzig and Berlin.)
Silesian hard coal area.

3. From data obtained from the office of the National Load Dispatcher the total generating station capacity, both public utility and private plant, in 1944 was 22 million KW. From the German diagram of principal interconnecting transmission lines, dated 15 February 1945, Exhibit D, it appears that the distribution of the more important generating stations both public and private of 50,000 KW capacity and over was as follows:

Plant Size KW (x 1000)	Hard Coal	Brown Coal	Hydro	Thermal Hydro	Total
Over 200	1	4	0	0	5
100 to 200	22	12	6	0	40
50 to 100	24	9	14	3	50
Total	47	25	20	3	95

- 4 -

Figure 11.25: United States Strategic Bombing Survey. 1947. *German Electric Utilities Industry Report.* p. 4. https://books.google.com/books?id=U9Q9TS-FtSgC



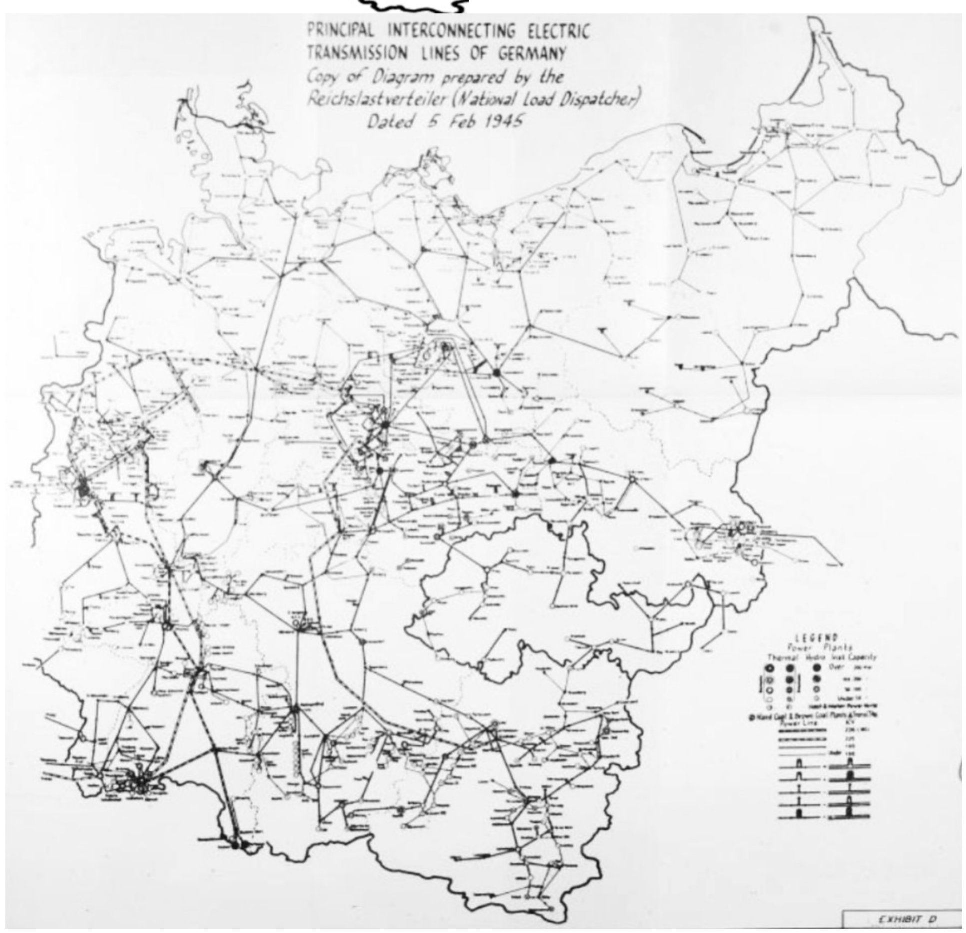


Figure 11.26: United States Strategic Bombing Survey. 1947. *German Electric Utilities Industry Report.* Exhibits C and D. https://books.google.com/books?id=U9Q9TS-FtSgC

BIOS 342. *The German Wartime Electricity Supply: Conditions, Development, Trends.*

9. **Power plant was, of course, also built outside this priority programme; at the end of the war about 40 stations (public and industrial) were either under construction or being extended.**

10. **After re-armament had begun industrial undertakings were roughly one year ahead of the power supply in industry in deciding on the extension of their power plant. Works of the 4-year plan were given priority.**

11. **Despite all difficulties, an annual average of 750 MW of new plant was installed in Greater Germany in public stations from 1939 to 1944. Figures of new plant put into commission in industrial stations are not complete but are estimated to have been roughly of the same order. In the early stages of the war more industrial plant was put into commission than public; in the later stages of the war the position was reversed.**

12. **The capacity of the electrical manufacturing industry of Greater Germany was of the order of 1800 MW of generating plant per year; it was limited mainly by the production capacity for the rotors of turbo-generators. The manufacturing capacity for high voltage high capacity power transformers was adequate before the transformer works in Nuremberg and Berlin were heavily damaged by air raids.**

13. **The following table gives, in statistical form, a rough outline of the development of electricity generating capacity, electricity production and utilisation of plant from 1935 to 1944.**

Altreich						Greater Germany					
Year; increase	Capacity: installed cap. MW	Capacity: not available cap. %	Capacity: output cap. MW	Production million kWh	Plant factor[ø] %	Year; increase	Capacity: installed cap. MW	Capacity: not available cap. %	Capacity: output cap. MW	Production million kWh	Plant factor[ø] %
Public stations											
1935	8340	9.5	7550	20260	30.9	1939	11270	13.0	9800	37020	43.3
+ % =	35%	131%	24.5%	96%	56%	+ % =	16%	44.5%	11%	22%	9%
1941	11230	16.2	9400	39800	48.3	1941	13050	16.3	10920	45030	47.2
+ % =			21.2%	6.8%	-6.8%	+ % =			22%	5.6%	-8.5%
1944			11500	42500[x]	45.0[x]	1944			13300	47500[x]	43.2[x]
Industrial stations											
1935	5820	9.8	5250	16440	35.8	1939	9430	23.0	7250	29300	46.4
+ % =	69%	356%	38%	84%	33%	+ % =	23%	45.5%	16.3%	18.2%	1.3%
1941	9840	26.5	7240	30200	47.7	1941	11610	27.3	8440	34680	47.0
+ % =			21.5%	11%	-2.1%	+ % =			15%	8%	-2.8%
1944			8800	33500[x]	46.7[x]	1944			9700	37500[x]	45.7[x]
All stations											
1935	14160	9.7	12800	36700	32.9	1939	20700	17.6	17050	66320	44.6
+ % =	49%	224%	30%	91%	46%	+ % =	19%	45%	13%	20%	5.6%
1941	21070	21.0	16640	70000	48.0	1941	24660	21.3	19360[a]	79710[b]	47.1
+ % =			22%	8.6%	-4.8%	+ % =			19%	7%	-6.2%
1944			20300	76000[x]	45.7[x]	1944			23000	85000[x]	44.2[x]

ø based on output capacity.
x figure for 1943.

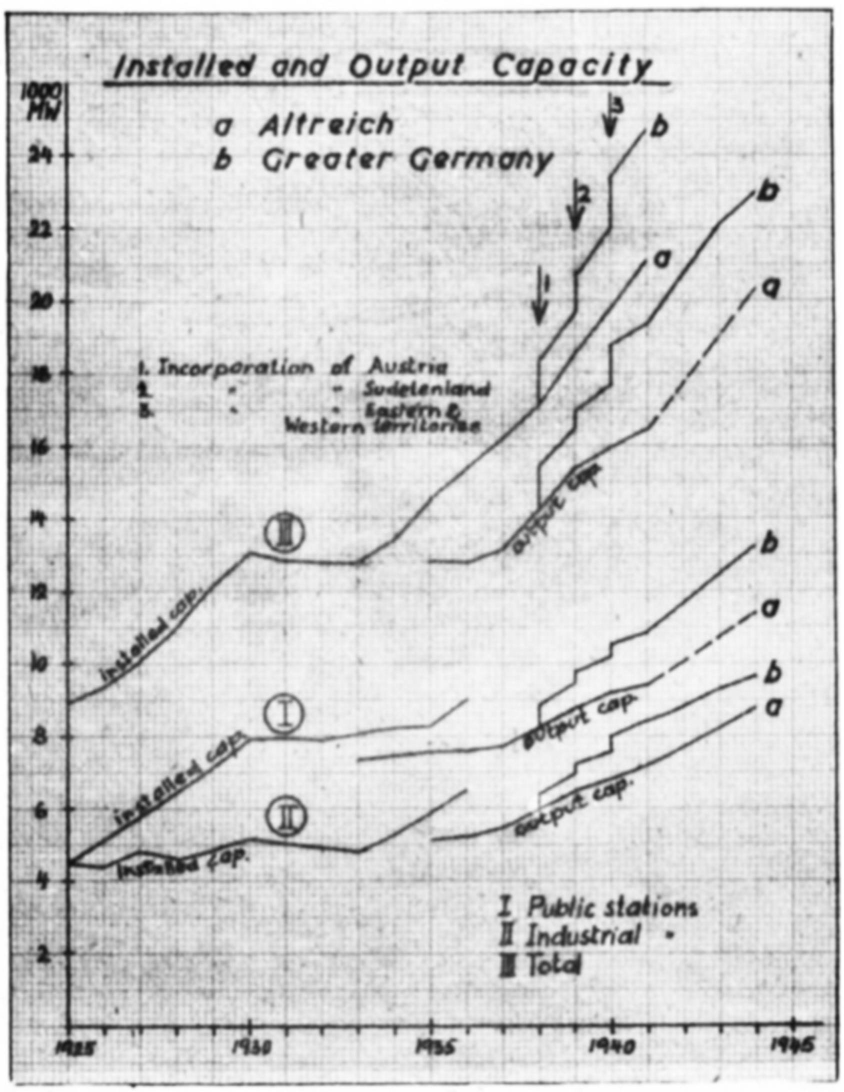
a), b) of this in:	hard coal,	brown coal,	water power,	other stations
a	45.5%	30.4%	14.4%	9.7%
b	40.0%	36.0%	14.9%	9.1%

Figure 11.27: BIOS 342. *The German Wartime Electricity Supply: Conditions, Development, Trends.*

BIOS 342. *The German Wartime Electricity Supply: Conditions, Development, Trends.*

from the political side, on the supply undertakings, which were publicly accused of having over-invested in 1929 for their own benefit and of having thus misused public funds. This opinion was held even in the highest quarters and, when the quota system for steel was introduced in 1937, the electricity supply industry was at first refused an allocation. This refusal was, perhaps, the alarm signal for the supply undertakings, which now realised that their plant reserves had shrunk and that in the future it might not be at all easy, owing to the shortage of raw materials, to obtain the now necessary permission to build new plant.

Diagram 2



The electricity supply industry reacted quickly, but too late. As a result of numerous interventions and petitions a steel quota was allocated for power supply purposes in the autumn of 1937, but this was adequate neither to enable the supply industry to make good the plant shortage resulting from their own shortsightedness, nor to

- 2 -

Figure 11.28: BIOS 342. *The German Wartime Electricity Supply: Conditions, Development, Trends.*

Postwar transferred German-language documentation

In September 1945, R. P. Linstead and T. J. Betts, the British and American chairs of the Combined Intelligence Objectives Subcommittee (CIOS), bragged about the acquisition and processing of "thousands of bags" of German technical documents from up to 3377 targeted locations and scientists [AFHRA A5186 electronic version pp. 904–1026, Ch. 4, pp. 30, 32–33]:

> This file of CAFT Assessment Reports, giving details on 3,377 assessed targets is probably unique in the European Theatre. It is not a target list in the usual sense of the word, for it is not compiled from intelligence sources and therefore based on inferences regarding what should be found at the target. This file will doubtlessly serve as a primary source for target investigations in Germany for many months to come. [...]
>
> The Secretariat was responsible for the processing and despatch of thousands of bags of documents evacuated by CIOS investigators. It published accession lists giving the brief title of each document, thereby informing all concerned of the nature of documents temporarily available in the London area.

In fact, the United States transferred over 111,000 tons of German-language research documentation within just a three month period to one location (see p. 5318). Considering that the occupation and document removal process lasted several years, that documents were harvested by many different organizations and sent to many different locations, and that similar processes were carried out not just by the United States but also the United Kingdom, France, and Soviet Union, the total amount of transferred technical documents was almost certainly well over 111,000 tons—probably many multiples of that figure, likely over 1,000,000 tons of German technical documents.

The U.S. government then gave U.S. companies such as Bell Laboratories private access to captured German-language documentation [Gimbel 1990a, pp. 68, 71]:

> All of the letters asked for assistance in the recruitment of personnel whom OTS proposed to employ and send to Germany, but letters that went to private firms, such as the Bell Telephone Laboratories, also asked if the firms would be willing and able to send people to Washington for two or three months at company expense to analyze and index "an immense backlog of German technical documents" already on hand. Such "without compensation" (WOC) industrial representatives, who would obviously be in a position to benefit their employers directly, were promised "office space, secretarial and typing help, reproducing facilities, as well as the necessary access to all reports and documents"...
>
> Experts who volunteered would benefit by being the first to scrutinize the material. They could, in fact, use the original German materials for preparing professional articles that OTS would include in a "forthcoming Government Compendium of German wartime technology." Obviously—but apparently this was never stated explicitly—they could also apply what they found to their firms' research or use it in any other way that the firms and agencies that released them and paid them desired.*

> [...] As a matter of fact, the project was never completed and the proposed compendium never appeared, with the result that individuals and firms got private access to "intellectual reparations" that were originally intended for dissemination to the general public. [...]
>
> *For example, one of Bell Laboratories' people was spending half-time in Washington to go over technical literature gathered by OTS "and search for reports that might be of interest to the Laboratories."

For relevant documents, see p. 2979 and many other documents in Section B.5.

Similarly, after the war hundreds of thousands of patents from German-speaking inventors were transferred to the United States. The seizure of the patents by the United States was covered in a number of contemporary newspaper articles, such as the following examples:

To Keep German Patents: Alien Property Custodian Will Avert Return to Reich Owners [NYT 1945-06-06 p. 11]:

> James E. Markham, Alien Property Custodian, said today that every effort would be made to prevent German-controlled-corporations and patents, seized during the war, from returning to German hands.

German Patents To Aid U.S. Plants [NYT 1946-03-14 p. 44]:

> American industry will benefit substantially as a result of the quantities of patents and manufacturing information seized by the American technical group in the United States zone of occupation in Germany and the vast amount of information obtained by the first American technical expedition in the Russian zone, Robert B. MacMullin, chief investigator of the technical industrial intelligence branch of the Department of Commerce, said yesterday[...]
>
> More than 4,000 documents covering a multiplicity of processes and scientific data have been prepared for selection alike by the corporations and the small businessman, he said and two-thirds of those included the German data. The Department of Commerce ultimately, Mr. MacMullin continued, expects to offer 100,000 of such documents, disseminating information hitherto known only to enemy countries.
>
> These patents, Mr. MacMullin emphasized, will enable American manufacturers in many instances to replace their lines with enemy developments.

100,000 German Patents Available [NYT 1946-08-09 p. 8]:

> James E. Markham, Alien Property Custodian, said today that more than 100,000 German patents seized during the war will become available, royalty-free, to countries that signed the patent accord in London last week.

U.S. Said To Seize German Patents: Russian Says That Billions in Reparations Have Been Taken Since Occupation [NYT 1947-02-16 p. 3]:

> An article in [the Soviet paper] The New Times said today that the United States and Britain already had taken from Germany the richest war booty ever obtained by victorious powers. [...]
>
> The longest article of all asserted that the two countries already had extracted "many billions of dollars" worth of reparations from Germany in the form of patents, technical information and the services of scientists and technicians.
>
> Mr. Rubenstein, author of the article, said that although the United States and Britain had not set a total of the reparations due them from Germany, "removal of reparations by them in various forms has been carried on since the beginning of the occupation." [...]
>
> Mr. Rubenstein asserted that in obtaining German patents United States capitalists had "the active help" of United States occupational authorities and the Government in Washington.
>
> "Expert engineers and qualified German scientific workers" were described as appearing in German research institutions, laboratories and industrial plants, learning all the secrets, condensing them and filming them for transmission to the United States.
>
> The writer said that hundreds of United States technicians had been sent to Germany to learn the secrets of her industry and hundreds of German and Austrian scientists had been sent to the United States to do research work and eventually become citizens.

German Patents List: Applications Filed in War Years Available for Allied Countries [NYT 1950-07-02 p. E7]:

> The Office of Technical Services of the Department of Commerce issues a new "finding" guide to wartime German patent applications, which may now be used freely in Allied countries. The guide is a subject index to the 200,000 German applications filed in the Berlin Patent Office over the period 1940–1945.
>
> The Association for the Diffusion of Documentation, Paris, France, compiled the finding guide, now translated for American use. The association is offering, at $3 each, microfilm copies of complete patent applications. The fee not only covers the preparation of the reproduction but the task of locating the application on some one thousand microfilm reels on which the German applications were copied.
>
> Copies of the German patent application finding guide, entitled "Subject Outline of the Unpublished Applications for Patents Filed at the German Patent Office 1940–1945," are available on request from the Office of Technical Services, United States Department of Commerce, Washington.

While early newspaper articles mentioned 100,000–200,000 seized German patents, the actual total appears to have been over 750,000. A 21 April 1947 letter from the Technical Industrial Intelligence Division to R. P. Isaacs stated [NARA RG 40, Entry UD-75, Box 12, Folder Technical Inquiries - H -, Technical Industrial Intelligence Division to R. P. Isaacs, 21 April 1947]:

> You will probably be interested in knowing that single copies of almost all German patents issued during the war years up to V-E Day are on numerical file in the Patent Office Library in the Commerce Building. These files of German patents were seized at the Berlin Patent Office and evacuated to the United States in the spring of 1946. The German Patent No. 750986 is the latest one available. Photostatic copies of these patents may be ordered at 20 cents per page from the U.S. Patent Office, Washington 25, D.C.

See Figs. 11.30–11.31 for this complete document. If German Patent No. 750986 was the last known patent by the end of the war, the United States presumably would have possessed and asserted rights to German patents all the way back to the first one. See also the document in Fig. 11.50.

In fact, the total number of seized patents was likely even higher, since it would have included:

- Granted German patents up to at least number 750986.
- Granted Austrian patents.
- Patent applications filed but not granted in Germany by the end of the war.
- Patent applications filed but not granted in Austria by 1938.
- Secret classified German and Austrian patents.
- Patents and patent applications filed in other countries by German and Austrian inventors.

In addition to the United States, the Soviet Union seized huge numbers of German patents, and other countries may have as well.

CONFIDENTIAL

WAR DEPARTMENT
P. O. Box 2610
WASHINGTON, D. C.

23 July 1945

Subject: German patent records.

To: The Military Attache, American Embassy, London, England
Attention: Captain George B. Davis

The attached newspaper clipping is being forwarded to your office for your information and such action as deemed necessary.

FRANCIS J. SMITH,
Major, Corps of Engineers.

Incl.
1 Clipping

1st Ind.

Maj. H. K. Calvert, OMA, American Embassy, London, England. 22 August 1945.
To: Major F. J. Smith, Room 5119, New War Dept. Bldg., Washington, D. C.

1. Lt. Col. E. L. McLendon, Legal Division, U.S.G.C.C. of Germany, Directors Building, Berlin, was contacted on 15 August 1945 over the status of the German patent records.

2. It was learned that, as the newspaper stated, that there are presently around 150 tons of unclassified patents and Allied papers located in the German Patent Office, Berlin. Inasmuch as the building had been severely damaged and the records are in no condition at the present time for analysis it is difficult for Col. McLendon to estimate what percentage this 150 tons is the overall amount of German unclassified patents. However, it is safe to say that it is well over 50%. In regard to secret German patents, the only evidence uncovered to date is the German secret patent registry book which merely gives the name of the patent and title of the patent. This document is being microfilmed and will be ready for examination shortly. While McLendon has learned that the original secret patent files were destroyed it is still hoped that a duplicate set will be found and an extensive search is going ahead with that in mind.

3. It is requested that this office be advised as to what information about patents was obtained from the captured TA documents and any comments you might have to this matter.

For the Military Attache:

H. K. CALVERT,
Major, FA,
Assistant to the Military Attache.

Incl.
cy of clipping.

2nd Ind.

Major Amos E. Britt, P. O. Box 2610, Washington, D. C. 1 September 1945.
To: Major H. K. Calvert, The Military Attache, American Embassy, London, England.

No further information is available or has been obtained from the captured TA documents regarding the German patents. Should such information be obtained it will be cabled immediately.

AMOS E. BRITT,
Major, Corps of Engineers.

GERMAN PATENT OFFICE AND 200 OF STAFF SEIZED

By the Associated Press.

BERLIN, July 19. — American authorities have seized the 700-room German patent office in Berlin and found "almost all" the patent records intact in a deep sub-basement, it was announced today.

Two hundred German officials still were on duty when the American officers, led by Col. Ernest McLendon of Baltimore, arrived.

EVENING STAR, Washington, D. C.

DECLASSIFIED
Authority NND 917017

NARA RG 77, Entry UD-22A, Box 169, Folder 32.21 Germ. Res. Gen.

AMERICAN EMBASSY
OFFICE OF THE MILITARY ATTACHE
1, GROSVENOR SQUARE, W. 1.
LONDON, ENGLAND

30 October 1945

Subject: German Patents.

To: Major A. E. Britt, Room 5004, New War Dept. Bldg., Washington, D. C.

1. Reference is made to our letter of 28 September 1945 of same subject. A follow-up investigation of this subject by Lt. Warner in Berlin was made on 25 October 1945. Lt. Warner visited the German Patent Office and interviewed Lt. Col. Kessenick, U. S. Officer in charge of patent processing; Col. Monroe, British Officer in charge; and a British Officer by the name of Addison, who is assisting Monroe. A Major Billings, formerly with the personnel procurement section of OCE War Department, now with the Legal Section of US Group Control Council, and a patent lawyer by profession, was also interviewed for corroborative information.

2. All of the above named officers were agreed that all secret classified German patents were destroyed by the Germans in a city called Herringen near Kassel, Germany. Lt. Col. Kessenick inspected the charred remains of these documents and stated that they were incapable of being restored to legibility. Over 180,000 unclassified patent applications are now being processed and catalogued. Of those thus far catalogued no indication has been found that patents of interest to General Groves' office are among them.

3. Lt. Warner was advised that the American and British authorities in Berlin have definite information that 40 truckloads of "patent material" were removed by the Russians prior to British-American entry into Berlin. The Russians are stated as having denied this, however.

4. Lt. Col. Kessenick ventured the opinion that the processing of the German patent documents would require several years.

For the Military Attache:

HK Calvert
H. K. CALVERT,
Lt. Col, CE,
Assistant to the Military Attache.

SECRET

15 November 1945

Subject: German Patents.

Memorandum to General Groves:

1. Lt. Warner of our London office visited the German Patent Office in Berlin on 25 October 1945 and interviewed Lt. Col. Kessenick, U. S. officer in charge; Col. Monroe, British Officer in charge; and a British officer by the name of Addison who is assisting Monroe. A Major Billings, who is with the Legal Section of US Group Control Council, was also interviewed for corroborative information.

2. All of the above named officers agreed that all secret classified German patents were destroyed by the Germans in a city called Herringen near Kassel, Germany. Col. Kessenick inspected the charred remains of these documents and stated that they were incapable of being restored to legibility. Over 180,000 unclassified patent applications are now being processed and catalogued. Thus far no patents of interest to this office have been found.

3. Lt. Warner was advised that the American and British authorities in Berlin have definite information that 40 truckloads of "patent material" were removed by the Russians prior to British-American entry into Berlin. The Russians are stated as having denied this, however.

4. Col. Kessenick ventured the opinion that the processing of the German patent documents would require several years.

S
SHULER

DECLASSIFIED
Authority NND919019
By [illegible] NARA Date 1/25/[illegible]

SECRET

Figure 11.29: [NARA RG 77, Entry UD-22A, Box 169, Folder 32.21 Germ. Res. Gen.]

NARA RG 40, Entry UD-75, Box 12, Folder Technical Inquiries - H -

Technical Industrial
Intelligence Division
Room 6829

21 April 1947

Mr. R. P. Isaacs
Hammill & Gillespie, Incorporated
225 Broadway
New York 7, New York

Dear Mr. Isaacs:

Your inquiry of 2 April 1947 for technical information on the manufacture of pumice bricks and pumice slabs by the Binstein Company in Germany has recently been referred to my attention.

Among the technical reports on file in this office we have been unable to find any references to the subjects of your inquiry. However, I have referred a copy of your letter to FIAT (Field Information Agency Technical), our agency at Karlsruhe, Germany, for further investigation. Any information on these subjects that can be located in the current files of FIAT or can be uncovered within the next few months in the course of our document research program in Germany, will be transmitted, through military channels, to this office for public release.

All technical reports and microfilmed documentary data thus acquired will be listed in our Bibliography of Scientific and Industrial Reports, which is described in the enclosed folder entitled, "Technical Facts for Industry". On the chance that you are not a subscriber to this Bibliography, I will be glad to keep you informed of our efforts to obtain the information that you have requested.

You will probably be interested in knowing that single copies of almost all German patents issued during the war years up to V-E Day are on numerical file in the Patent Office Library in the Commerce Building. These files of German patents were seized at the Berlin Patent Office and evacuated to the United States in the spring of 1946. The German Patent No. 750986 is the latest one available. Photostatic copies of these patents may be ordered at 20 cents per page from the U.S. Patent Office, Washington 25, D.C. Orders for copies should be accompanied by check or money order, made payable to the Treasurer of the United States. For further

Figure 11.30: After the war, more than 750,000 patents from German-speaking inventors were transferred to the United States [NARA RG 40, Entry UD-75, Box 12, Folder Technical Inquiries - H -, Technical Industrial Intelligence Division to R. P. Isaacs, 21 April 1947].

NARA RG 40, Entry UD-75, Box 12, Folder Technical Inquiries - H -

2-Mr. R. P. Isaacs-21 April 1947

information about the German patents that are available, I would suggest that you communicate with Mr. E. W. Chapin, Librarian, U.S. Patent Office, Room 1888, Commerce Building, Washington 25, D.C.

The complete file of German patents is open to public examination at any time during office hours. Since the files are arranged numerically, to facilitate reproduction of individual copies ordered, it would be quite difficult to conduct a direct search for all patents on a specific subject. However, each issue of the Bibliography of Scientific and Industrial Reports contains a list of several hundred of these patents grouped by subjects. In this list patent numbers, titles, dates of issuance, inventors, and assignees are indicated.

The weekly issues of this Bibliography also contain a listing of several hundred German patent applications to which O.T.S. report numbers have been assigned. These patent applications are also grouped by subjects. Report numbers, patent application numbers, titles, inventors, and brief descriptive abstracts are indicated in each case. These patent applications have been acquired in the course of our current document research program in Germany and transmitted through military channels to the United States for public release by this office. Copies are available in microfilm only.

If there are any German-owned United States patents on the subject of your inquiry, the Office of the Alien Property Custodian, Rm. 647, National Press Building, Washington 25, D.C., would be able to advise you about the existence of such patents and their availability for private use.

If you have any further questions about our technical intelligence program, I would be happy to answer them at your request.

Very truly yours,

Joseph T. Mayer
Technologist

Enclosure

cc: Thoertel, for FIAT ACTION

Figure 11.31: After the war, more than 750,000 patents from German-speaking inventors were transferred to the United States [NARA RG 40, Entry UD-75, Box 12, Folder Technical Inquiries - H -, Technical Industrial Intelligence Division to R. P. Isaacs, 21 April 1947].

A detailed 1946 news article provided a great deal of contemporary insight into how all of these German-language materials were used by the U.S. government and industry [Charles Walker 1946]:

> If you always thought of war secrets—as who hasn't?—as coming in sixes and sevens, as a few items of information readily handed on to the properly interested authorities, it may interest you to learn that the war secrets in this collection run into the thousands, that the mass of documents is mountainous, and that there was never before been anything quite comparable to it.
>
> The collection is today chiefly in three places: Wright Field (Ohio), the Library of Congress, and the Department of Commerce. Wright Field is working from a documents "mother lode" of fifteen hundred tons. In Washington, the Office of Technical Services (which has absorbed the Office of the Publication Board, the government agency originally set up to handle the collection) reports that tens of thousands of tons of material are involved. It is estimated that over a million separate items must be handled, and that they, very likely, contain practically all the scientific, industrial and military secrets of Nazi Germany.
>
> One Washington official has called it "the greatest single source of this type of material in the world, the first orderly exploitation of an entire country's brain-power." [...]
>
> The German Patent Office put some of its most secret patents down a sixteen-hundred-foot mine shaft at Heringen, then piled liquid oxygen, in cylinders, on top of them. When the American Joint Intelligence Objectives team found them, it was doubtful that they could be saved. They were legible, but in such bad shape that a trip to the surface would make them disintegrate. Photo equipment and a crew were therefore lowered into the shaft and a complete microfilm record made of the patents there. [...]
>
> For the war secrets, which conventionally used to be counted in scores, will run to three-quarters of a million separate documentary items (two-thirds of them on aeronautics) and will require several years and several hundreds of people to screen and prepare them for wide public use.
>
> Today translators and abstracters of the Office of Technical Services, successor to the OPB, are processing them at the rate of about a thousand a week. Indexing and cataloguing the part of the collection which will be permanently kept may require more than two millions cards; and at Wright Field the task is so complicated that electric punch-card machines are to be installed. A whole new glossary of German-English terms has had to be compiled—something like forty thousand words on new technical and scientific items.
>
> With so many documents, it has, of course, been impossible because of time and money limitations to reprint or reproduce more than a very few. To tell the public what is available, therefore, the OTS issues a bibliography weekly. This contains the newest war secrets information as released—with titles, prices of copies currently available or to be made up, and an abstract of contents.
>
> The original document, or the microfilm copy, is then generally sent to the Library of Congress, which is now the greatest depository. To make them more easily accessible to the public, the Library sends copies, when enough are available, to about 125 so-called "depository" libraries throughout the United States.

> And is the public doing anything with these one-time war secrets? It is—it is eating them up. As many as twenty thousand orders have been filled in a month, and the order rate is now a thousand items a day. Scientists and engineers declare that the information is "cutting years from the time we would devote to problems already scientifically investigated." And American business men...! A run through the Publication Board's letters file shows the following:
>
> The Bendix Company in South Bend, Indiana, writes for a German patent on the record player changer "with records stacked above the turntable." Pillsbury Mills wants to have what is available on German flour and bread production methods. Kendall Manufacturing Company ("Soapine") wants insect repellent compounds. Pioneer Hi-Bred Corn Company, Iowa, asks about "interrogation of research workers at the agricultural high school at Hohenheim." Pacific Mills requests I. G. Farbenindustrie's water-repellent, crease-resistant finish for spun rayon. The Polaroid Company would like something on "the status of exploitation of photography and optics in Germany." (There are, incidentally, ten to twenty thousand German patents yet to be screened.)
>
> The most insatiable customer is Amtorg, the Soviet Union's foreign trade organization. One of its representatives walked into the Publication Board office with the bibliography in hand and said, "I want copies of everything." The Russians sent one order in May for $5,594.00 worth—two thousand separate war secrets reports. In general, they buy every report issued. Americans, too, think there is extraordinarily good prospecting in the war secrets lode. Company executives practically park on the OTS's front doorstep, wanting to be first to get hold of a particular report on publication. Some information is so valuable that to get it a single day ahead of a competitor, may be worth thousands of dollars. But the OTS takes elaborate precautions to be sure that no report is ever available to anyone before general public release.
>
> After a certain American aircraft company had ordered a particular captured war document, it was queried as to whether the information therein had made it or saved it any money. The cost of the report had been a few dollars. The company answered: "Yes—at least a hundred thousand dollars."
>
> A research head of another business firm took notes for three hours in the OTS offices one day. "Thanks very much," he said, as he stood to go, "the notes from these documents are worth at least half a million dollars to my company."
>
> And after seeing the complete report on the German synthetic fiber industry, one American manufacturer remarked:
>
> *This report would be worth twenty million dollars to my company if it could have it exclusively.*
>
> Of course you, and anybody else, can now have it, and lots of other once secret information, for a few dollars. All the war secrets, as released, are completely in the public domain.

Konrad Adenauer, the first post-war Chancellor of West Germany, summarized the extent of the continuing damage to Germany in his memoirs [Adenauer 1966, pp. 147–148]:

> Let me mention the question of German patents in this context. You know that all German patents were released. At the end of 1948 the director of the American Office for Technical Services, Mr. John Green, gave the press a report on his activities, which were concerned with the exploitation of German patents and industrial secrets. What strikes one in this report is the fact that AMTORG was the keenest purchaser. That is Moscow's foreign trade organization. During one month alone the Russians bought more than two thousand Wehrmacht reports on secret German weapons for which they paid six thousand dollars. According to a statement made by an American expert the patents formerly belonging to IG Farben have given the American chemical industry a lead of at least ten years. The damage thus caused to the German economy is huge and cannot be assessed in figures. It is extraordinarily regrettable that the new German inventions cannot be protected either, because Germany is not a member of the Patent Union. Britain has declared that it will respect German inventions regardless of what the peace treaty may say. But America has refused to issue such a declaration. German inventors are therefore not in a position to exploit their own inventions. This puts a considerable brake on German economic development.

Figure 11.32 presents a photo of German and U.S. scientists sorting and translating "tons" of captured German and Austrian technical documents at Wright Field, Ohio, in 1946.

Figures 11.33–11.34 show further examples of rows and rows of bookcases filled with boxes of reports taken from and written about German and Austrian science and engineering programs, collected after World War II and stored at the U.K. Imperial War Museum in Duxford.

One key conduit for the transfer of published and unpublished scientific information out of the German-speaking world was Ján Ludvík Hoch (1923–1991), who was born in Czechoslovakia, moved to the U.K. during the war, and changed his name to Robert Maxwell, by which he ultimately became famous. Because Hoch/Maxwell was fluent in many languages, young, intelligent, and personally extremely ambitious, he found strong support in the British military and intelligence communities during and after the war. Biographer John Preston summarized his role in transferring scientific information [Preston 2021, pp. 20, 22, 25–27]:

> Maxwell's first job in Germany was at the Intelligence Corps headquarters at Iserlohn, 250 miles from Berlin. Along with the other British officers working there, he was given a pseudonym to protect his identity. For the next six months, he became 'Captain Stone', part of a team interrogating German prisoners and others who had worked for the Nazi regime. [...]
>
> Berlin had now been divided into four zones: the French, the British, the Russian and the American. Fluent in Russian, English, and French [as well as his native Czech and German], Maxwell could easily pass from zone to zone without attracting attention. As he'd proved before, he also had a natural bent for subterfuge. All this made him a highly prized asset as far as British Intelligence was concerned. [...]
>
> 'One of my secret jobs was to find out what the Russians were up to, stripping East German industries,' Maxwell told Goodman. [...]
>
> Maxwell also went on a number of undercover trips to Czechoslovakia, then teetering on the brink of a communist takeover—it would become part of the Eastern Bloc in February 1948. According to documents in the Secret Service archive in Prague, Maxwell's

> presence in the country soon attracted the suspicions of the Czech Ministry of the Interior[....]
>
> Springer-Verlag had published books by most of the world's leading scientists, including Albert Einstein and Max Born, the father of quantum mechanics. They also published a large range of scientific journals. The beauty of the business was that the books and journals they produced had a captive readership: every library, every university, every scientific institute, wanted a copy. What's more, the scientists who wrote these books and journals were so thrilled to see their work in print that they scarcely expected to be paid anything in return. [...]
>
> No new academic research had been published during the war, and as a result, Springer had a colossal backlog of material. Sixty-three thousand books, along with tens of thousands of journals, had been removed from Berlin and stored in an enormous warehouse a hundred miles away to escape the Allied bombing. There was also a huge amount of scientific research conducted during the war that had never even been printed due to lack of paper.
>
> [...A]t the time German nationals were forbidden from making large shipments to other countries. Springer was convinced the demand was there. All over the world academics were dying to read about the latest research[....]
>
> In November 1947, 369 'large packets' were sent from Germany to London. By then, Maxwell had been demobbed from the army and had gone back to England to be with Betty and their baby son. He had also secured worldwide distribution rights to all of Springer-Verlag's publications. Four months later, 150 tons of books and another 150 tons of journals were loaded on to a goods train and taken to Bielefeld in western Germany. From there, a convoy of trucks brought them to London. These were followed by another enormous consignment of manuscripts—so large that seven railway carriages were needed to transport it[....]
>
> Where did Maxwell get the money from to set up in business? Certainly not from Ferdinand Springer, who was in no position to fund anything at the time. [...]
>
> Shortly before his death in 2000, Desmond Bristow, a former Intelligence Officer, spoke about MI6's relations with Maxwell: 'It was obvious that Maxwell had been doing odd things for MI6 in Germany, and he suggested we should subsidize him to buy a book business. He effectively became our agent. [...] I was certainly not aware of any other case of MI6 buying a business for anyone.'

After being placed in charge of a (mostly captured German) scientific publishing empire by the intelligence community, Hoch/Maxwell went on to enrich himself by wining and dining influential scientists to persuade them to publish more and more papers and to create more and more scientific journals [Buranyi 2017; Francis 2020; Sarkowski 2001]. Thus Hoch/Maxwell was a highly influential force in corrupting the scientific community from its historical emphasis on publishing quality over quantity to its modern obsession with endless quantity (and exorbitant journal and book prices) while abandoning most concerns about quality, originality, or even correctness (pp. 50–51, 2257–2262, 2274–2275). Although the details are murky, Hoch/Maxwell seems to have had other unsavory effects on society, a tradition that was apparently continued by part of his family and by his younger associate Jeffrey Epstein [p. 2263 and Preston 2021].

Tons of German documents referring to aeronautics are studied by technicians. Two men at left are German, two at right are American.

Figure 11.32: German and U.S. scientists sorting and translating "tons" of captured German and Austrian technical documents at Wright Field, Ohio, in 1946 [*Dayton Daily News*, 8 December 1946, p. 55]. See also p. 5323.

Figure 11.33: Bookcase aisles filled with boxes of reports taken from and written about German and Austrian science and engineering programs, collected after World War II and stored at the U.K. Imperial War Museum (Duxford).

Figure 11.34: Bookcase aisles filled with boxes of reports taken from and written about German and Austrian science and engineering programs, collected after World War II and stored at the U.K. Imperial War Museum (Duxford).

For historians, even worse than the Allied *removal* of German-language documents was the intentional and systematic Allied *destruction* of German-language documents. As shown in Figs. 11.35–11.36, postwar Allied reports explicitly discussed "the denial of certain archives, records, and papers to the Germans" by "the organized destruction of papers... which must not be permitted to fall into German hands after the departure of occupation forces" [NARA RG 40, Entry UD-75, Box 62, Report German Documents Conference].

Unfortunately, those plans for the wholesale destruction of historical documents were not only discussed but actually carried out. Michael Howard was an intelligence officer in the British T-Force, which investigated and removed vast amounts of German technology, including German documents. In two different sections of his memoir, he described the large-scale destruction of documents in the years and decades after the war, in order to forever bury the actual historical events [Howard 2010, pp. 253, 334]:

> From about 1948 the Control Commission for Germany began to destroy their files and documents, and this continued until 1956 when the remaining 240 tons were brought back to the UK. Then the Foreign Office set about them, employing mostly retired officials who had been given a brief, the details of which were never disclosed, but which did not leave much to chance. Today, less than two tons of those documents remain. It was a deliberate attempt to make the task of writing a complete history of a unit whose very name was not to be voiced in the public domain very difficult. Great care has been taken to prevent a cataloguing of what we took out, and above all to avoid setting a monetary value upon it. [...]
>
> The records and documents of the Control Commission for Germany [CCG], including those of T-Force, came ultimately under the aegis of the Foreign & Commonwealth Office, and in 1983 I corresponded with Ellie Blaney, head of the FCO Library and Records. From her I learned that a large quantity of CCG files, including those of T-Force, were destroyed in Germany between 1948 and 1956. The remainder, some 240 tons, were brought to the UK where the destruction continued unabated to the point where by 1986 less than two tons remained. Much of this material remained secret, even after forty years, and some remains so even today (in particular, I suspect, any that quantify the monetary value of the depredations of T-Force). It is still a sensitive and controversial subject.

What quantities of German documents were destroyed by the Allies?

What information did those documents contain that prompted the Allies to destroy them?

Were any copies or microfilms of those documents retained in any countries?

CONFIDENTIAL

HEADQUARTERS
U.S. FORCES, EUROPEAN THEATER
Office of the A.C. of S., G-2

OPENING STATEMENT OF THE CHAIRMAN

Mission of the Document Conference.

The mission of the Document Conference is the recommendation and formulation of the most effective standard operating procedures for the handling of documents, archives, and records captured and seized in the occupation zones under control of United States Forces, European Theater and United States Forces, Austria. The conference is also to deal with proposals to be formulated for quadrupartite consideration on the destruction of documents, archives, and records which are of no value to the Allies, and which must be denied to the Germans.

Details of Conference.

The Document Conference is being conducted by the Documents Control Section, United States Forces, European Theater, at the direction of the A.C. of S., G-2, Headquarters, United States Forces, European Theater.

Date: 22 October 1945

Place: G-2 Conference Room, Headquarters, United States Forces, European Theater.

Represented:

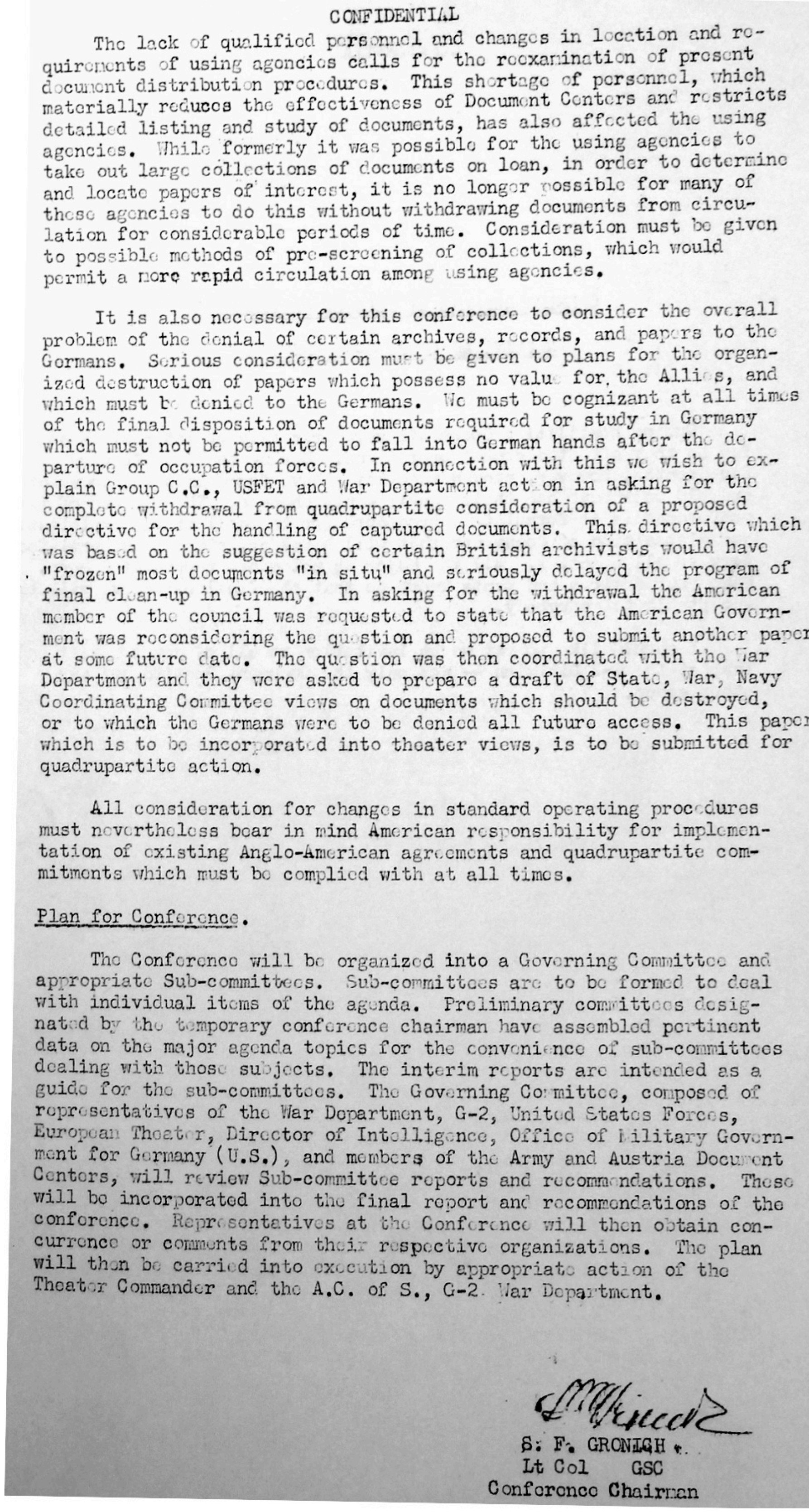
War Department General Staff
Berlin District
United States Forces, European Theater
London Military Document Center
Office of Military Government for Germany (U.S.)
  Director of Intelligence
Third U.S. Army (Eastern Military District)
Seventh U.S. Army (Western Military District)
United States Forces, Austria
Field Information Agency, Technical
United States Air Forces in Europe
Bremen Sub-District
United States Naval Forces, Europe
United States Naval Forces, Germany

Observers:

A.C. of S., G-3, U.S. Forces, European Theater
Office of Military Government (U.S. Zone)
  Monuments and Fine Arts
Military Attache, U.S. Embassy, London
Judge Advocate General, War Crimes Commission
Office of Chief of Counsel (US) for Prosecution of
  Axis Criminality
Library of Congress Mission, Europe
Theater Service Forces, European Theater, G-2
Office of Military Government for Germany (US)
  Reparation, Delivery and Restitution
Central Tracing Bureau and Records Office, UNRRA

NARA RG 40, Entry UD-75, Box 62, Report German Documents Conference p. 3

Figure 11.35: Postwar Allied reports explicitly discussed “the denial of certain archives, records, and papers to the Germans” by “the organized destruction of papers... which must not be permitted to fall into German hands after the departure of occupation forces” [NARA RG 40, Entry UD-75, Box 62, Report German Documents Conference].



CONFIDENTIAL

The lack of qualified personnel and changes in location and requirements of using agencies calls for the reexamination of present document distribution procedures. This shortage of personnel, which materially reduces the effectiveness of Document Centers and restricts detailed listing and study of documents, has also affected the using agencies. While formerly it was possible for the using agencies to take out large collections of documents on loan, in order to determine and locate papers of interest, it is no longer possible for many of these agencies to do this without withdrawing documents from circulation for considerable periods of time. Consideration must be given to possible methods of pre-screening of collections, which would permit a more rapid circulation among using agencies.

It is also necessary for this conference to consider the overall problem of the denial of certain archives, records, and papers to the Germans. Serious consideration must be given to plans for the organized destruction of papers which possess no value for the Allies, and which must be denied to the Germans. We must be cognizant at all times of the final disposition of documents required for study in Germany which must not be permitted to fall into German hands after the departure of occupation forces. In connection with this we wish to explain Group C.C., USFET and War Department action in asking for the complete withdrawal from quadrupartite consideration of a proposed directive for the handling of captured documents. This directive which was based on the suggestion of certain British archivists would have "frozen" most documents "in situ" and seriously delayed the program of final clean-up in Germany. In asking for the withdrawal the American member of the council was requested to state that the American Government was reconsidering the question and proposed to submit another paper at some future date. The question was then coordinated with the War Department and they were asked to prepare a draft of State, War, Navy Coordinating Committee views on documents which should be destroyed, or to which the Germans were to be denied all future access. This paper, which is to be incorporated into theater views, is to be submitted for quadrupartite action.

All consideration for changes in standard operating procedures must nevertheless bear in mind American responsibility for implementation of existing Anglo-American agreements and quadrupartite commitments which must be complied with at all times.

Plan for Conference.

The Conference will be organized into a Governing Committee and appropriate Sub-committees. Sub-committees are to be formed to deal with individual items of the agenda. Preliminary committees designated by the temporary conference chairman have assembled pertinent data on the major agenda topics for the convenience of sub-committees dealing with those subjects. The interim reports are intended as a guide for the sub-committees. The Governing Committee, composed of representatives of the War Department, G-2, United States Forces, European Theater, Director of Intelligence, Office of Military Government for Germany (U.S.), and members of the Army and Austria Document Centers, will review Sub-committee reports and recommendations. These will be incorporated into the final report and recommendations of the conference. Representatives at the Conference will then obtain concurrence or comments from their respective organizations. The plan will then be carried into execution by appropriate action of the Theater Commander and the A.C. of S., G-2 War Department.

S. F. GRONICH
Lt Col GSC
Conference Chairman

NARA RG 40, Entry UD-75, Box 62, Report German Documents Conference p. 5

Figure 11.36: Postwar Allied reports explicitly discussed "the denial of certain archives, records, and papers to the Germans" by "the organized destruction of papers... which must not be permitted to fall into German hands after the departure of occupation forces" [NARA RG 40, Entry UD-75, Box 62, Report German Documents Conference].

Postwar transferred English-language documentation

Beginning even before the war ended and continuing for several years afterward, the United States and United Kingdom sent many thousands of government, university, and industrial investigators into areas formerly controlled by the Third Reich to interview German-speaking scientists and engineers. Under threat of imprisonment—for example at facilities such as "Dustbin" in Germany (p. 2138), "Halstead Exploitation Centre" in the United Kingdom (pp. 2139–2141), or Fort Hunt in the United States (pp. 2057, 4929)—or execution for war crimes, the scientists and engineers were "interrogated" (as the Allies openly called it) for anywhere from days to months at a time, or even repeatedly by different investigators for years after the war, and required to give the Allied investigators detailed explanations, documentation, and hardware for all of their work. In many cases, as described afterward by German-speaking scientists, Allied investigators did not even properly identify themselves, and simply seized all copies of a scientist's work, leaving no trace of where those copies ultimately went.

This policy applied to all research and development activities, not just those with military histories or potential. Allied investigators inspected and wrote detailed reports on the manufacture of items as diverse and as non-military as German:

- Planetarium projectors [BIOS 218].
- Harmonicas [BIOS 227].
- Ice skates [BIOS 506].
- Mattress springs [BIOS 601].
- Fishing rods [BIOS 1086].
- Spoons and forks [BIOS 1647].
- Sewing thread [FIAT 308–312].

Reports such as BIOS 769 (*German Manufacture of Sewing Machines, Garment Making Machines, Cloth Cutting Machines, Sewing Machine Needles*) gave detailed lists of documents and machines to be "evacuated" from Germany and Austria to the United States and United Kingdom for "research" purposes.

In fact, Allied investigators combed not only former Axis countries and territory for innovations they could harvest, but Switzerland as well, even though Switzerland had remained neutral and independent in the war. Numerous reports documented such investigations in Switzerland [e.g., BIOS 1417; CIOS XXXI-22; FIAT 306; FIAT 509]. According to the U.S. State Department's own documents, in 1946 the United States tried to forcibly conscript Jakob Ackeret (1898–1981), even though he was a Swiss citizen, had been born in Zurich, and was a well-known professor of aerodynamics who had been teaching at the university in Zurich since 1931 (pp. 5465–5466). Based on the number of published Allied reports openly documenting their own lack of regard for Swiss sovereignty and intellectual property, it seems unlikely that Ackeret's case was unique.

Even German doll makers and the stuffed toy manufacturer Steiff were exhaustively mined for any design or production secrets that could help U.S. and U.K. toy manufacturers out-compete them in the postwar market [Gimbel 1990a, pp. 165–166; BIOS 1371; BIOS 1622].

That brazen exploitation continued for many years after the war. Mattel's iconic Barbie doll (1959) was directly copied from the earlier German Bild Lilli doll created by Reinhard Beuthien (German, 1911–1970) and Max Weissbrodt (German, 19??–19??). Ruth Handler, the American who claimed to have "invented" Barbie, made millions of dollars, while the true inventors Beuthien and Weissbrodt were largely forgotten [Warnecke 1995]. Toward the end of her life, in 1997, Handler gave an interview in which she confessed that she had simply copied the Lilli doll [BBC 2023]:

> Ruth Handler and her husband Elliot founded the toy company Mattel in a garage workshop in Southern California in 1945; she came up with the idea for the Barbie doll, which was launched in 1959. [...]
>
> Handler had an epiphany, however, when the family went on holiday to Switzerland.
>
> RH: We passed a toy store and there in the window was a beautiful display of an adult-figured doll about 11.5, 12 inches tall, and this doll was sitting on a rope swing dressed in a very European ski clothes, and there were six or seven other of the same dolls each with a different European type ski outfit, where Barbara and I thought the dolls were just gorgeous. We just flipped—the doll's name was Lilli.
>
> A German doll based on a comic strip published in a national newspaper, Lilli was marketed to both children and adults. Even though she was then 15 [in 1956], Barbara wanted one.
>
> RH: She couldn't make up her mind which one she wanted because each ski outfit was different. And so I said to the lady in the store, "Can I buy this style and buy that costume?" And the lady in the store looked at me as if I was nuts. Only a crazy American would ask such a silly question. She said: "No, you want that costume, you buy that doll; you want this costume, you buy this doll." By then my mind had clicked.

Kransberg Castle, or "Dustbin" for 1945–1946 interrogations

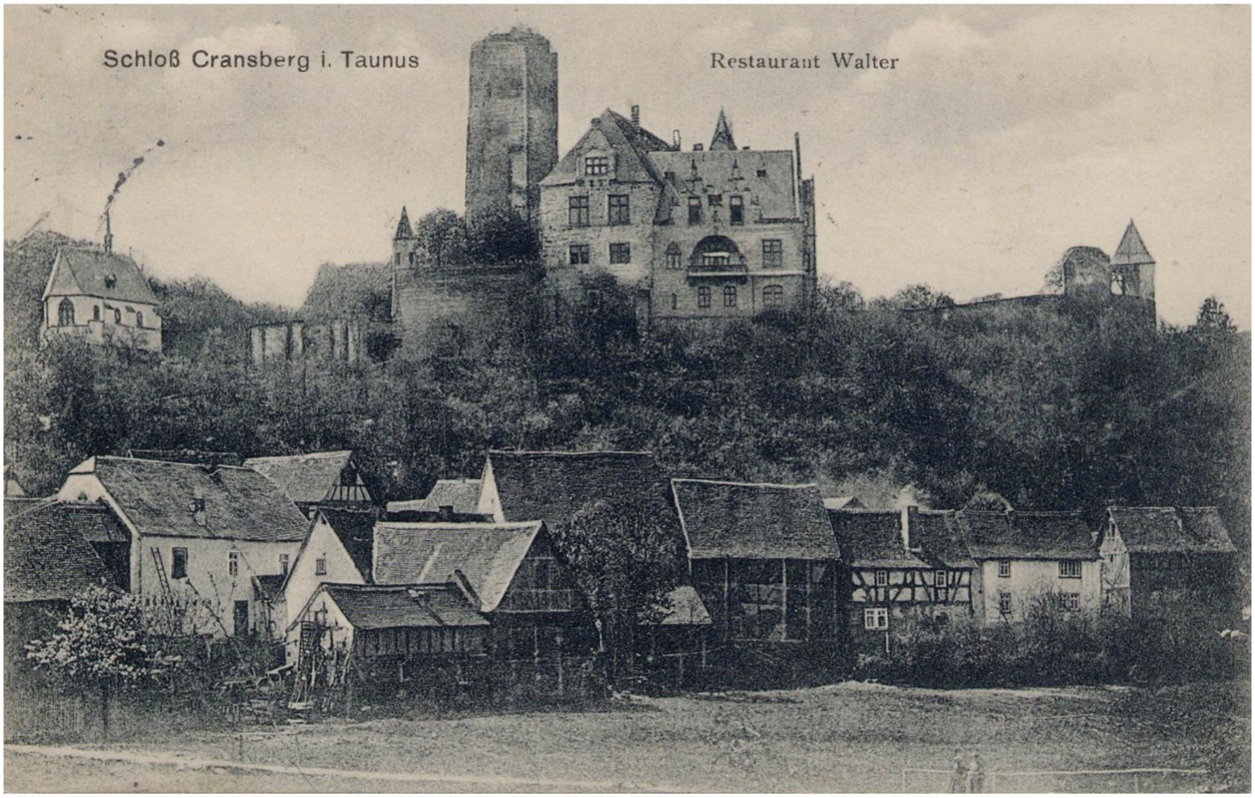


Figure 11.37: Kransberg Castle, used by U.S. and U.K. forces as the "Dustbin" detention center during 1945–1946 for imprisoning and interrogating scientists, engineers, and military officers with especially valuable scientific knowledge.

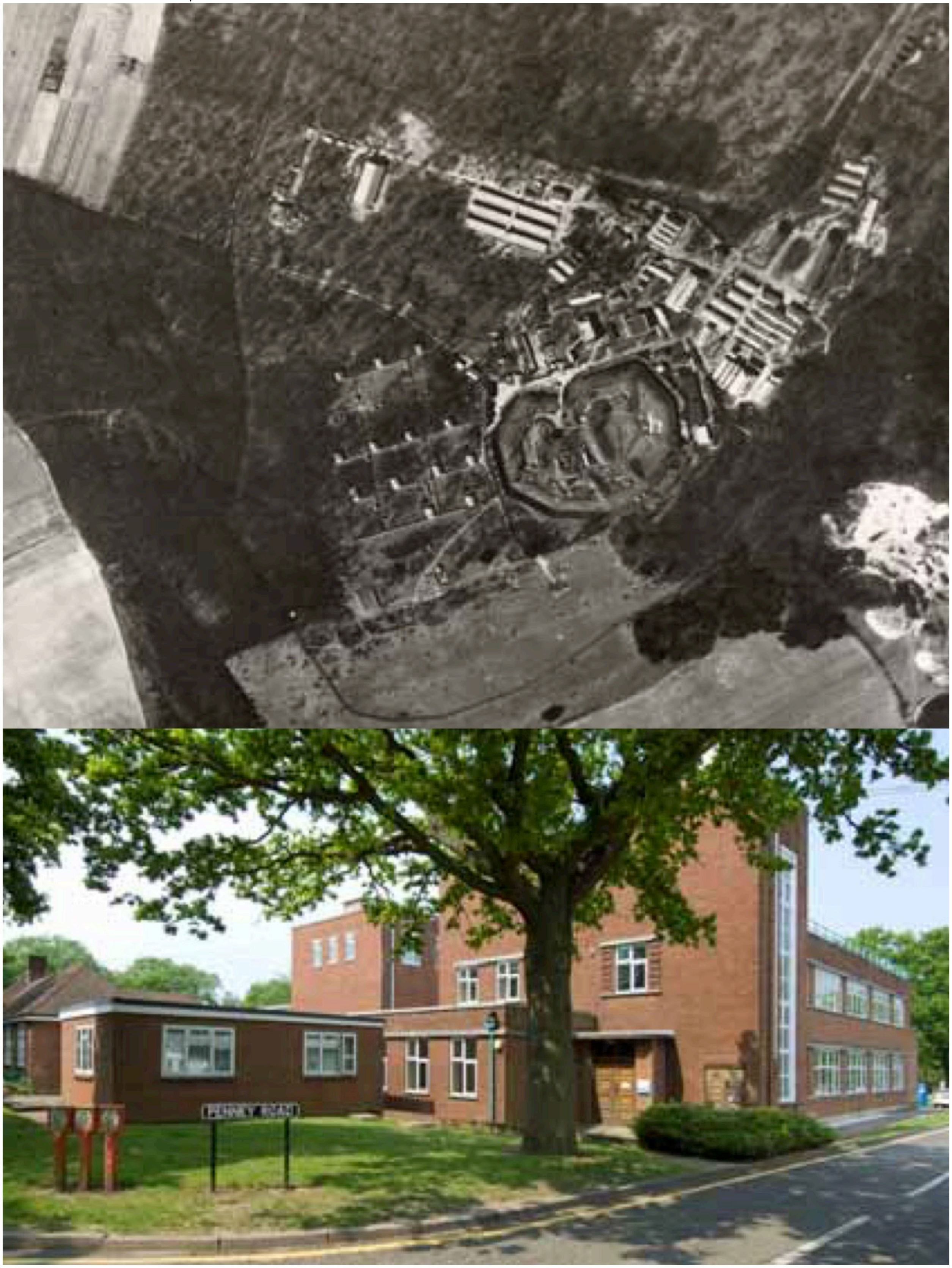


Figure 11.38: Fort Halstead in the United Kingdom, where (a) large numbers of German-speaking scientists were interrogated during and after the war (the "Halstead Exploitation Centre"), (b) thousands of captured German-language reports were translated to English (HEC series reports), and (c) the first British nuclear weapons were developed after the war (likely not a coincidence) [Cocroft 2010]. See also pp. 4204–4207 and 5056.

Figure 11.39: Fort Halstead in the United Kingdom, where (a) large numbers of German-speaking scientists were interrogated during and after the war (the "Halstead Exploitation Centre"), (b) thousands of captured German-language reports were translated to English (HEC series reports), and (c) the first British nuclear weapons were developed after the war (likely not a coincidence). See also pp. 4204–4207 and 5056.

Figure 11.40: Fort Halstead in the United Kingdom, where (a) large numbers of German-speaking scientists were interrogated during and after the war (the "Halstead Exploitation Centre"), (b) thousands of captured German-language reports were translated to English (HEC series reports), and (c) the first British nuclear weapons were developed after the war (likely not a coincidence) [Cocroft 2010]. See also pp. 4204–4207 and 5056.

The total number of U.S. and U.K. investigators is unclear from existing records, but may well have greatly exceeded the number of German-speaking scientists and engineers being interrogated.

Between 22 August 1944 and 13 July 1945, at least 2197 different U.S. and U.K. investigators visited at least 3377 separate scientific targets (places and/or people) in Europe on behalf of CIOS [AFHRA A5186 electronic version pp. 904–1026, Ch. 4, pp. 29–30]. Those numbers do not include investigators or locations visited during that time by organizations other than CIOS.

The number of U.S. investigators who visited between July 1945 and June 1946 is difficult to locate but must have numbered in the thousands. At least 4994 U.S. FIAT (Field Information Agency, Technical) investigators visited Germany during the 12-month period of 1 July 1946–30 June 1947 [Gimbel 1990a, p. 79]. Of course, that number does not include U.S. investigators from agencies other than FIAT, or investigators from other countries.

At least 1300 U.K. investigators visited Germany just during July–August 1945, and at least 2800 more between then and February 1946 [Glatt 1994, p. 163].

A 1947 *New York Times* article stated that at least 6000 U.S. industry experts had been sent to Germany in search of files, patents, and factories [NYT 1947-05-26 p. 35]:

> German Secrets Net U.S. $1,500,000: 400,000 Copies of Documents Already Sold to Industry—Russia Good Customer.
>
> The United States is collecting reparations from Germany at the rate of $6,000 a week from sale of Nazi wartime technical and scientific inventions.
>
> To date, sale of these hitherto secret inventions and scientific reports to American citizens and corporations has yielded the Commerce Department a gross revenue of $1,500,000, and the amount is still growing.
>
> This has been disclosed by John C. Green, director of the new Office of Technical Services, whose 600 employees have been collecting, classifying and microfilming German patents and documents since the end of the war.
>
> More than 400,000 copies of scientific documents, according to Mr. Green, already have been sold to American concerns at an average fee of $3 to $4 a document. He estimates new orders are coming in from American businessmen at the rate of 1,000 a day.
>
> Mr. Green says that, to his knowledge, this is the only Federal agency in Washington currently collecting reparations from Germany.
>
> Since the end of the war, the agency has processed 75,000 original technological reports and still has on hand 2,000 truckloads—with an estimated 400,000 unprocessed documents—which have been shipped here from Germany.
>
> Many of the processes and inventions are considered “priceless” by officials. Several large United States corporations are said to have been willing to pay as high as $20,000,000 for exclusive rights to a German process.
>
> The Government, however, has laid down the policy that seized scientific information is to be made available to all comers at nominal fees.

> Under this policy, it is estimated that the Russian Government has purchased $17,000 worth of documents totaling nearly 5,000 separate items. The Russian purchasing agency, Amtorg, has been ordering documents at a token price since last year, according to officials.
>
> Although Commerce Department officials at first were reluctant to sell the information to the Russian Government, the State Department laid down the policy that reports should be sold to Amtorg because the material is being made public and anyone could write in and get it.
>
> The German "brain-picking" project is the joint venture of business and Government. To help Commerce employees dig out the documents, United States industry sent 6,000 experts of its own to Germany in the search of I. G. Farben files, patents and factories. [...]

Many documents from this time testify to the large number of investigators who visited individual German and Austrian scientists. For example, BIOS 100, *Development of Panzerfaust*, pp. 1, 15 recorded the visitors (most of whom were apparently not even from known U.S. agencies) for two different scientists, Drs. Langweiler and Kittel (see also p. 564):

> Dr. LANGWEILER [the inventor of Panzerfaust] stated that he had been interviewed 16 times before. On each occasion some of his documents and equipment had been removed. He was finally left with only an incomplete set of drawings of PANZERFAUST 150. No record or report of any of these previous interviews can be found by the writers of this report. [...]
>
> Kittel stated that he had been interrogated in June by an American officer and an American technician. No record of this interrogation can be traced at FIAT, USFET, Third US Army, or Seventh US Army. It is recommended that the report on this previous interrogation should be obtained and circulated to the organisations concerned.

Similarly, BIOS 115, *Report on the Interrogation of Dr. Kurt Stenge*, p. 3, reported the treatment of Dr. Stenge prior to his latest (but probably not last) interrogation:

> Dr. STENGE had previously been kept for a month at Paris where he was submitted to several interrogations, mainly by American investigators, but including one by Commander STUDDERT (sie), R.N. Subsequent to this he lived near MAGDEBURG where he was visited by Commander WASHBURN, R.N., who was stated to have removed all his records.

As another example, the most recent Allied investigators to interrogate Robert Pohl, a solid state physics professor, were surprised that he was not immediately thrilled to see them after all of his previous Allied interrogators (BIOS 870, *Physics of the Solid State*, p. 4):

> Professor Pohl was inclined at first to be cold and formal, presumably because he had been investigated by rather a large number of people in British uniform, but he warmed up increasingly as he understood how much our interests had in common with his own, and from then on the visit was a great success.

Describing the investigators, the *New York Times* wrote [NYT 1947-02-23 pp. SM33–35]:

An American invasion of Germany which started even before V-E Day is now at the peak of operations, with its mission approximately half completed. It is made up of business men, scholars, researchers and technical experts, military and civilian, who have been ferreting out German secrets of science and industry, particularly Nazi wartime developments. [...]

The dollar value of these discoveries cannot be accurately estimated. Yet, an indication was given when an official of the I. G. Farben Company in Germany, handing over a chemical formula to a member of the Commerce Department's Office of Technical Service, which directs the operation, said: "We spent $500,000 in developing this process."

American action in taking these data from Germany gives a new meaning to the old adage that "To the victor belong the spoils," points out John C. Green, director of the OTS. "We are giving worldwide distribution to scientific knowledge; already nationals of twenty-eight countries have received our reports. And, in addition, we are blasting the German-controlled cartels." [...]

Today a startling number of products and processes which offer considerable promise have already been analyzed and are being publicized. Among these are the magnetophone, a sound-recording and reproducing machine using plastic tape (coated with iron oxide) instead of disks, and magnetism instead of needles; a "negative-positive" process for colored moving pictures which accomplishes in two steps what now requires nine; a superior photoelectric cell, used particularly in speaking along a beam of light; an ingenious "fixed paper" condenser; a butter-making machine, and improved processes in mass production of radar and radio chassis, in supersonics, and in acetylene and carbon monoxide chemistry. [...]

Several German cinema films made with the new color process have been exhibited in the Commerce Building in Washington, notably "The Girl of My Dreams" and "Golden City." The color has been described almost lyrically by reviewers. A report on this process is scheduled for release soon.

The "Gudden" photoelectric cell—twenty to fifty times more sensitive than any developed in the United States—was used by the Nazis in the war through the "photophone." With this outfit persons several miles apart, and in situations where telephone wires cannot be strung, can converse over a beam of visible light or invisible infra-red light.

The "fixed paper" condenser, developed by the Robert Bosch Company, is of interest to American makers of electrical and electronic systems, automobiles, radio sets and radar equipment. In it the usual metal foil is replaced by a very thin, vaporized zinc coating, applied directly onto paper separators. Its special features are that it is smaller, cheaper, "heals" automatically after breakdown and may be operated at from 20 to 50 per cent higher voltages than is possible with paper-and-foil capacitors. [...]

The German acetylene processes may turn out to be the most valuable of all, in the making of plastics, drugs, dyes and fuels.

These devices, with hundreds of others, are now finding their way into the hands of American manufacturers for close study.

These U.S. and U.K. investigators wrote over 8000 English-language reports, as shown in Table 11.7.

Report series	**Abbreviation**	**Number**
British Intelligence Objective Subcommittee final reports	BIOS	≥1874
British Intelligence Objective Subcommittee miscellaneous reports	BIOS Misc.	≥110
British Intelligence Objective Subcommittee overall reports	BIOS Overall	≥50
British Intelligence Objective Subcommittee evaluation reports	BIOS ER	≥576
Combined Intelligence Objectives Subcommittee final reports	CIOS	≥1131
Combined Intelligence Objectives Subcommittee evaluation reports	CIOS ER	≥390
Field Information Agency, Technical final reports	FIAT	≥1388
FIAT Review of German Science 1939–1946	*FIAT Review*	84
Joint Intelligence Objectives Agency final reports	JIOA	≥80
Naval Technical Mission in Europe letter reports	NavTecMisEu LR	≥239
Naval Technical Mission in Europe final reports	NavTecMisEu	≥557
Technical Oil Mission reports	TOM	???
Interrogation, interim, and unpublished reports for above agencies		>2000
Total		>8479

Table 11.7: Some major series of English-language reports on German creations.

The U.S. and U.K. governments made almost all of those reports available to anyone (even the Soviet Union) simply for the printing costs of each report copy [Gimbel 1990a, pp. 96, 101]:

> The subjects of the reports offered for sale by the OTS touched virtually every aspect of German industry and technology: acetylene chemistry, synthetic fuels and rubber, synthetic lubricating oils, synthetic fibers and textile manufacturing, ceramics, diesel motors, optics and glass, wind tunnels, heavy presses, infrared, tape recorders and metalized plastic tapes, cold extrusion of steel, electron microscopes, electric condensers, a butter-making machine, fruit juices, a machine to wrap chocolates, a process to preserve soybean oil, white carbon black, cellulose products and wood sugars, dental supplies, synthetic mica flakes, synthetic sapphires for watch, clock, and instrument bearings, color film and color-film processing, quartz clocks, pharmaceuticals, insecticides, synthetic blood plasma, artificial leather, plastics, colors and dyes, soaps and detergents, woodworking machinery, slide fasteners, sewing needles, cheese-making equipment, potentiometers and other precise measuring instruments, milk cans, manure spreaders, motorcycles, and cameras and photographic equipment, among other things.

> Neither the investigators who wrote the Publication Board reports nor the firms that bought them from OTS were obligated to report back on how the reports were used or on the benefits derived from them. Some of them did, however, thus providing a few insights into what remains essentially a closed book.
>
> [...] In May 1947, Robert Reiss, of OTS, listed—albeit without giving details—the names of seven companies known to be using the German acetylene chemical processes, three companies using German circuit-breaker technology, two companies using synthetic mica developed in Germany, two companies using the Fischer-Tropsch synthetic fuels technology brought from Germany, and individual firms that were using information from Germany on radio condensers, tape recorders, phase-contrast microscopes, cold extrusion of steel, and synthetic fibers.

Even though U.S. companies spent a great deal of time and money sending investigators to interview German-speaking creators and procuring copies of English and German documentation on their work, and then soon thereafter produced new products bearing a remarkable resemblance to those German creations, U.S. companies were loath to publicly admit any direct transfer of technological knowledge [Gimbel 1990a, pp. 224 note 26]:

> It is indicative of how hard it is to come by information on American companies' use of German technology that after John C. Green presented some of Reiss's information in testimony before Congress, some firms denied vigorously that they had, in fact, used or benefitted from German technology. For example, Bruce K. Brown, of the Standard Oil Company, denied Green's assertion that Stanolind Oil and Gas Company of Kansas was using Fischer-Tropsch process techniques, arguing that the information was available before the war and that the basic principles were generally known. U.S. research laboratories and pilot plants, he said, had existed in the United States "since well before World War II." But this argument flies in the face of the verifiable fact that the U.S. Technical Oil Mission swarmed over Germany in 1945 and that the American Petroleum Institute and the Bureau of Mines sent several follow-up missions to Germany to gather information on the Fischer-Tropsch process—information that, as we have seen elsewhere in this study, American industry and the American government continued to try to expropriate as late as 1951. [...] Further, W. A. Steiger, the patent attorney for Westinghouse Electric Company, wrote to Congressman Karl Stefan—also in response to Green's testimony before Congress—that the OTS/FIAT operation had been useless to his company. "So far as our company is concerned, I have investigated the situation, and it is my personal opinion that this particular Government activity is of no value to us." [...] Green reacted by informing Steiger that OTS records showed that between 1945 and Feb. 1948, Westinghouse had purchased 388 copies of reports...

Postwar transferred unwritten knowledge

In addition to technical knowledge transferred via documentation written in German or English, a vast amount of knowledge was transferred in unwritten form.

One route for unwritten transfer was of course the knowledge and work of the more than 6000 German-speaking scientists and engineers who ultimately moved to the United States [Mick 2000, p. 316], the more than 9000 who worked for the Soviet Union either in the Soviet Union or in East Germany [Mick 2000, pp. 15–17; Naimark 1995, pp. 230–232], and the thousands of others who worked for the United Kingdom, France, and other countries.

However, a less well known yet still pervasive and highly influential form of unwritten knowledge transfer occurred as the many thousands of Allied investigators took information that they did not record in their reports [Gimbel 1990a, pp. 107–112]:

> These reports and other records of FIAT and OTS provide a basis for illustrating the nature of the scientific and technical know-how removed from Germany, but much of what the Americans gained and the Germans lost remained unreported.
>
> *Incomplete Reports.* Investigators, who were not required to discuss their reasons for wanting to visit specific targets if they thought doing so would reveal industrial or trade secrets of their own, often spent days and weeks at a given location in Germany without including more than a passing reference in their reports to what they did there. Sometimes they admitted quite frankly that they had been "exposed to all sorts of little interesting gadgets and tricks of the trade which are too numerous and detailed, it is believed, to cover in this report." Echoing those words, a FIAT summary report of 20 November 1946 talked about "the various bits of 'know-how', the gadgets and 'tricks of the trade' which investigators observe in passing through the plants, possibly making no particular mental note or record at the time" but which they can use "later when back on the job and facing a problem where the same application can be made." The OTS director, John C. Green, who praised his operation publicly as the source of "the only solid and permanent reparations we are going to get out of this war" and as the provider of "intellectual reparations, prizes of victory which can be shared by every American businessman," nevertheless noted that "in countless cases, a process, device, or tool observed by an investigator in Germany will be passed on to an American firm to increase efficiency and lower costs." Furthermore, in at least one instance he admitted privately that investigators and document screeners were "pocketing some information they obtained instead of including it in their reports or contributing it to microfilmed material."
>
> *Inadequate Reports.* [...] As a case in point Green mentioned the two FIAT reports by C. H. Reynolds, of the Sheffield Corporation, which were judged by the Publication Board to be so poorly done as to be unpublishable, even though Reynolds's own company considered his findings important enough to send him and one of his colleagues back to Germany for more detailed investigations. Meanwhile, the rest of the industry knew nothing of the details of what Reynolds had learned, although they knew about it in general. FIAT's response, though devoid of solutions, shows that Green's case in point was but the tip of the iceberg. [...]

> *No Reports.* In a letter of 11 April 1946 to the Office of Military Government for Germany (OMGUS), whose field-branch office in Stuttgart had complained that FIAT operations were little more than a conveyor belt for industrial espionage, Colonel Ralph M. Osborne, the U.S. chief of FIAT, wrote that even though investigators came from private firms, all of them were under government contracts requiring them to report their findings and prohibiting them from using their positions to secure special information for their own firms. [...]
>
> Without-compensation (WOC) investigators often did not cooperate. Some of them had obviously used FIAT "as a pretext to get into Germany" to conduct their own private affairs; those who had previous business connections in Germany were particularly hard to handle. Many investigators simply used target-assessment reports in the FIAT files as models for their own perfunctory final reports; some of them refused to write reports; and others who had initially refused to write reports wrote inadequate ones when they were pressured to do so.
>
> OTS's solution to the problem of incomplete, inadequate, and nonexistent reports was to open the floodgates and send as many people to Germany as it could, presumably so that as many as possible could get what they wanted for themselves. [...]
>
> In February 1947, John C. Green [...] published "Last Call for Germany." "The opportunity to enter any factory, see any documents, inspect any equipment and interrogate any expert cannot last indefinitely," he warned. "This is American industry's last chance to acquire, at small cost, a wealth of scientific and technical information." [...] Green observed that "victory opened the doors and the files of German factories and laboratories to American investigators." He concluded that "it will be a national tragedy... if we allow the doors to shut before we have added all of the best of Germany's technical knowledge to our own."

Describing this form of unwritten knowledge transfer, Bradley Dewey, president of the American Chemical Society, remarked [Gimbel 1990a, p. 227]:

> ...that most valuable material is not in reports but in the ideas which [the] investigator keeps in his own head.

Postwar influence on the structure of the U.S. research system

Many of the general approaches that had made the German-speaking world so effective at producing revolutionary creators and creations were at least temporarily adopted by the United States research system. As discussed in Section 11.2, those general approaches played a critical role in the successes of the U.S. R&D programs during the 1940s–1960s. Unfortunately, the abandonment of those approaches after that period seems to have greatly contributed to the steady decline in revolutionary innovation from the 1970s to the present, as described in Section 11.3.

Net impact

From archival documents and authoritative sources, it seems clear that:

- By the first several decades of the twentieth century, German-speaking scientists and engineers were generally many years ahead of others in biology and medicine, chemistry and materials science, earth and space science, applied mathematics and physics, electrical and electromagnetic engineering, mechanical engineering, nuclear science and engineering, and aerospace engineering. In many fields, they were over a decade ahead of everyone else, according to postwar Allied investigators.

- German-speaking creators and their creations played critical roles in advancing the scientific and technological levels of other countries in all of those fields to some extent before and during World War II (due to scientific refugees and published information) and to an enormous degree after the war.

- The transfer of German-speaking creators and creations to the United States, United Kingdom, France, Soviet Union, and other countries was equivalent to the transfer of a vast amount of wealth, including past financial investments in making the discoveries and inventions, then-current and future financial income from products based on the discoveries and inventions, and the sheer economic value of thousands of factories, countless amounts of equipment and materials, and thousands of trained specialists that were physically transferred. Allied countries publicly described that transfer as "reparations" and continued to benefit from it for decades after the end of World War II. Germany and Austria suffered the corresponding loss.

In June 1945, U.S. Assistant Secretary of State William L. Clayton testified before the U.S. Senate, openly describing the Allied plan for systematically removing scientific innovations from Germany and Austria [Clayton 1945, pp. 34–37]:

> I should like now to turn to certain questions related to German technological information and scientific research. If we are prepared to acknowledge that German research and scientific development have been important in the past, we must also be prepared to draw the obvious conclusion that the exclusive possession or control of certain kinds of advanced technology by German nationals involves a possible danger to our security and provides German nationals with important assets which in the past have induced other parties to join them in international cartel arrangements.
>
> Our intentions with respect to German research and scientific information may be summarized as follows:
>
> 1. We intend to secure the full disclosure of all existing German technology and invention for the benefit of the United Nations.
>
> 2. Through seizure by the Governments of the United Nations of German-owned patent rights on inventions developed before and during the war, we shall be able to withhold from German nationals the usual technological assets which have proved to be the main inducements for other parties to join the Germans in international cartel arrangements.

> 3. We intend to allow organized research and invention in Germany during the period of military occupation only when we are fully satisfied that such research will not contribute to Germany's future war potential.
>
> [...] Naturally, a considerable portion of the acquired enemy technology has been assigned secret status by the U.K.-U.S. military authorities, since it is in the interest of the two governments that certain classes of information should not be directly or indirectly disclosed to our remaining enemy.

In this testimony before the U.S. Senate, the State Department stated that most revolutionary scientific innovations had been coming exclusively from the German-speaking world. The State Department further admitted that the United States and other countries were not developing revolutionary innovations such as those, which put them at a great economic and military disadvantage.

The solution proposed by the United States was for Allied countries to seize all revolutionary innovations and information on them from the German-speaking world, deny the German-speaking world the right to use its own innovations or economic income from them, and prevent the German-speaking world from creating new revolutionary innovations. The officials did not propose that the United States and other countries should invest the careful thought, funding, labor, time, and effort necessary to create large numbers of new revolutionary innovations of their own; they only proposed to exploit the existing German innovations they seized. Their proposed solution also involved classifying and burying "a considerable portion" of the acquired technology.[8]

In September 1945, R. P. Linstead and T. J. Betts, the British and American chairs of the Combined Intelligence Objectives Subcommittee (CIOS), declared [Fig. 11.41, AFHRA A5186 electronic version pp. 904–1026, Foreword, p. 5]:

> The effective exploitation of German technical development has proven one of the significant results accruing from the conduct of the European War. The value of the scientific knowledge and "know how" thus obtained cannot now be fully measured. That this intelligence contributed to the defeat of Japan is well established. The benefits of this knowledge to British and US industry will be measured in terms of economic progress and well-being for many years to come.

These conclusions regarding the value of German technology that could be "exploited" as "reparations" by Allied countries were publicly stated by people from high-ranking government officials to journalists at that time. A good example from the press is Ian Bevin, Germany Disgorges Her Rich Secrets, *News Chronicle* (London) 21 February 1946 p. 2 (which made extensive use of the September 1945 Linstead and Betts report):

[8] As demonstrated by the relative dearth of truly new revolutionary innovations over the following decades, that is basically what indeed happened. The United States and other countries harvested and consumed the entire crop of revolutionary innovators and innovations that the German-speaking world had been cultivating for many decades, yet ultimately proved unwilling to properly cultivate a whole new crop of innovators and innovations of their own, or to allow the German-speaking world to properly cultivate a new crop of innovators and innovations. The whole system that had produced so many revolutionary innovators and innovations for over 150 years was deliberately sacrificed for short-term enrichment, resulting in the world of relative stagnation in which we have been living ever since (Sections 1.1 and 11.3). Moreover, apparently many details of the original German-speaking work still remain classified or otherwise buried, depriving historians, scientists, and the public of the knowledge of what truly happened before, during, and after World War II.

> Allied agents have unearthed information of inestimable industrial value. [...]
>
> Technical and scientific knowledge gleaned from conquered Germany has provided the first great reparations payment to the Allies. [...]
>
> Just how the Governments will dispose of German industrial secrets to competitive private enterprises is not yet clear, but, as the information gained from Germany is regarded as a form of reparations, it will presumably be used for national rather than private gain. [...]
>
> These [long list of examples] are only a few of the thousands of discoveries made by CIOS, ranging from major industrial secrets to minor points of manufacturing technique, and adding up to one of the richest war prizes any victor could hope for. All that remains is for the Allies to use the information they have gained, and not let it lie forgotten in the files of Government departments.

For other examples of contemporary press reports, see the *American Magazine* article on p. 2062, *Harper's Magazine* article on p. 2126, and *New York Times* articles on pp. 2142 and 2143.

In March 1946, U.S. Army Colonel Ernest Gruhn, the first director of the Joint Intelligence Objectives Agency, wrote an amazingly candid draft press release that described how dependent the United States was not only on the massive postwar influx of German-speaking creators and creations, but also on earlier German-speaking immigrant scientists as well [Figs. 11.42–11.46. Ernest Gruhn. 14 March 1946. Exploitation of Germany for Technological and Scientific Information. NARA RG 330, Entry A1-1A, Box 4, Folder 383.7 Policy–1946.]:

> After World War I there was no real attempt by the victors to exploit Germany for technical and scientific knowledge. However, long before World War II with Germany had ended, plans were made by the Joint Chiefs of Staff for the complete exploitation of Germany for technical information.
>
> In accordance with these plans, the government is now engaged in exploiting Germany for all the technical and scientific information that can be obtained. Exploitation has involved the sending of several hundred highly qualified American technicians and scientists into Germany close upon the heels of our conquering armies. These investigators have examined manufacturing plans and equipment, records and documents and have interrogated German personnel. The information of industrial value that has been collected is being made available to the public by the Department of Commerce.
>
> Steps are now being taken to extend this exploitation by bringing the best German scientists and technicians to this country so that their talents can be used here. [...]
>
> In the past, the United States has depended to a considerable extent upon German scientists for pure basic scientific research. Such research forms the basis of practical developments. [...]
>
> The exploitation of these highly trained Germans will be of great value to the development of new types of weapons which were being planned by the Germans as the war

> ended. It will also be in the national interest to use them to increase our production potential in many industrial fields. [...]
>
> Closely related to the exploitation of German scientists and technicians is the government program for exploitation of German developments in industrial machinery, tool, equipment and materials. Samples of these are being procured through reparations procedures for shipment to the United States where they are made available for study by American industry on a non-restrictive open-to-the-public basis.
>
> From the above, it is evident that the government is using vacuum cleaner methods to acquire all the technical and scientific information that the Germans have. The value of this information to the United States will probably far exceed any cash reparations.

The U.S. Joint Chiefs of Staff responded to Colonel Gruhn's proposed press release by immediately classifying and burying it; see Fig. 11.47.

In June 1946, U.S. Army Air Forces Major General Curtis LeMay did give a public assessment of the German-language materials transferred after the war [LeMay 1946]:

> At Wright Field, O[hio]., German scientists are now assisting American scientists in translating great masses of captured German scientific documents. These documents reveal, as the materiel at Freeman Field indicates, the extent to which German science had out-distanced American science in basic and applied scientific research and in aircraft development. It has been estimated that the Germans were 10 to 15 years ahead of us in fundamental research.

(For a closely related document, see p. 5323.)

This same estimate that German-speaking innovators were at least a decade ahead of the United States and other countries in a wide variety of fields was independently given by other sources (e.g., pp. 428, 2128). For example, the *New York Times* reported [NYT 1947-05-17 p. 2]:

> German Scientists' Help Said To Save Us 10 Years
>
> The importation of 350 German scientists has "already put the United States ten years ahead of schedule in some fields of research and has saved millions of dollars in research costs," American Army headquarters said today.
>
> The German scientists in the United States are employed on such studies as guided missiles, supersonic planes, jet engines, cancer, photography, meteorology, metallurgy, textiles and cereals—all under the supervision of the War Department.
>
> However, headquarters said, "the War Department will begin soon to release German scientists to American industry under the supervision of the Department of Commerce."

U.S. Army Air Forces Major Alexander de Seversky, who led a five-month study of German technologies at the end of the war, wrote [De Seversky 1952, p. 603]:

> At the end of World War II the Germans were at least a decade ahead of the world in the development of jet engines and supersonic aerodynamics. [...] After V-E Day our scientists and engineers had the opportunity to survey German technological progress. Having secured the necessary data, they came home satisfied that they would be able to start where the Germans left off.

In January 1947, L. B. Kilgore from the U.S. Technical Industrial Intelligence Division (TIID) of the Department of Commerce explicitly described how much German-derived knowledge had been transferred to the United States and how important it was for the country [Figs. 11.48–11.50. L. B. Kilgore. 10 January 1947. Proposal for a Compendium of German War Time Technology, Draft No. 2. NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss.]:

> The accumulation of the technical industrial information, which has resulted from the detailed investigations of the German industry for the past two years by this office, has reached such enormous proportions that it has become difficult to inform the public of the possible benefits available to it. This accumulation of information not only represents the greatest transfer of mass intelligence ever made from one country to another, but it also represents one of the most valuable acquisitions ever made by this country.

In December 1947, U.S. Air Force General Donald Putt explained that German and Austrian scientists were so far ahead of U.S. scientists in a wide range of fields that suitable American scientists could not be found for U.S. programs, that large numbers of German and Austrian scientists were now developing their creations for the U.S. military, and that the United States was making them work for substandard wages compared to what it paid other employees [Figs. 11.51–11.52. Donald Putt to Joseph McNarney. 10 December 1947. German Specialist Program at the Air Materiel Command, Tab F. AFHRA A2056 electronic p. 405–406.]:

> (a) With the exception of those eliminated by a continuous screening process during the one-year probationary period, all specialists now assigned to the various laboratories and activities of Air Materiel Command are outstanding in their respective scientific and engineering fields.
>
> The majority have specific talents and all were associated with German research and development during the war period.
>
> The majority were selected for their work in fields of aeronautical research, such as supersonics, jet and rocket engines, guided missiles, ceramics, jet and rocket fuels, etc., in which American technicians had little or no experience, due to emphasis being placed on other lines of development. Today, however, USAF development is concentrated on those fields in which the Germans had advanced beyond our own knowledge in those same fields.
>
> Millions of dollars were spent by the Germans in research in these fields. By utilization of the German specialists, the Air Force can start where German research left off, rather than spending many dollars of public funds repeating what has already been accomplished or determined to have been unsatisfactory. Not to take advantage of this possibility is short-sighted and unrealistic. [...]

> (e) The German specialists now on duty at Air Materiel Command have been and are now making significant contributions to the development of Air Force items of equipment and to technical and scientific literature. The specialists are an important cog in the Air Force research and development program. [...]
>
> (g) Salaries being paid to the German specialists are less than would be required for equivalent American technicians if they were available.

An official U.S. Air Force program history written in 1948 again stated that German scientists were many years ahead of their American counterparts [Fig. 11.56. Edna Jensen. 1948. *History of AAF Participation in Project Paperclip, May 1945–Mar 1947*, p. 44. AFHRA A2055 electronic p. 747]:

> Recommendations to the Commanding General, U.S. Strategic Air Forces in Europe (Lt. Gen. Carl Spaatz), from his Deputy (Maj. Gen. H. J. Knerr) included the comment, "Occupation of German scientific and industrial establishments has revealed the fact that we have been alarmingly backward in many fields of research. If we do not take this opportunity to seize the apparatus and the brains that developed it and put the combination back to work promptly, we will remain several years behind while we attempt to cover a field already exploited."

Another official U.S. Air Force history written in 1954 yet again confirmed that during and after World War II, German scientists were many years ahead of American scientists in a wide range of fields [Figs. 11.57–11.58. *History of the Air Research and Development Command.* 1954. Chapter IX. Dr. Charles A. Johnson. Project "Paperclip," pp. 258, 265. AFHRA K2838 (15390) electronic pp. 887, 894]:

> World War II had proven that Germany was many years ahead of the United States in a number of scientific and technical fields, notably in propulsion, jet and rocket engines, jet fuels, and guided missiles. While extensive know-how in these scientific areas was in the possession of many outstanding scientists and engineers living in Occupied Germany and the U.S. Zone of Austria, within the United States itself there was a particular shortage of knowledge.
>
> Colonel Donald L. Putt, leading the Air Force Intelligence teams that took over these German research laboratories and experimental stations, made this evaluation: "I visited a great many of them . . . . Their research progress in jet and rocket propulsion, aerodynamics, thermodynamics, supersonics, and other fields was clearly far ahead of anything of the kind we had done."

In 1949, the U.S. Army likewise admitted that German scientists were up to a decade ahead of the U.S. during the war and that in postwar U.S. programs, the German scientists were making enormous contributions in a wide variety of fields that were beyond the capabilities of U.S. scientists (pp. 4936–4938). Senator Harry Byrd reached the same conclusions (pp. 5574–5577).

No less an authority (and a very cautious and conservative one at that) than Dwight Eisenhower wrote in a secret 1945 cable to Washington D.C. that German scientists were even further ahead than that at the end of the war [Ordway and Sharpe 1979, p. 198; Mieczkowski 2013, p. 38]:

> Have in custody over 400 top research development personnel of Peenemünde. Developed V-2. [....] They are anxious to carry on research in whatever country will give them the opportunity, preferably US, second England, third, France. The thinking of the scientific directors of this group is 25 years ahead of US. [...] Immediate action is recommended to prevent loss of whole or part of this group to other interested agencies.

Of course, as illustrated by the evidence throughout this book, it was not only the abstract scientific thinking of the German experts that was years ahead of the United States, but also their test facilities, prototypes, experimental demonstrations, industrial mass production, and use of those new technologies.

The United States was not the only country to benefit from German-speaking creators and their creations. Historian Charlie Hall described the net impact of the technology transfer on the United Kingdom [Hall 2019a, pp. 229–231]:

> [...H]ow much did Britain benefit from the scientific and technological spoils of war? Unfortunately, it is almost impossible to give a definite answer to this question. [...] Some, including Michael Howard who served with T-Force after the war, suspect that the files containing official government valuations have either been destroyed or remain closed to the public. [...]
>
> Turning first to the material spoils, one of the most useful resources which emerged from the British exploitation programme was the collection of BIOS, CIOS, and FIAT Final Reports[...] As we have seen, a government publicity drive brought these reports to the attention of business owners throughout Britain who almost certainly implemented some of the techniques described to increase the efficiency or output of their enterprises—calculating the total value of these improvements would be utterly impossible, but we can be confident that they existed and were fairly widespread. Alongside these reports, BIOS and its related organisations were responsible for the removal of equipment and material too. Under reparations arrangements, Britain received just under 380,000 tons of dismantled German capital equipment[...] A much larger amount of material, most of which would have been far more useful, was taken outside of the official reparations channels and thus remains unaccounted for.
>
> Some material within these removals would have been more valuable than others. For example, under the auspices of Operation Surgeon, some 14,000 tons of aeronautical equipment was removed, including highly specialised wind tunnels and equipment for investigating high-velocity flight at stratospheric altitudes. Much of this went to furnish the new Royal Aircraft Establishment at Farnsborough and would, therefore, have played a direct role in British aeronautical developments moving forward. [...]
>
> It is also worth noting that, from the perspective of British industrial concerns, the greatest benefit of exploitation was not what they gained, but rather what the Germans lost. In short, the damage that exploitation and dismantling wrought to their German rivals allowed them to increase their export capacity at the expense of these German firms. [...]
>
> While the Allies were quick to assert that Germany had lost no more than her leadership in some industries and techniques, many Germans did not agree. [...] Indeed, many of

> these complaints were directed more at the Allied programme of industrial dismantling than at scientific and technological exploitation, though the two schemes ultimately fell under the same broad umbrella. In particular, just as dismantling threatened to severely damage German industry's productive capacity, exploitation was accused of being little more than a 'conveyor belt' for commercial espionage. Both tactics sought to give British business a competitive edge over their renascent German rivals.

As mentioned by Charlie Hall, Michael Howard was an intelligence officer in the British T-Force. In Howard's memoir, he described assisting with the removal of thousands of tons of technology from Germany on a daily or weekly basis, and he speculated on the monetary value of that transferred technology [Howard 2010, pp. 195, 204–205]:

> For ten days we had been victims of the latest false alarm: that everything had to be sent out by the end of the year [1946]. But after ten days of working pretty well night and day, I still had six and a half thousand tons of equipment valued at five million pounds to get out. [...] I never knew who had set that valuation upon the stuff to go, probably its depreciated cost, but it was nowhere near the valuation settled on it in 1948/9. [...]
>
> Coming under fire in some quarters for its very existence, T-Force had a vested interest in putting figures to the results of its work, an extraordinarily difficult and complex calculation. The figure that I mentioned, current by December 1946, might have covered evacuation up to, say, the end of October, but will have referred only to tangibles, i.e. machinery and equipment, upon which it was possible to hang some sort of price-tag, and which were seen as reparations. But what about the intangibles, the intellectual property? A figure produced in 1970 from German sources, for the value of appropriated patents alone, was of the order of £250 million in the coin of post currency-reform (June 1948). On top of these were to be added: 'sharp' battlefield weapons and the means of producing them; industrial processes and the documents and drawings which described them, over the whole field of industry; the knowledge obtained by British scientists and industrialists from their interrogation of their German counterparts and of academics; and access to the records and archives of all of these. I was not shocked or entirely surprised by the figure of £2,000 million quoted privately to me in 1949 by the last remnants of T-Force who had been tasked with making such a valuation (Rufus Harris and Wigg and a handful of others, by now with G Branch, Research Division of the CCG).

Even Howard's descriptions and estimates were only a fraction of the total technology transfer to the British. They did not include transfers that were carried out by organizations other than T-Force, such as the Royal Navy and specific British companies. Moreover, they did not include British exploitation of Austria, or of German technology that the British discovered in formerly German-controlled territory such as France and Norway. They also did not assign a monetary value to the more than 1,000 German-speaking scientists who worked for the United Kingdom after the war. With all of those factors in mind, the total technology transfer to the British was probably quite comparable to that to the United States.

The impacts of the technology transfer on the Soviet Union and France were presumably at least as large as those on the United States and United Kingdom.

John Gimbel quoted the best available estimates of the financial value of the technology transfer to the United States [Gimbel 1990a, p. 152]:

> ...It is perhaps fitting to refer briefly to the discussion of value contained in a manuscript on the history of FIAT, which may be found in the archives records of the OMGUS Historical Office. After commenting that the Russian figure of $10 billion announced by Molotov at the Moscow CFM was too high, the unnamed authors argued that only in time—after tests, trials, and applications—could a precise value be established. Nevertheless the authors "estimated that FIAT activities should save the government and industry in the United States at least five billion dollars." If we were to accept this as a fair global figure, and if we were to make the altogether reasonable assumption that the British received value roughly equal to that of the United States, it would follow that Molotov at the Moscow CFM was right on the button.

Donald Putt and Senator Harry Byrd gave a similar estimate of billions of dollars for the United States (pp. 5574–5577). Considering that these estimates were lower bounds and that the French and especially the staggering Soviet removals were not included, the total value of technologies transferred out of the German-speaking world after the war almost certainly exceeded 20 billion 1940s-era U.S. dollars.

There are at least four factors that were not considered in the above financial estimates, and that could increase the true total value of technologies that were transferred out of the German-speaking world potentially by orders of magnitude beyond the lower bound of 20 billion 1940s-era U.S. dollars:

1. Some of the most valuable technologies that were transferred were either secret or at least not widely known during and immediately after the war, and the historical facts that they were in fact transferred and not spontaneously invented in postwar Allied countries remain classified, buried, or ignored to this day. Examples include oral contraceptives and other advanced pharmaceuticals (p. 356), fuel-air explosives (p. 563), advanced materials (Section 3.8), stealth technology (p. 1243), biotechnology (Section A.1), biological weapons (Section A.3), chemical weapons up through advanced V-series nerve agents (Section A.4), transistors (Section B.1), printed circuits (Section B.2), integrated circuits (Section B.3), light emitting diodes (Section B.4), lasers (Section C.3) and other directed energy technologies (Appendix C), advanced fission bombs (Sections D.14 and D.15.5), hydrogen bombs (Sections D.9 and D.14), intercontinental jets (Section E.1), intercontinental rockets (Section E.2), space planes (Section E.3), submarine-launched and advanced solid propellant rockets (Section E.4), and many others. Because the details of their transfer were obscured, all of these advanced technologies were not included in the earlier financial estimates, yet they certainly should be.

2. The true value of the transfer must reflect what it would cost to fully nullify the transfer now. Obviously this situation is purely hypothetical, yet it is useful nonetheless for calculating the financial value in modern terms. If other countries were to fully repay Germany and Austria now for the cost of all the creators, creations, materials, and services that were transferred in the 1940s, they would need to repay not the original number of 1940s-era dollars (whatever that number may be), but rather the far larger number of modern dollars that would be equivalent, taking inflation into account. Moreover, if the transfer were considered a loan like any other financial transaction, countries would also owe Germany and Austria the interest on that transferred amount that had accumulated and compounded at fair-market rates from the 1940s to the current day.

3. The total value of the German-speaking creators and creations that were transferred must also take into account their true value to the countries that received them, from World War II through the present. The transferred creators and creations formed the basis of whole industries in biotechnology, pharmaceuticals, chemicals and materials, microelectronics and electronic devices, energy, aerospace, and other areas. They provided all types of weapons of mass destruction (biological, chemical, and nuclear), all methods to deliver them (intercontinental jet bombers, cruise missiles, intercontinental ballistic missiles, and submarine-launched missiles), and all of the technologies for modern conventional warfare as well. Therefore, transferred creators and creations allowed certain countries to greatly prosper or even become dominant throughout all the years since the war. What value could one place on the resulting success of those national economies and militaries over all the postwar decades?

4. Likewise, the total value of the German-speaking creators and creations that were transferred must consider the true value of their loss for Germany and Austria. If Germany and Austria—instead of other countries—had had the benefit of all of those creators and creations during all of the postwar decades, what would have been the resulting success of their national economies?

Although one might be tempted to cite the Marshall Plan as an example of money being given back to Germany and Austria, the United States provided less than $2 billion total to West Germany and Austria under the Marshall Plan, and most of that was simply loans that had to be fully repaid to the United States within a certain period of time [Schain 2001]. Thus Germany and Austria essentially fully funded their own postwar reconstruction and rebirth, in addition to shouldering much of the burden of postwar industrial and scientific development in the United States, United Kingdom, France, Soviet Union, and other countries.

It is possible that all of the countries involved might agree that the true total value of the technology transfer was an appropriate amount for reparations, but at the very least, the true value should be properly calculated, publicly acknowledged, and clearly stated in the history books.[9]

[9] Just to avoid any misunderstandings, I do not at all mean to disregard or minimize any of the other ethical issues, atrocities, injustices, casualties, losses, and unfortunate effects that were associated with the war, and that have been so thoroughly documented and discussed elsewhere. Rather, I am endeavoring to shed light on this additional issue that has not received much scrutiny to date, and that should be considered along with all of the others. Even more importantly, I would like to emphasize the enormous long-term economic and societal benefits that can be generated if countries fully fund and properly support revolutionary innovators and revolutionary innovations, as demonstrated by these historical examples.

For reasons of length, this study cannot even begin to address the large number of other ethical questions that are already covered so well and in so much detail by many other authors; I highly recommend that all readers seek out those books and study them. See for example: Bar-Zohar 1967; Beyerchen 1977; Black 2012a, 2012b, 2017; Borkin 1978; Bower 1987; Campbell and Harsch 2013; Cornwell 2003; Crim 2018; Deichmann 1996; Joseph Fisher 2017; Friedrich et al. 2017; Geissler 1998a, 1998b, 1999; Gellermann 1986; Georg 2012; Gimbel 1986, 1990a, 1990b, 1990c; Gröhler 1989; Guillemin 2005; Friedrich Hansen 1993; István Hargittai 2006; Harris Paxman 2002; Haunschmied et al. 2007; Hayes 2001; Heim et al. 2009; Hentschel and Hentschel 1996; Linda Hunt 1991; Jacobsen 2014; Jeffreys 2008; Karlsch and Laufer 2002; Kaszeta 2020; Kater 1989; Keynes 2019; Klee 2001; Kurowski 1982; Lasby 1971; Leff 2019; Le Maner and Sellier 2001; Julian Lewis 2002; Lichtblau 2014; Macrakis 1993; Milton Mayer 2017; Medawar and Pyke 2000; Mick 2000; Nachmansohn 1979; Nash 2013; Michael Neufeld 1995, 2002, 2003, 2007; Plumpe 1990; Posner and Ware 2000; Pringle 2006; Renneberg and Walker 1993; Sasuly 1947; Schambach 2011; Sellier 2003; Simpson 1988; Spitz 2005; Stoltzenberg 1994, 2005; Sutton 1976; Szöllösi-Janze 2001, 2015; Tucker 2006; Wachsmann 2015; Bernd Wagner 2000; Jens-Christian Wagner 2011, 2015; Wallace 2004; Whitman 2018.

For reference, the total amount that the United States spent on its own R&D programs (including the Manhattan Project, radar, penicillin, etc.) throughout all of World War II was only approximately 3 billion 1940s-era dollars. The United Kingdom spent much less, and other Allied countries spent relatively little on R&D. For the R&D that the United States and other countries acquired from the German-speaking world, even the lower-bound $20 billion estimate is nearly one order of magnitude larger than the U.S. R&D. Including the other factors listed above, the transferred R&D may well have had a total financial value several orders of magnitude greater than the endogenous R&D.

Thus whether one considers the number of truly revolutionary scientific innovators, the number of revolutionary scientific innovations (Chapter 2–9 and Appendices A–E), or the financial value of the innovators and innovations, the amount of science and technology that was transferred out of the German-speaking world appears to absolutely dwarf the amount that was "home grown" within the other countries. Perhaps the only thing more remarkable than this technology transfer is how nearly it has been forgotten by the modern world.

Charlie Hall gave an impassioned plea for the massive technology transfer from the German-speaking world to be much more widely studied and far more prominently featured in history books [Hall 2019a, p. 238]:

> This wholesale removal of a defeated nation's scientific and technological resources, including recruitment of expert personnel, by its military conquerors, has no parallel in modern history and deserves greater scrutiny. There is, without doubt, more to be said about the exploitation schemes of all four occupying powers, as well as about the involvement of other nations, including those whose participation in the Second World War was peripheral at best. [...] It would be excellent to see exploitation feature more prominently in histories of the military-industrial complex, of scientific intelligence, of post-1945 arms races, of transnational transfers of technology and expertise and of the Second World War and Cold War more generally. This would hopefully lead to a stronger presence for the programme in the public consciousness and would ensure that never again could it be described as a 'forgotten history.'

RESTRICTED

FOREWORD

This is a general description of the work of the Combined Intelligence Objectives Subcommittee -- its origin, mission, growth, and achievements.

The effective exploitation of German technical development has proven one of the significant results accruing from the conduct of the European War. The value of the scientific knowledge and "know how" thus obtained cannot now be fully measured. That this intelligence contributed to the defeat of Japan is well established. The benefits of this knowledge to British and US industry will be measured in terms of economic progress and well-being for many years to come.

This record of achievement will prove all the more interesting when it is recalled that prior to the formation of CIOS no planned and coordinated exploitation of enemy technical intelligence had ever been attempted. It was therefore natural that the growth of CIOS should have followed a flexible pattern. All the more so since it was seldom possible to determine in advance the exact form that combat operations would take. It was necessary to modify plans and machinery for the exploitation of technical objectives as military operations themselves changed. The constant aim was to investigate targets with the maximum of speed, the most efficient use of specialist personnel and the minimum demand on facilities needed for combat operations.

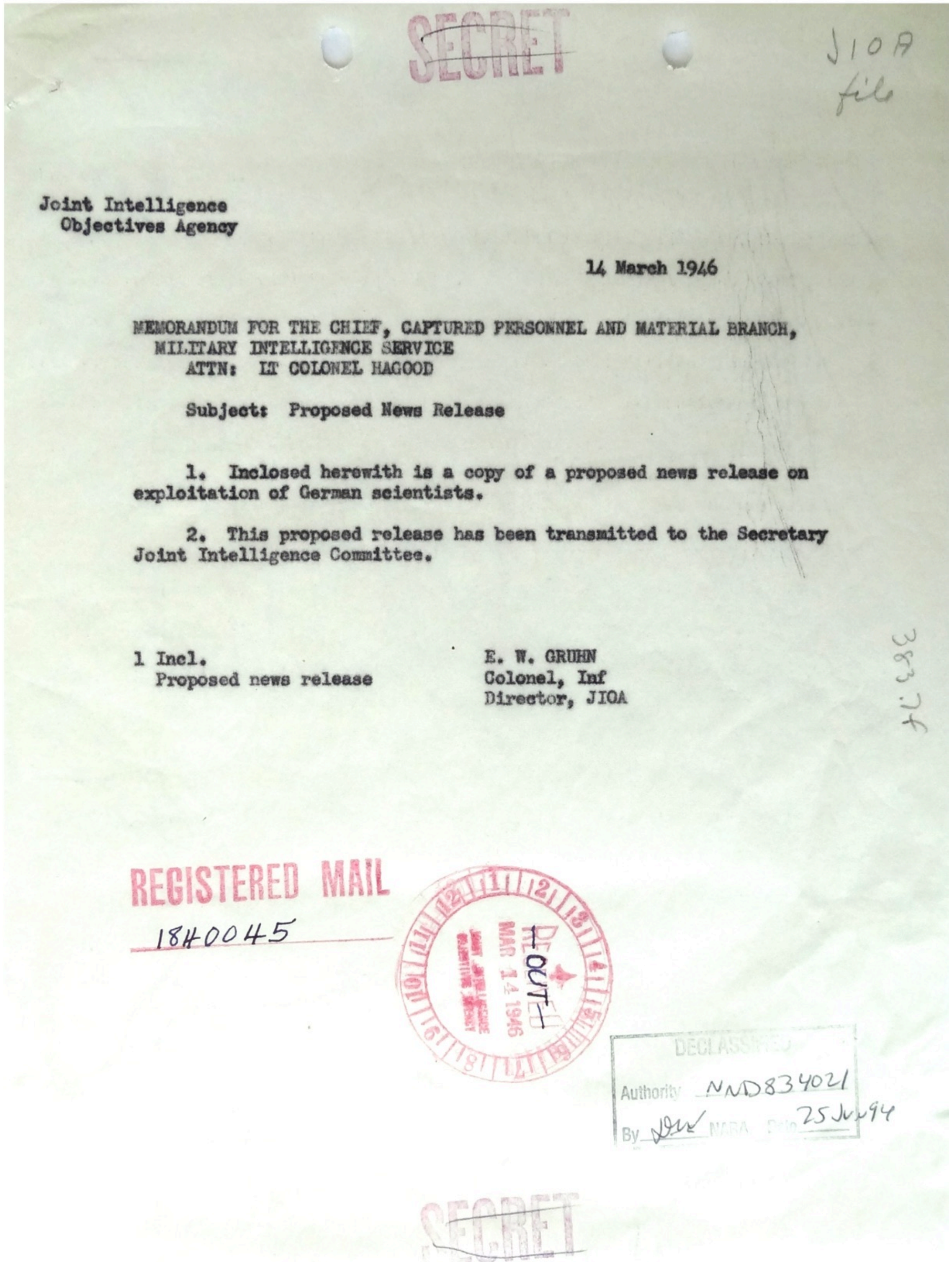
In this record it is not possible to make detailed acknowledgement of the many authorities that assisted CIOS. The Committee would, however, like to express its thanks for guidance given by its parent organization, the Combined Intelligence Committee, and the Joint Intelligence Committees; and for the operation of "T" Sub-Division of G-2 SHAEF, G(T) and CW

-5-

AFHRA A5186 electronic p. 907.
R. P. Linstead and T. J. Betts. September 1945.
The Intelligence Exploitation of Germany.

Figure 11.41: R. P. Linstead and T. J. Betts. September 1945. *The Intelligence Exploitation of Germany.* Foreword, p. 5 [AFHRA A5186 electronic p. 907].

NARA RG 330, Entry A1-1A, Box 4, Folder 383.7 Policy–1946



SECRET

JIOA file

Joint Intelligence
Objectives Agency

14 March 1946

MEMORANDUM FOR THE CHIEF, CAPTURED PERSONNEL AND MATERIAL BRANCH, MILITARY INTELLIGENCE SERVICE
ATTN: LT COLONEL HAGOOD

Subject: Proposed News Release

1. Inclosed herewith is a copy of a proposed news release on exploitation of German scientists.

2. This proposed release has been transmitted to the Secretary Joint Intelligence Committee.

1 Incl.
Proposed news release

E. W. GRUHN
Colonel, Inf
Director, JIOA

383.7f

REGISTERED MAIL
18H0045

MAR 14 1946
OUT

DECLASSIFIED
Authority NND834021
By NARA Date 25 Jun 94

SECRET

Figure 11.42: Ernest Gruhn. 14 March 1946. Exploitation of Germany for Technological and Scientific Information. [NARA RG 330, Entry A1-1A, Box 4, Folder 383.7 Policy–1946].

DECLASSIFIED
Authority NND 883004

NARA RG 330, Entry A1-1A, Box 4, Folder 383.7 Policy–1946

Secret
~~RESTRICTED~~ SECRET

- Proposed News Release On -

EXPLOITATION OF GERMANY FOR TECHNOLOGICAL AND SCIENTIFIC INFORMATION

After World War I there was no real attempt by the victors to exploit Germany for technical and scientific knowledge. However, long before World War II with Germany had ended, plans were made by the Joint Chiefs of Staff for the complete exploitation of Germany for technical information.

In accordance with these plans, the government is now engaged in exploiting Germany for all the technical and scientific information that can be obtained. Exploitation has involved the sending of several hundred highly qualified American technicians and scientists into Germany close upon the heels of our conquering armies. These investigators have examined manufacturing plants and equipment, records and documents and have interrogated German personnel. The information of industrial value that has been collected is being made available to the public by the Department of Commerce.

Steps are now being taken to extend this exploitation by bringing the best German scientists and technicians to this country so that their talents can be used here.

Several governmental agencies are involved in the technical exploitation of Germany program in addition to the Department of Commerce. These are the War and Navy Departments, the Department of the Interior, and the Department of Agriculture. The State Department is establishing several consulates in the American zone for the purpose of issuing visas under the President's program for limited immigration quotas.

Many of the German scientists and technicians will be brought over here for exploitation by the Navy and War Departments in connection with weapon developments

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Figure 11.43: Ernest Gruhn. 14 March 1946. Exploitation of Germany for Technological and Scientific Information. [NARA RG 330, Entry A1-1A, Box 4, Folder 383.7 Policy–1946].

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Authority NND 883004

NARA RG 330, Entry A1-1A, Box 4, Folder 383.7 Policy–1946

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for reasons of national security. These agencies already have about one hundred and fifty German scientists and technicians in this country. However, these were brought here without their families with the intention of returning them to Germany within six months to a year.

Other German scientists and technicians will be brought to the U. S. for exploitation for civil purposes, primarily for American industry. As these will only be brought over after it has been definitely determined to be for the national interest, they will be exploited on an unrestricted basis rather than being employed by certain firms. This exploitation for non-military purposes will be sponsored by the appropriate Federal agency or department.

The number of German scientists to be brought to American for exploitation will be strictly limited. Present estimates are that the total number will not exceed three hundred, limited to those who can make positive valuable contributions to our national welfare. They will include the best of the pure scientists, those comparable to Prof. Einstein. In the past, the United States has depended to a considerable extent upon German scientists for pure basic scientific research. Such research forms the basis for practical developments. They will also include eminent physicists, outstanding chemists, Nobel prize winners and leaders in various research and development fields.

The exploitation of these highly trained Germans will be of great value in the development of new types of weapons which were being planned by the Germans as the war ended. It will also be in the national interests to use them to increase our production potential in many industrial fields. Due to our dwindling natural resources, it has become a strategical necessity that our nation develope substitute and synthetic materials.

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Figure 11.44: Ernest Gruhn. 14 March 1946. Exploitation of Germany for Technological and Scientific Information. [NARA RG 330, Entry A1-1A, Box 4, Folder 383.7 Policy–1946].

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NARA RG 330, Entry A1-1A, Box 4, Folder 383.7 Policy–1946

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Great Britain, France and Russia have recognized the value of exploiting German expert personnel and it is quite probable that such neutrals as Sweden, Switzerland and Spain will encourage immigration of German scientists and technical experts as soon as Germans are allowed to immigrate to such countries. The ban on certain war industries and other war-supporting industries like aluminum, synthetic oil, synthetic rubber, and ball-bearings will cause the highly skilled German technicians in these industries to seek employment in other countries and thus aid such countries in increasing their war potential.

However, it is now well known that after the last war and because of the disarmament provisions of the Versailles Treaty, the German government arranged for many technicians to be employed in countries like Sweden, Russia, Switzerland and Spain in war production industries. Then when German rearmament began these technicians were called back to Germany.

With this knowledge in mind, adequate provisions and safeguards will be made to protect our secrets.

Those to be brought over will be carefully screened so that no active Nazis are included. Also those that are selected will be brought to the U.S. only if they volunteer. An honest desire to become U.S. citizens and never return to Germany will also be a consideration in selecting the individuals.

Only the immediate members of the families of those scientists who intend to live in this country will be brought over. The members of the families will be checked as to Nazi sympathies as some German youths were among the most rabid Nazis.

In view of the small number of families that will come, the effect on the housing situation will be very slight. It may well be that movement of families may have to be postponed until housing is available in each particular case. Movement

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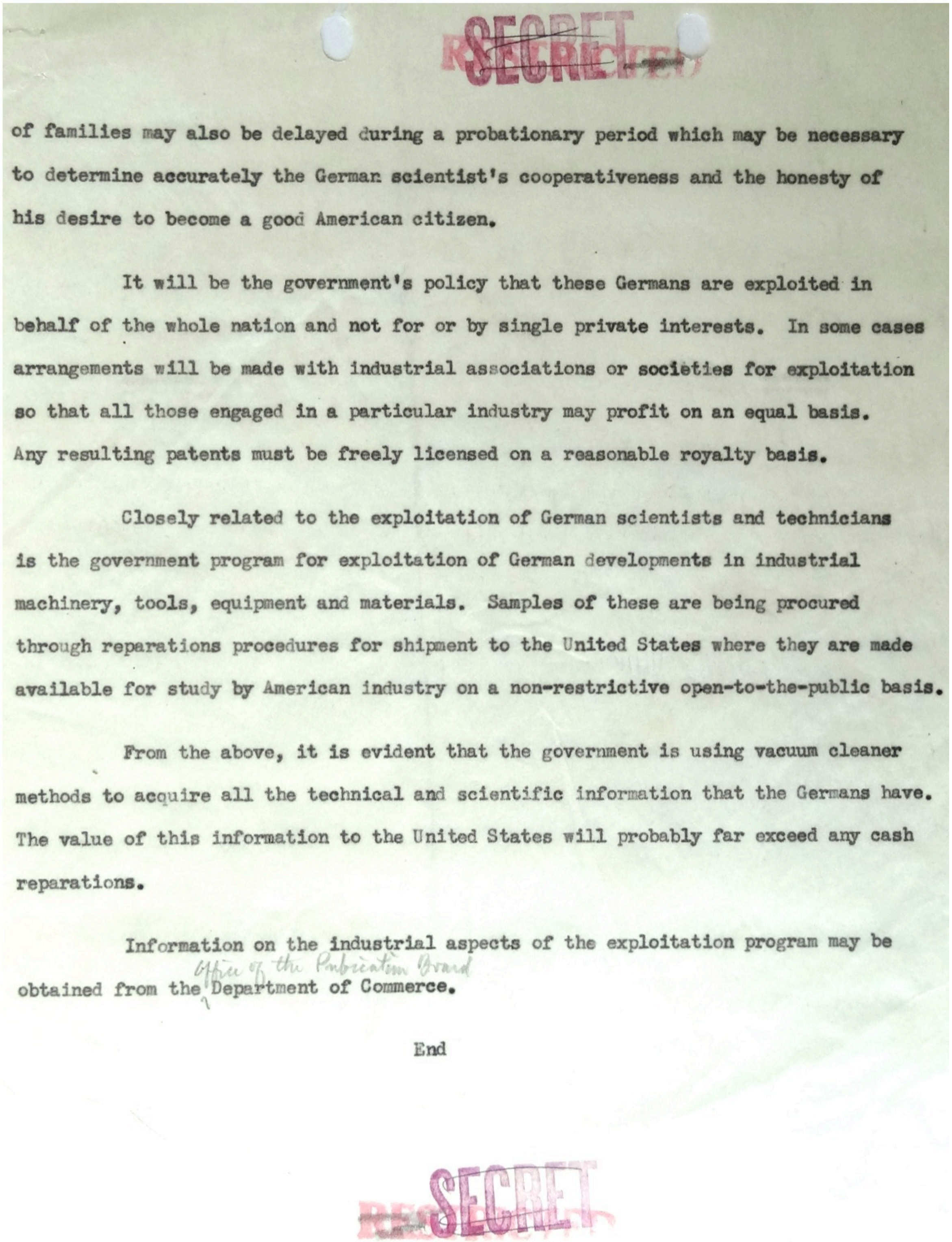
Figure 11.45: Ernest Gruhn. 14 March 1946. Exploitation of Germany for Technological and Scientific Information. [NARA RG 330, Entry A1-1A, Box 4, Folder 383.7 Policy–1946].

NARA RG 330, Entry A1-1A, Box 4, Folder 383.7 Policy–1946



SECRET

of families may also be delayed during a probationary period which may be necessary to determine accurately the German scientist's cooperativeness and the honesty of his desire to become a good American citizen.

It will be the government's policy that these Germans are exploited in behalf of the whole nation and not for or by single private interests. In some cases arrangements will be made with industrial associations or societies for exploitation so that all those engaged in a particular industry may profit on an equal basis. Any resulting patents must be freely licensed on a reasonable royalty basis.

Closely related to the exploitation of German scientists and technicians is the government program for exploitation of German developments in industrial machinery, tools, equipment and materials. Samples of these are being procured through reparations procedures for shipment to the United States where they are made available for study by American industry on a non-restrictive open-to-the-public basis.

From the above, it is evident that the government is using vacuum cleaner methods to acquire all the technical and scientific information that the Germans have. The value of this information to the United States will probably far exceed any cash reparations.

Information on the industrial aspects of the exploitation program may be obtained from the Office of the Publication Board Department of Commerce.

End

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Figure 11.46: Ernest Gruhn. 14 March 1946. Exploitation of Germany for Technological and Scientific Information. [NARA RG 330, Entry A1-1A, Box 4, Folder 383.7 Policy–1946].

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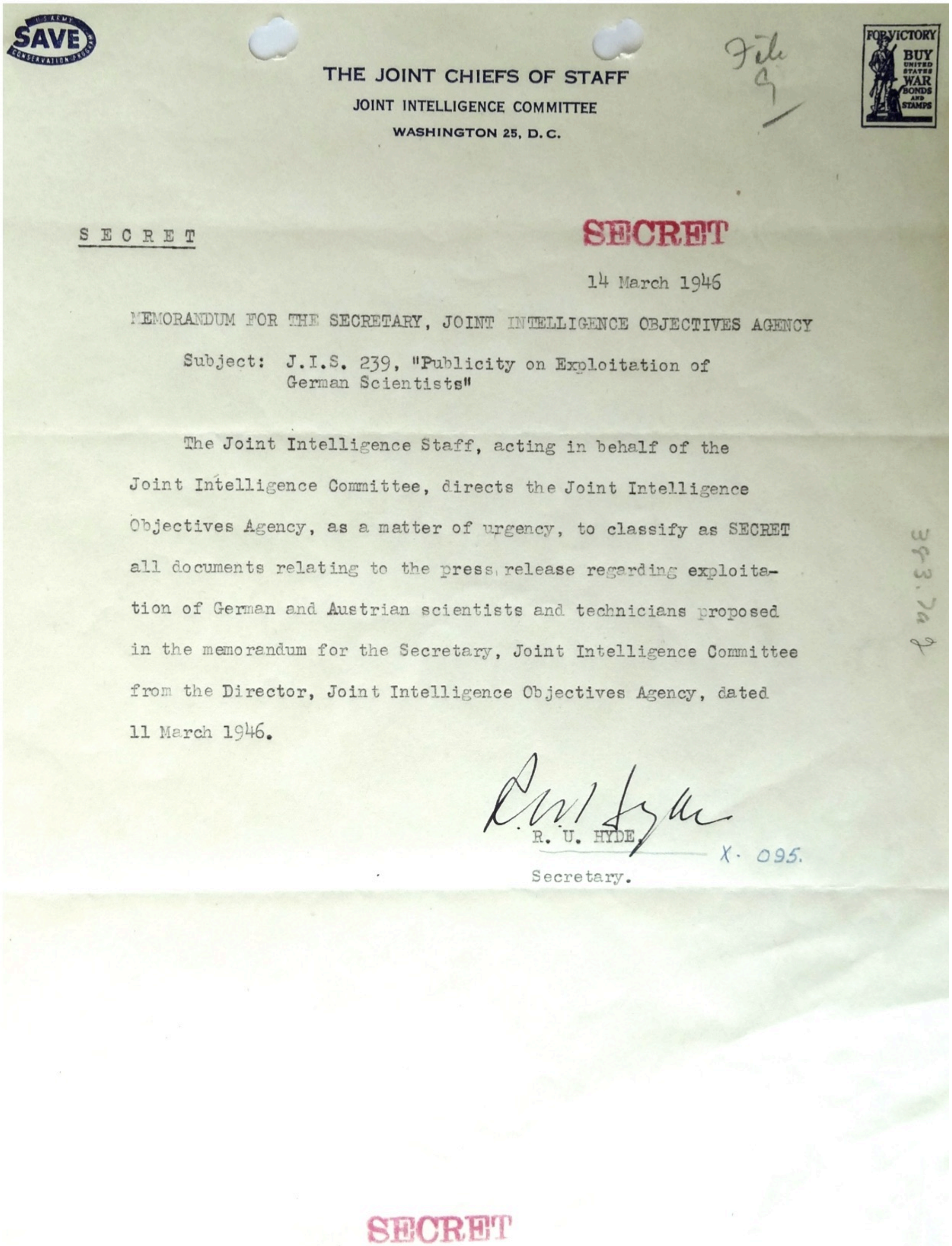
NARA RG 330, Entry A1-1A, Box 4, Folder 383.7 Policy–1946



THE JOINT CHIEFS OF STAFF
JOINT INTELLIGENCE COMMITTEE
WASHINGTON 25, D. C.

S E C R E T

SECRET

14 March 1946

MEMORANDUM FOR THE SECRETARY, JOINT INTELLIGENCE OBJECTIVES AGENCY

Subject: J.I.S. 239, "Publicity on Exploitation of German Scientists"

The Joint Intelligence Staff, acting in behalf of the Joint Intelligence Committee, directs the Joint Intelligence Objectives Agency, as a matter of urgency, to classify as SECRET all documents relating to the press release regarding exploitation of German and Austrian scientists and technicians proposed in the memorandum for the Secretary, Joint Intelligence Committee from the Director, Joint Intelligence Objectives Agency, dated 11 March 1946.

R. U. HYDE,
Secretary.

SECRET

Figure 11.47: Ernest Gruhn. 14 March 1946. Exploitation of Germany for Technological and Scientific Information. [NARA RG 330, Entry A1-1A, Box 4, Folder 383.7 Policy–1946].

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Authority NND 968018

NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss

Draft No. 2
January 10, 1947

PROPOSAL FOR A COMPENDIUM OF GERMAN WAR TIME TECHNOLOGY

Introduction

The accumulation of the technical industrial information, which has resulted from the detailed investigations of the German industry for the past two years by this office, has reached such enormous proportions that it has become difficult to inform the public of the possible benefits available to it. This accumulation of information not only represents the greatest transfer of mass intelligence ever made from one country to another, but it also represents one of the most valuable acquisitions ever made by this country. The problem becomes, therefore, to make the contents of this acquisition fully known to the public. Although a few high lights have been brought to public attention by general press notices, it is obvious that this means is not practicable for more than an infinitesimal amount of the available information. It is equally obvious that the complete accumulation now available through the Publication Office cannot be so publicized. A few organizations which have professional library research workers for the purpose have followed the details from the beginning with great benefit. However, the general public does not know of the availability of this information largely because the average man does not realize it may contain material in which he is vitally interested.

Now that the end of the collection program is in sight, it is proposed to set up a plan whereby all this information can be correlated, evaluated and condensed for publication in a permanent form suitable for the use of the average business man. Specifically, such a publication would take the form of a compendium of the German industrial information obtained in Germany by the

Figure 11.48: L. B. Kilgore. 10 January 1947. Proposal for a Compendium of German War Time Technology, Draft No. 2 [NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss].

**NARA RG 40, Entry UD-75, Box 3,
Folder Inter-Office Memoranda:
To and From Robert Reiss**

Technical Industrial Intelligence Committee (later "Division"). This compendium is envisioned as a systematic compilation of condensed discussions, information covering all the fields of industry wherein the Germans were found to have something to offer, presented in a readable manner which would enlist and stimulate the interest of the American business and professional men. This would be accompanied by the references whereby this interest could be followed up in the individual reports and photo reproductions to give the details necessary for reduction to practice.

I. <u>Resume of Present Status of TIID Information</u>

The investigation of German industrial intelligence was begun with the assured invasion and occupation of Germany the latter part of 1944 as a cooperative effort of U.S. and U.K. through the Joint Chiefs of Staff. With the close of the war and the division of Germany the authority was shifted to the respective military governments where it now resides. (For a detailed discussion see "Collection of Technical Industrial Intelligence in Germany", December 10, 1946, from this office.) Under these authorities thousands of field reports and millions of pages of reproductions have been returned to this country. Upon arrival in this country, this material has been variously "processed" after clearance by the Joint Intelligence Objectives Agency for security and stored in several repositories of the government.

The locations of the reports and documents transferred to this country from Germany during the various investigations are as follows:(1)

(1) Compiled by Mr. Clyde Aitchinson of this office.

-2-

Figure 11.49: L. B. Kilgore. 10 January 1947. Proposal for a Compendium of German War Time Technology, Draft No. 2 [NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss].

NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss

REPORTS -

Originating in the Technical Industrial Intelligence Committee, and Technical Industrial Intelligence Division, O.T.S.:

Repository Libraries -
Library of Congress
Department of Agriculture Library
Library of the Surgeon General
Notes: Additional copies of some of the reports may also be found in other U.S.A. libraries.

Technical Industrial Intelligence Division Units

Central Files, T.I.I.D. (Some tabulation as reports and documents.)

GERMAN PATENTS -

U. S. Patents by Germans pre-war - Alien Property Custodian

Printed copies of German patents during the war period up to No. 751,000 - Library of Patent Office.

Some German patent numbers may be found in Bibliography of Scientific and Industrial Reports, as microfilmed.

Applications made to the German Patent Office during the war now being microfilmed, are being listed in the Bibliography of Scientific and Industrial Reports.

DOCUMENTS OF GERMAN ORIGIN -

The reference to each microfilm reel as it becomes available is furnished in the Bibliography of Scientific and Industrial Reports.

Microfilm reels are located in repository libraries:

Library of Congress
Department of Agriculture Library
Library of Surgeon General

Microfilm (and also reports) relating to the subject of fuels and lubricants, as well as certain associated chemical products and processes may be found in Liquid Fuels and Lubricants Unit, Room 4343, South Interior Building.

A similar accumulation of German war time technological information is located in the U.K. Furthermore, this accumulation is being condensed and evaluated by the U.K. for public usage, a coincidental circumstance which

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Figure 11.50: L. B. Kilgore. 10 January 1947. Proposal for a Compendium of German War Time Technology, Draft No. 2 [NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss].

AFHRA A2056 electronic p. 405.
Donald Putt to Joseph McNarney. 10 December 1947.
German Specialist Program at the Air Materiel Command. Tab F.

SUBJECT: Justification for Continued Utilization of German Specialists by Air Materiel Command

1. Purpose:

To discuss and present some of the benefits accruing to the Air Force from continued utilization of German specialists by Air Materiel Command.

2. Discussion:

(a) With the exception of those eliminated by a continuous screening process during the one-year probationary period, all specialists now assigned to the various laboratories and activities of Air Materiel Command are outstanding in their respective scientific and engineering fields.

The majority have specific talents and all were associated with German research and development during the war period.

The majority were selected for their work in fields of aeronautical research, such as supersonics, jet and rocket engines, guided missiles, ceramics, jet and rocket fuels, etc., in which American technicians have had little or no experience, due to emphasis being placed on other lines of development. Today, however, USAF development is concentrated on those fields in which the Germans had advanced beyond our own knowledge and experience in those same fields.

Millions of dollars were spent by the Germans in research in these fields. By utilization of the German specialists, the Air Force can start where German research left off, rather than spending many dollars of public funds repeating what has already been accomplished or determined to have been unsatisfactory. Not to take advantage of this possibility is short-sighted and unrealistic.

(b) Many of the German specialists are not directly replaceable by American personnel because of their specialized experience and skills which are non-existent in the United States.

(c) Other specialists could possibly be replaced by American personnel if such were available. These

Figure 11.51: Donald Putt to Joseph McNarney. 10 December 1947. German Specialist Program at the Air Materiel Command, Tab F [AFHRA A2056 electronic p. 405].

AFHRA A2056 electronic p. 406.
Donald Putt to Joseph McNarney. 10 December 1947.
German Specialist Program at the Air Materiel Command. Tab F.

replacements are not available and probably could not be employed due to existing limitations on Civil Service grades if they were available. Even then replacements for many of the specialists would have to be trained under the German for a period of six months.

(d) Other specialists would be directly replaceable if such were available to Air Materiel Command, but such is not the case.

(e) The German specialists now on duty at Air Materiel Command have been and are now making significant contributions to the development of Air Force items of equipment and to technical and scientific literature. These specialists are an important cog in the Air Force research and development program.

(f) Specialists are not included in any man-power allotment ceiling and thus increase the total number of highly qualified personnel available to Air Materiel Command. The shortage of this category of technicians is extremely critical.

(g) Salaries being paid to the German specialists are less than would be required for equivalent American technicians if they were available.

(h) Due to the use of Project 612 Research and Development Funds for payment of salaries and exclusion of the specialists from manpower ceilings, the German specialists <u>are not</u> holding positions which could be filled with American citizens. If all specialists were returned to Germany, no additional American personnel could be employed at Air Materiel Command by virtue of their departure.

(i) Employment of the German specialists definitely presents a present and future possible security hazard. However, it is considered to be a calculated risk with possibilities of gain far exceeding a possible risk to national security. To abandon the project and return the specialists to Germany at this time would be a great blunder and definitely jeopardize the security of the United States, since a majority of the specialists would fall into the hands of or seek employment in other European countries where they would be exploited for their knowledge of U.S. aeronautical reseach and development.

Figure 11.52: Official U.S. government policy was to underpay German-speaking scientists for their work. Donald Putt to Joseph McNarney. 10 December 1947. German Specialist Program at the Air Materiel Command, Tab F [AFHRA A2056 electronic p. 406].

THIS PAGE DECLASSIFIED IAW EO 13526 **AFHRA A2055 Frame 1265**

ATSC Form No. 10-3 (19 Mar. 46) (7) 7-411

ROUTING AND RECORD SHEET AIR TECHNICAL SERVICE COMMAND

Use this form for inter-office correspondence within headquarters. Use authorized office symbols to designate addressor and addressee. Place initials of dictator and typist, telephone number and location to right of signature.

Use full width of sheet, both sides. Number all comments consecutively. Separate comments by horizontal lines across page.

SUBJECT Distribution of German Scientists' Reports.

TO TSDIN Colonel Putt FROM TSNFE DATE 29 July '46 COMMENT NO. 1.

1. In an attempt to attain wider distribution for the reports written by German scientists, these reports are being re-edited and published IN the form of T-2 Technical Reports, and will be sent to companies and organizations whose representatives have interrogated German scientists, and to those who it is felt have an interest in the work of the scientists. These reports will be sent only to the companies and organizations who have signed the secrecy agreement.

2. Acting on recommendations contained in the letter from JIOA dated 9 May, 1946, reports will be classified "Confidential" but all reference to German scientist's name and his background will be put on one page of the report with a note that upon removal of that page, the remainder of the document may be down-graded from "Confidential" to "Restricted", unless, of course, the subject matter in itself has a classification higher than restricted.

3. Unless otherwise directed by Deputy Commanding General of Intelligence T-2, this office will proceed with distribution of T-2 Technical Reports by German scientists as outlined above.

Roy W. Gustafson

ROY W. GUSTAFSON
Lt. Colonel, Air Corps
Chief, Foreign Exploitation Section
Analysis Division
Intelligence T-2.

CHB/mmp
Bldg.11
3 rd flr
2-3172

T TSNFE FROM TSDIN 1 AUG 46 # 2

1. approved

D. L. Putt Col AC
D/CG T-2.

Figure 11.53: Official U.S. government policy was to classify or remove the names of German-speaking scientists from technical reports they wrote for the United States. Roy W. Gustafson. 29 July 1946. Distribution of German Scientists' Reports [AFHRA A2055 Frame 1265].

13. The Alien Property Custodian must consult the Secretary of State before vesting title in himself to a patent application. Executive Order 9193, supra.

14. Legal title to a patent is assignable by an instrument in writing, recordable in the United States Patent Office. U.S. Code, title 35, sec. 47.

15. The courts are not agreed that legal title to a patent will re-vest in an assignor merely upon the occurrence of a named event and without a re-assignment in writing.

16. The German scientists are not anxious to cooperate with Government personnel in disclosing possibly patentable inventions known to them prior to their entry into the United States while the title is likely to be vested by the Alien Property Custodian; but are desirous of cooperating in such disclosures if the United States takes the title even though the title may not be re-assigned for some years and possibly never, depending on the nature of the invention.

CONCLUSIONS

17. It is concluded that:

a. The United States should take title to such inventions as are disclosed by the German Scientists now employed under Project Overcast where the invention requires secrecy and is important to the armament or defense of the United States.

b. Patent applications on such inventions should be prepared and filed by Government personnel now assigned to similar work.

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Figure 11.54: Official U.S. government policy was to deny German-speaking scientists ownership of their inventions, or in some cases even to be named as the inventor of that technology. Joseph W. Hazell. 28 February 1946. Project Overcast [AFHRA A2055 Frame 1177].

 AFHRA A2055 Frame 1178

g. None of the German scientists should be given a re-assignment of title until (1) the need for secrecy and Government control no longer exists and also (2) it is lawful in the United States for the scientist to have and control the title.

RECOMMENDATIONS

18. It is recommended that:

a. A contract be signed by each scientist with the United States as represented by the Secretary of War, and signed by the Secretary of War, providing for assignments of title to the United States, in trust for the scientist, such title to be re-assigned to him when, and not until, the need for secrecy and Government control no longer exists and also (2) it is lawful for the scientist to have and control the title.

b. Such contract provide that while the United States holds the title in trust it shall have, royalty-free, all rights of a licensee; and that upon re-assignment of the title the United States shall receive an irrevocable royalty-free license.

COORDINATION

19. This report and recommendation have been informally coordinated with the Deputy Chief of Air Staff for Research and Development; Deputy C.O. Intelligence (T-2) Air Technical Service Command, Wright Field; Office, Deputy Assistant Chief of Air Staff 4; Office, Deputy Chief, Research and Engineering Division, AC/AS 4; Office, Assistant Secretary of War for Air; AC/AS-2 and, on legality of recommended procedure, with Office, Air Judge Advocate; Office, Procurement Judge Advocate; Patents Section, Claims Division,

[redacted]

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Figure 11.55: Official U.S. government policy was to deny German-speaking scientists ownership of their inventions, or in some cases even to be named as the inventor of that technology. Joseph W. Hazell. 28 February 1946. Project Overcast [AFHRA A2055 Frame 1178].

> Believe this development would be important for Pacific War. . . . The research directors and staff realize impossibility for continuation of rocket development in Germany. . . . They are anxious to carry on their research in whatever country will give them the opportunity, preferably United States, second England, third France.

(9-A)

Excerpt from letter is as follows:

> Dr. von Karman estimates that here at this one place there is information immediately available that would take us at least two years of research in the U.S. to obtain. Also enough here to expedite our jet engine development program by six to nine months.

(5-A)

Recommendations to the Commanding General, U. S. Strategic Air Forces in Europe (Lt. Gen. Carl Spaatz), from his Deputy (Maj. Gen. H. J. Knerr) included the comment, "Occupation of German scientific and industrial establishments has revealed the fact that we have been alarmingly backward in many fields of research. If we do not take this opportunity to seize the apparatus and the brains that developed it and put the combination back to work promptly, we will remain several years behind while we attempt to cover a field already exploited." In addition, it was suggested that immediate dependent families be allowed to accompany the scientists, a move considered essential in view of the political and economic factors involved in their general uprooting. As these and other communications indicate, it was believed urgent that immediate action be taken to transport scientists to the United States without delay. The motivating reason was to insure the employment of those top-ranking scientists who were without question the

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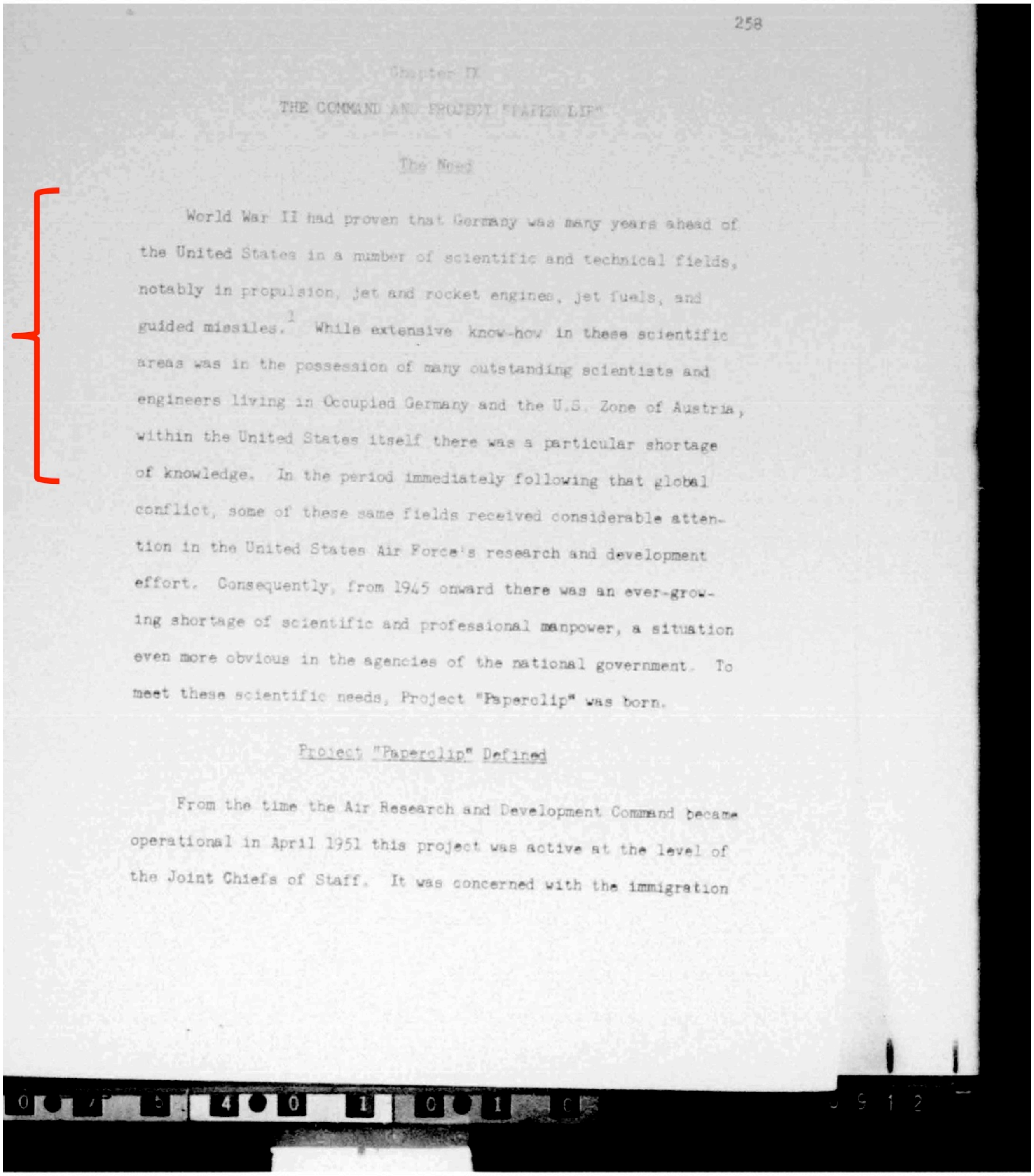
AFHRA A2055 electronic p. 747. Edna Jensen. 1948. *History of AAF Participation in Project Paperclip, May 1945–Mar 1947*. p. 44

Figure 11.56: Edna Jensen. 1948. *History of AAF Participation in Project Paperclip, May 1945–Mar 1947*, p. 44 [AFHRA A2055 electronic p. 747].

AFHRA K2838 (15390) electronic p. 887.
***History of the Air Research and Development Command.* 1954.**
Chapter IX. Dr. Charles A. Johnson. Project “Paperclip” p. 258.



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Chapter IX

THE COMMAND AND PROJECT "PAPERCLIP"

The Need

World War II had proven that Germany was many years ahead of the United States in a number of scientific and technical fields, notably in propulsion, jet and rocket engines, jet fuels, and guided missiles.[1] While extensive know-how in these scientific areas was in the possession of many outstanding scientists and engineers living in Occupied Germany and the U.S. Zone of Austria, within the United States itself there was a particular shortage of knowledge. In the period immediately following that global conflict, some of these same fields received considerable attention in the United States Air Force's research and development effort. Consequently, from 1945 onward there was an ever-growing shortage of scientific and professional manpower, a situation even more obvious in the agencies of the national government. To meet these scientific needs, Project "Paperclip" was born.

Project "Paperclip" Defined

From the time the Air Research and Development Command became operational in April 1951 this project was active at the level of the Joint Chiefs of Staff. It was concerned with the immigration

Figure 11.57: *History of the Air Research and Development Command.* 1954. Chapter IX. Dr. Charles A. Johnson. Project “Paperclip,” p. 258 [AFHRA K2838 (15390) electronic p. 887].

AFHRA K2838 (15390) electronic p. 894.
***History of the Air Research and Development Command.* 1954.**
Chapter IX. Dr. Charles A. Johnson. Project "Paperclip" p. 265.

IX 265

scientists departed from Europe between 15-12 September 1945. One week later, they arrived in Boston and were on their way to Wright Field. Project "Overcast" was in full swing.[11]

Army Air Force interest in using these German scientists and technicians had become active during the very early stages of Germany's collapse. Equipment of intelligence value, captured during the months preceding V-E Day, was to be shipped from abroad to Wright Field for evaluation and study. This exploitation program had been coordinated with the British Chiefs of Staff who were to share in its results. Obviously, it would not only be advantageous but also "a measure of necessity" to export experienced German technicians to America along with the equipment. Colonel Donald L. Putt, leading the Air Force Intelligence teams that took over these German research laboratories and experimental stations, made this evaluation:[12]

> I visited a great many of them . . . . Their research progress in jet and rocket propulsion, aerodynamics, thermodynamics, supersonics, and other fields was clearly far ahead of anything of the kind we had done.

From this consideration grew the realization by American military leaders of the exploitation value of the German military research and development program, particularly in the weapons fields, in prosecuting an all-out war against Japan. The program also served to snatch away certain researchers from the Soviet

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Figure 11.58: *History of the Air Research and Development Command.* 1954. Chapter IX. Dr. Charles A. Johnson. Project "Paperclip," p. 265 [AFHRA K2838 (15390) electronic p. 894].

[The following 3 articles were translated from Russian to German to English.] **The Billion-Dollar Object Germany. 20 Million Dollars for a Single German Patent! *Die Tat* (Zürich), 4 March 1947, p. 5. http://www.e-newspaperarchives.ch/?a=d&d=DTT19470304-01.2.18**

Under the title: "How the USA and England get reparations from Germany", D. Melnikov writes in the Moscow weekly "New Era," the latest one to arrive here, among other things:

Neither England nor the USA has yet declared their reparations claims to Germany. However, they have already obtained goods from Germany that significantly exceed the amount of 10 billion dollars.

As Colonel Wilkinson, the head of the industrial department of the American military government in Germany, announced, at the end of last year a number of companies in the western zones were made available as advance payments for the reparation account. However, when the dismantling of these factories began, the Allied authorities used all possible means to stop the shipment of machinery and equipment to the Soviet Union, while the removal of the unique equipment intended for England and the USA was carried out at a rapid pace. The most important companies in the American occupation zone were dismantled. All nickel works, 90% of the aircraft engine factories, 70% of the motorcycle engine factories, a significant (part) of the municipal businesses, the machine tool factories, etc. were exported, etc.

This is the official dismantling program. However, the confiscation of industrial equipment by England and the USA goes far beyond this program, as can be seen even from the sparse press reports. The Anglo-Saxon countries mainly cover their reparations claims through so-called "invisible reparations," which not only include machinery, but also the industrial products that are continually manufactured. We would like to give some examples.

According to a Reuters report, machines of the latest models from ongoing production at the Fritz Müller works in Ober-Eßlingen were shipped to England in the second half of 1946. At the beginning of January 1947, a significant number of machines were again sent to a number of larger English companies, including numerous unique sample and test machines. At the end of last year, the English authorities confiscated almost the entire finished production of the Siemens-Schuckert-Werke in Müllheim, which produces turbines and turbine components, and transported them to England. In the second half of 1946, as the "Berliner Zeitung" dated 21 January this year reported that 300,000 tons of wood worth 1.5 pounds sterling were shipped from Germany to England. The English military government even has control over all the products from the 20 fountain pen factories in the English occupied zone.

Industrial products are also confiscated in the American zone. According to the orders of the American occupation authorities, over 12,000 tons of aluminum were collected here, melted down and shipped to the USA. The occupation authorities have access to 95 percent of all cameras manufactured by the well-known Munich Agfa factories. End of November last year, the Directorate of the State Council of the American Zone turned to the military government with a request to cancel an order to the shoe factories for the delivery of 245,000 pairs of shoes. Consequently, such deliveries must have taken place.

Another category of reparations that England and the USA receive from Germany are German patents and inventions. The occupation authorities of the western zones have placed their hands on approximately 200,000 patents. At the end of last year, a reporter for the "News Chronicle" managed to gain insight into the report of an Anglo-American special commission that investigated the possibility of exploiting German inventions. The rapporteur places a very high value on the practical value of these inventions. An American manufacturer offered the US government $20 million for the use of a single production process patented in Germany.

Furthermore, England and the USA confiscated the largest part of the German gold reserve, amounting to 160–170 tons, which had been brought to the West by the Hitlerite fascists before the end of the war and was mainly concentrated in the American zone of occupation. In addition, the Swiss government has agreed to hand over the 50 tons of German gold in their country to England and the USA, and the Swedish government has agreed to hand over 7 tons. This means that over 200 tons of German gold are already in the hands of England and the USA. It should also be added that the British and American occupation authorities confiscated an enormous amount of valuables.

Ultimately, the USA, England including the Dominions and France received 470,000 GRT from the German merchant fleet.

The above shows how many reparations the Anglo-Saxon states have already secured within Germany, and yet this information does not yet provide a complete picture. England and the USA have received the extensive German foreign assets in the so-called neutral states as well as in the USA, in England, in Latin American and other countries.

The Berlin newspaper "Die Tribüne" has made an approximate estimate of how much reparations England and the USA have already received and states that the German foreign investments that are to be handed over to England and the USA are estimated at 3.3 billion dollars. The value of the German merchant fleet in the hands of the Allied Western Powers is 2.2 billion dollars. The German gold and the German patents and inventions confiscated by England and the USA are estimated at 5 billion dollars. In total, that's already 10.5 billion dollars, apart from the confiscated industrial products and the German plants and machines confiscated by the British and Americans and bought up at extremely low compulsory prices.

These facts show that England and the USA are satisfying their reparation claims very extensively, and that the reparations paid to them by Germany already exceed the total reparation demand of the Soviet Union (10 billion dollars).

Moscow about the Patent Loot in Germany. *Die Tat* (Zürich), 20 March 1947, p. 5. http://www.e-newspaperarchives.ch/?a=d&d=DTT19470320-01.2.16

"The seizure of German patents by American and English monopolies" is explained in the Moscow weekly "Neue Zeit" among other things:

As is well known, American and English companies, apart from other acquisitions on reparations accounts, have also acquired large quantities of German patents. In order to get a full idea of the value and significance of this part of the reparations revenue, one must understand the importance of patents in the world economy.

Under modern capitalism, patents are a powerful weapon of monopolies. In many cases, the possession of particularly valuable and important patents served as the basis for international cartel agreements.

Before the Second World War, the large trusts of the USA, England, and Germany had concentrated hundreds of thousands of patents in their hands, most of which were never exploited but served as a means of squeezing competitors.

At the American military government in Germany, in Frankfurt am Main, a special apparatus was created under the name Field Information Agency Technical, which was subordinate to General Clay. In this institution there is a special "Technical Intelligence Branch" which has a rich engineering staff in various fields and specialists in photophotography. The US Department of Commerce has a so-called Office of the Publication Board, which, through a decree of President Truman under No. 9604, is responsible for collecting information about scientific and technical achievements, inventions, improvements, etc. in enemy and liberated countries; notice that this recollection has been made mandatory by the decree. This office forwards requests from American industry to the aforementioned bodies of the occupation authorities and informs them of their needs.

John C. Green, the executive secretary of the mentioned publication office, reports in the Journal of the American Chemical Society the following about the methods used in obtaining patents from Germany:

A group of specialist engineers, supported by qualified German scientists and engineers, who have been examined by the military authorities, appear at a research institute, laboratory or company, carefully familiarize themselves with the technological process or research topic and determine which technical or... scientific achievements, inventions and perfections have been achieved here over a longer period of time. Afterwards, German microphotographers, under the supervision of the Americans, photograph these materials on microfilm, while the first working group (that began to collect) goes off to visit the next target. The microfilms are developed in Frankfurt, cataloged using a carefully developed system and sent to the USA. By the fall of 1946, of the 3.5 billion pages of technical documents these groups had produced that were of value to American industry, 3.5 million pages had been microfilmed. John Green shares:

"Among the stacks of data recently discovered and continually microfilmed by the search groups are all the valuable inventions that the IG-Farben industry has applied for patents or was about to do so with the German Patent Office."

Green rightly adds: "Apparently these are reparations in the most productive sense of the word." The above-mentioned publication office at the US Department of Commerce not only deals with the publication of patents, drawings, chemical recipes and the like, it also generously sends scientists and qualified engineers from the industrial trusts to Germany so that they can be on site to familiarize themselves with the activities of the relevant German industrial sectors. These scientists and engineers visit important companies and research laboratories of this or that branch of the economy, collect technical information and write detailed reports. After that they return to their jobs at the concerned companies, which cover all expenses for these business trips.

The listed methods for acquiring German scientific and technical experience are essential additions to the ownership of German patents, since the exploitation of patents is now often only possible if the corresponding production experience is available, which the Americans call "know how" ("wissen wie"). Without such detailed experimental knowledge, the patent can remain dead capital.

In addition to the patents exported from Germany, the Foreign Property Trust Administration in the United States, which was liquidated in the fall of 1946, held in its hands 45,000 patents, about 500,000 copyrights and a number of other technical documents that belonged to German (but also Japanese) citizens in the United States.

This category of reparations, from the strictest industrial secrets to the subordinate problems of production technology, is one of the richest spoils of war that has ever fallen to a victor.

Pravda: German Patents in the US and England. *Die Tat* (Zürich), 7 April 1949, p. 5. http://www.e-newspaperarchives.ch/?a=d&d=DTT19490407-01.2.29

N. Kharlamov writes about this and among other things reports the following:

Anglo-Saxon propaganda has long been campaigning for the complete cessation of reparations deliveries to the countries devastated by Hitler's aggression, whose legally justified demands are ignored because the ruling circles in the USA are focused on and have taken the decision of restoring West Germany's defense industrial potential. The "Voice of America" recently announced that the

United States was not interested in German reparation payments.

On the other hand, we know from numerous clearly established incidents how blatantly unembarrassed the occupation authorities in the western zones of Germany are sounding and acting, and that practically—from the very beginning—the United States and England have extracted, and are still extracting, huge reparations from Germany. The German patents and inventions, which have already brought American and English companies billions of dollars in profits, are just one but nevertheless very striking example of what is happening. The value of the German patents confiscated by the US as “spoils of war” alone was estimated at more than 5 billion dollars by the “Berlin Information Letters” published by the French Military Government in Berlin, an estimation based on original American sources. And it should be taken into account that the exploitation of patents is only a part of the hidden and disguised reparations that the Western powers are taking from Germany.

For over three years, hundreds of engineers and technicians from the American ‘Office of Technical Services’ have been working to sort, register and examine German patents brought to the United States, documents that weigh a total of more than 10,000 tons!

But not all German patents and documents about technological processes and scientific discoveries crossed the ocean; some remained in Germany and were brought to Höchst am Main, where the American authorities opened a kind of branch of the “New York Central Office for the Processing of German Patents.”

Several hundred scholars and engineers select the most valuable documents at this place and record them on microfilms, which are then sent every month to the USA, to the Office for Technical Information. Every month 30,000 meters of microfilmed documents are viewed and prepared for distribution to American companies as is also confirmed by the “Berliner Informationsbriefe” (‘Berlin Information Letters’). According to available information, more than 5 million meters of microfilms have already been sent to the USA.

Before the above-mentioned branch was set up in Höchst, the “Technical Intelligence Branch” carefully searched German companies and research institutes for documents on industrial planning, patents, new production methods, technological processes, etc. and found extremely valuable and unique machines and devices that were transported across the Atlantic. But in addition to the organs of the technical service of the US Army, special industrial missions were also busy with this task, which were directly interested in this or that branch of industry, such as the Schröder-Mission, which was launched immediately after Germany’s surrender and crossed the Atlantic to obtain material about the latest achievements of German technology in the field of producing synthetic fuel. Supported by US troops, the German chemical companies were carefully combed and the most valuable patents, samples of unique equipment and confidential documents were brought to the US to be studied there with the active participation of German scholars and then incorporated into the American industry. The Office for Technical Information is literally overwhelmed with orders from American companies for German patents. Every day they receive around 20,000 requests from all parts of the country, with orders from large corporations such as Dupont, International Harvester Company, etc. being preferred. Patents worth tens and hundreds of thousands of dollars are sold to the largest monopolies at ridiculous prices of 6 to 17 dollars. In London, an analogous office, the “German Patents Registration Office,” where German inventions are registered, sells the patents to the English monopolists for 2 shillings 6 pence! Despite these low prices, the New York headquarters have already collected hundreds of thousands of dollars. As the “Berliner Informationsbriefe” (‘Berlin Information Letters’) report, this institute recorded a net profit of over 100,000 dollars in 1947 alone.

This huge demand from Anglo-Saxon industry for German patents is quite understandable, since American specialists openly described them as "invaluable," gold mines of information for both military research and private industry. On November 7, 1948, the "Berliner Zeitung" reported that an American chemical company was using a German process to make synthetic rubber more resistant, others were using German patents to create new textile fibers, and still others were using German polyurethane to make high-quality bristles, fibers and coating compounds. More than 65,000 documents on technical information captured at the chemical plants of the IG group are being used to produce chemicals, dyes, medicines, alloys, and color photographic processes that were previously unknown in the United States.

These "technical achievements"—the American press makes no secret of them—have brought enormous profits to the chemical companies in the USA and made it possible to quadruple the export of chemicals compared to the pre-war years, as the US was able to take control of the former German sales markets, as confirmed by the "Chemical and Engineering News." The Winthrop Chemical Company produces a German substitute for morphine in large quantities, the Stearns & Co. produces adrenaline derivatives according to German patents and models, and other companies produce a painkiller "Methadone" invented by German chemists, which was previously known and sold as "Drug 10820" in Germany. The Wall Street Journal wrote: "Our country has become the heir to the relinquished empire of the German I.G. Farbenindustrie, and it intends to remain in its possession."

In England and her Dominions this exploitation takes place in the same manner. In England, for example, cameras were manufactured which are an exact copy of the German "Leica"; in 1949 10,000 such devices were to be exported. On 25 December last year the London radio explained that, through London, Australia had also received 4,000 reports on German technical processes that had been developed by German industry during the war.

Of course, special attention is paid to German patents in the field of war. The Anglo-Saxon intelligence service had very carefully collected the material about the headquarters of German military research centers, so that when they invaded Germany, immediately behind the front troops, technical specialists (so-called "investigation teams") immediately began to "acquire" the objects assigned to them. These specially trained squads proved to be excellently informed over the personnel and local conditions. For example, when Schongau was taken, an American officer immediately asked for Dr. Steinhoff, the head of the "Electromechanical Works" that had been relocated there, and quickly took him and his 500-man group into custody.

Already by September 1945, these teams had collected 160 different types of rocket projectiles at various stages of their manufacture and sent them to the US along with 150 tons of confidential drawings and documents on aircraft and engine construction, production of flying rockets, etc., which then became the basis for the creation a network of research institutes, laboratories and experimental bases.

England and the countries of the Empire have begun large-scale work on the same basis, which is mainly led by the Research Council for Aeronautics of the Nations of the British Empire, whose principal Director of Scientific Research, Sir Ben Lockspeiser, declared recently in Melbourne that Australia and New Zealand should be made the centers to implement the British research program and that £30 million should be made available to Australia for this research.

The above facts prove that the Western occupying powers received, as disguised reparations, German patents that are worth billions of dollars, and further prove that these patents are intended to be used to prepare for a new war.

[The above 3 articles were written for Soviet political purposes yet contain many interesting details.]

11.2 General Approaches Transferred from the German-Speaking World

After absorbing a huge number of German-speaking creators and creations, the U.S. research system had a very productive period during World War II and in the first decades after the war. During this period, the U.S. system also seems to have followed many of the approaches that had made the earlier German-speaking scientific world so successful, such as rapidly increasing research funding, management of the research system by enlightened despots, and other practices. Most of these approaches did not persist more than a few decades (beyond 1970 or so), which may help explain the apparent decline in the number of revolutionary new innovations in more recent times.

During the 1940s–1960s, the U.S. research system publicly unveiled a number of major inventions and discoveries. As covered in Chapters 2–9, 11.1, and the appendices, those innovations were generally adopted and developed from earlier German-based creations. Nonetheless, their implementation in the United States demonstrated that the U.S. system at that time was capable of carrying out revolutionary work that seems to be much less common now:

- During World War II, high-priority government programs created fission bombs and reactors, developed radar, mass-produced penicillin, and fielded other revolutionary technologies with military applications.

- Similarly, during the Cold War, high-priority government programs developed hydrogen bombs, nuclear submarines, intercontinental ballistic missiles, jet fighters, advanced air defense systems, satellites and spacecraft, computers, and other technologies.

- During the first few postwar decades, U.S. industry produced transistors, lasers, printed and integrated circuits, molecular medicines, new materials, jet airliners, nuclear power plants, and other very innovative products.

- Also during the first few postwar decades, U.S. academia published major discoveries in particle physics (relativistic quantum physics), molecular and cellular biology, and other areas.

This section examines the general approaches that the United States borrowed from the earlier German-speaking world and that facilitated this 1940s–1960s era of productivity in the U.S. research system. As shown later in this chapter, despite the successes that the United States achieved with the German-like general approaches, those approaches were largely abandoned after a few decades.

11.2.1 Cultural Attitudes Toward Science Education and Research

As in the earlier German-speaking world, popular culture in the United States glorified science education and research during the 1940s–1960s. Unfortunately, this attitude appears to have declined starting around 1970 or so. Although it is difficult to quantify such social attitudes with rigorous data, various types of illustrative examples are given here.

U.S. science fiction authors gained increasing prominence in magazines in the 1930s and 1940s, but arguably their greatest impact on children was through juvenile science fiction novels that were written from the late 1940s through the early 1970s, as exemplified by series such as:

- Robert A. Heinlein's juvenile novels. Heinlein was a retired U.S. Navy lieutenant and former engineering student, and was married to a retired Navy lieutenant commander and chemist, Virginia Heinlein [Dick 2008, pp. 341–352]. Heinlein's first novel, *Rocket Ship Galileo* (1947), described how three teenage budding engineers and their adult mentor from the Manhattan Project built a nuclear-powered rocket and traveled to the moon. (Ironically they found that German rocket engineers had secretly already gotten there.) Heinlein wrote a total of 12 juvenile novels through 1958's *Have Space Suit—Will Travel*, each depicting how young people assisted with a further step in space exploration. The popularity of his books prompted other authors such as those listed below to write juvenile science fiction novels [Clute 2017].

- Lester del Rey's juvenile novels. Del Rey was a longtime author, editor, and publisher of science fiction. From 1952 to 1968, he wrote over 20 juvenile novels in which young people created or assisted with projects on space flight (e.g., *Marooned on Mars*, 1952, and *Mission to the Moon*, 1956), submarines (*Attack from Atlantis*, 1953), robotics (*Runaway Robot*, 1965), time travel (*Tunnel Through Time*, 1966), and other innovations [Clute 2017].

- The *Tom Swift Jr.* series, published 1954–1971 by the Stratemeyer Syndicate (which also produced the *Hardy Boys* and *Nancy Drew* novels). Most of the 33 books in this series were written by James Duncan Lawrence, a former mechanical engineer and teacher. As depicted in these books, Tom Swift Jr. was a young inventor who used the resources of his father's large engineering company to build a series of increasingly sophisticated aircraft, spacecraft, submarines, robots, atomic devices, and other creations [Jonathan Cooper 2007; Open Library 2010].

- Bertrand Brinley's *Mad Scientists' Club* stories. Brinley was a retired Army captain, whose Army duties had included (among other things) advising children on how to safely experiment with rockets in the 1950s. Based on that work, he published the detailed nonfiction *Rocket Manual for Amateurs* in 1960, followed by a series of 1960–1974 fictional stories about students who formed the Mad Scientists' Club to create and test their own inventions [Brinley 2010].

- The *Danny Dunn* series, published between 1956 and 1977 by Raymond Abrashkin and Jay Williams. The books focused on discoveries and inventions that were made by young students and adult scientists usually working together. The discoveries and inventions combined some real-world scientific ideas and approaches with very fanciful science fiction adventures designed to appeal to young readers [Clute 2017].

Like their predecessors in the earlier German-speaking world (see p. 1980), these books presented children with fictional role models who through their scientific knowledge, hard work, and individualism created revolutionary innovations, despite both scientific obstacles and human opponents.

These books were extremely popular, became fixtures in public and school libraries in the United States, and inspired countless children to pursue careers in science and engineering. However, by the early 1970s, most books like these ceased to be produced, as shifts in children's interests made such books less marketable. More recent juvenile fiction tends to focus on children (e.g., Harry Potter), superheroes (e.g., Marvel and DC characters), or animals (e.g., cats, dragons, etc.) who are magically granted special powers, instead of having to achieve things using scientific knowledge and hard work.

Just as many German engineers had first become interested in their profession as children by watching films like Fritz Lang's *Frau im Mond* (1929), some of the German-speaking scientists who immigrated to the United States attempted to interest U.S. children in science. Examples included:

- Wernher von Braun, Ernst Stuhlinger, and other German scientists collaborated with Walt Disney to produce several entertaining but educational episodes of the *Disneyland* television series: "Man in Space" (1955), "Man and the Moon" (1955), and "Mars and Beyond" (1957) [Michael Neufeld 2007].

- Heinz Haber and other German scientists collaborated with Disney to produce another *Disneyland* episode, "Our Friend the Atom" (1957), that covered nuclear fission and fusion. Haber also wrote a corresponding children's book [Haber 1956].

- Willy Ley wrote popular descriptions of the science underlying rockets and space travel for numerous magazines and books, and was a consultant for television shows ranging from *Tom Corbett, Space Cadet* (adapted from Heinlein's *Space Cadet* novel) to *Disneyland* [Clute 2017].

- George Gamow wrote the *Mr. Tompkins* series of books from 1940 to 1967 to explain various scientific concepts in ways that children could understand [Gamow 1940, 1945, 1953, 1967].

- While not a scientist, George Pal (György Pál Marczincsak, Hungarian, 1908–1980) was a skilled German-speaking filmmaker who had worked in Prague and Berlin. He fled the Third Reich, and after the war he used his talents to present positive portrayals of fictional scientists to U.S. audiences in films such as *Destination Moon* (1950, adapted from Heinlein's *Rocket Ship Galileo*), *When Worlds Collide* (1951), *The War of the Worlds* (1953, adapted from the H. G. Wells novel but focusing on a scientist), *Conquest of Space* (1955, about a manned mission to Mars), and *The Time Machine* (1960, also adapted from an H. G. Wells novel).

Many scientists and engineers were first inspired by educational science kits that they experimented with as children. The early to mid-twentieth century, and especially the 1940s–1960s, were a golden age for such kits in the United States:

- A. C. Gilbert, an M.D. from Yale University, founded the A. C. Gilbert Company in 1909 in New Haven, Connecticut to produce science- and engineering-related kits for children. His sales steadily increased until World War II but really boomed after the war from the late 1940s until the 1960s. Gilbert's kits included Erector Set engineering construction kits for building everything from robots to locomotives; chemistry sets with dozens of chemicals; high-quality compound microscopes with slide-making accessories; and even the "U-238 Atomic Energy Lab" that provided children with several real uranium ore samples, other radioactive sources, a Geiger counter, a cloud chamber, an electroscope, and other nuclear physics supplies. However, Gilbert died in 1961, his company merged with the rival Porter company in 1967, and the combined company (Gabriel Industries) slowly petered out during the 1970s [Gilbert and McClintock 1954; Jitterbuzz 2017; Bruce Watson 2002].

- Harold Porter founded the Porter Chemical Company (Chemcraft) in 1914 in Hagerstown, Maryland to also produce science and engineering kits. The company's history very much paralleled that of the rival Gilbert company: sales increased until the wartime shortages of World War II, but then blossomed into a golden age from the late 1940s to the 1960s. Porter's products included lavishly equipped chemistry sets but also mineralogy kits, biology dissection sets, and a variety of microscopes. Porter died in 1963, and in 1967 Gabriel Industries bought and merged the Porter and Gilbert companies. The combined Gabriel company operated with declining sales and declining kit quality through the 1970s, changed hands in 1978, and finally ceased operations entirely in 1984 [Tyler 2003].

- The Skil-Craft company started up in the 1950s in Chicago to compete with the Gilbert and Porter companies in the postwar boom of demand for science and engineering kits. During the 1950s and 1960s, Skil-Craft produced high-quality kits in chemistry, microscopy, and other scientific fields. In 1968 they were bought out by Western Publishing/Golden Books, resulting in several 1970 sets in chemistry, biology, microscopy, and geology that combined Skil-Craft's well-thought-out experiments and Golden Books's beautiful illustrations [Fichter 1970a, 1970b; Parker and Martin 1970a, 1970b, 1970c]. Unfortunately, sales declined in the 1970s, the company changed hands in 1979, and operations ended in 1984.

In the 1940s–1960s, scientific innovators and innovations were widely and prominently heralded in news magazines, newspapers, and other media. Scientists and engineers were viewed as national heroes to be rewarded with fame and adulation, and to be presented as role models for young potential future scientists.

One especially illustrative example was the covers of *Time* magazine. *Time* was arguably the pre-eminent weekly news magazine in the United States during that period, and each issue's cover showcased an individual (or sometimes a group of individuals or an object) that was deemed to be especially important and newsworthy. Most of the covers featured political or military leaders from the United States or other countries, yet during the 1940s–1960s, a surprising number of *Time* covers were science-related, as listed in Tables 11.8 and 11.9. These *Time* covers featured [https://content.time.com/time/coversearch/0,16871,,00.html]:

- Most of the "enlightened despots" from Section 11.2.6 who directed U.S. research and development (e.g., Wernher von Braun, Vannevar Bush, James Conant, Lee DuBridge, Crawford Greenewalt, George W. Merck, Robert Oppenheimer, Hyman Rickover, Simon Ramo and Dean Woolridge, Bernard Shriever, Edward Teller, and Thomas Watson, Jr.).

- Scientists (e.g., Albert Einstein, Alexander Fleming, Edwin Hubble, Willard Libby, Jonas Salk, Glenn Seaborg, etc.).

- Test pilots and astronauts who piloted some of the newest inventions (e.g., Neil Armstrong, John Glenn, Alan Shepard, Chuck Yeager, etc.).

- Revolutionary innovations (e.g., computers, nuclear weapons, rockets, etc.)

- Whole categories of people. In 1961, *Time* declared all "U.S. Scientists" to be its "Men of the Year." It devoted an issue to "Great College Teachers" in 1966, and another issue to breakthroughs in "U.S. Medicine" in 1969.

Year	Issue	Person or object	Subject
1944	April 3	Vannevar Bush	"General of Physics"
1944	May 15	Alexander Fleming	Penicillin
1946	July 1	Albert Einstein	$E = mc^2$
1946	September 23	James Conant	Science education
1948	February 9	Edwin Hubble	Expanding universe
1948	July 19	Howard Hughes	Hughes Aircraft R&D
1948	November 8	J. Robert Oppenheimer	Science education/nuclear physics
1949	April 18	Chuck Yeager	Mach 1 rocket plane
1950	January 23	Mark III Computer	"Can man build a superman?"
1950	August 28	Irving Langmuir	Atmospheric science
1951	April 16	Crawford Greenewalt	Revolutionary new chemicals
1951	July 23	David Sarnoff	Electronics R&D
1952	August 18	George W. Merck	Revolutionary new pharmaceuticals
1952	December 8	Space Pioneer	"Will man outgrow the earth?"
1953	November 16	Igor Sikorsky	Helicopters
1954	January 11	Hyman Rickover	Nuclear-powered submarines
1954	March 29	Jonas Salk	Polio vaccine
1954	April 12	H Bomb	Nuclear weapons development
1954	June 14	J. Robert Oppenheimer	Nuclear weapons/security
1955	March 28	Thomas Watson, Jr.	Computers
1955	May 16	Lee DuBridge	Science education
1955	August 15	Willard Libby	Nuclear R&D
1956	January 30	"The Missile"	Rockets/nuclear technologies
1957	April 1	Bernard Schriever	Missile and rocket technologies
1957	April 29	Simon Ramo & Dean Woolridge	"Engineers"
1957	November 18	Edward Teller	"U.S. Science: Where It Stands Today"
1958	February 17	Wernher von Braun	Space program
1959	January 19	"Space Exploration"	"U.S. v. Russia"
1959	May 4	James Van Allen	Explorer I satellite/radiation belts
1959	September 14	James Conant	"U.S. Public Schools"
1959	July 27	John Heller	Cancer research

Table 11.8: Some science-related covers of *Time* magazine during the 1940s–1950s.

Year	**Issue**	**Person or object**	**Subject**
1960	March 28	Jacques Cousteau	Undersea exploration
1960	June 6	Satellites	Space program
1961	January 2	"U.S. Scientists"	Men of the Year
1961	January 6	Harry Felt	Advanced aircraft, missiles, subs
1961	January 13	Ancel Keys	Human physiology
1961	April 21	Yuri Gagarin	First man in orbit
1961	May 12	Alan Shepard	First American in space
1961	July 7	Leonard Larson	Medical improvements
1961	October 27	Tom Jones (Northrop)	Aerospace industry
1961	November 10	Glenn Seaborg	Nuclear physics
1961	November 17	John Enders	Virology
1962	March 2	John Glenn	First American in orbit
1963	May 24	Gordon Cooper	Another American in orbit
1963	August 23	U.S. Atomic Arsenal	Nuclear weapons development
1964	January 10	Buckminster Fuller	Engineering/architecture
1964	September 25	Nuclear Issue	Nuclear weapons development
1965	March 26	Alexey Leonov	First spacewalk
1965	April 2	"The Computer in Society"	Computers
1965	May 14	"The Communications Explosion"	Communications technologies
1965	June 11	Ed White and James McDivitt	First American spacewalk
1965	August 27	Chris Kraft	NASA Mission Control
1965	December 24	Gemini Rendezvous	Docking in orbit
1966	May 6	Great Teachers	Importance of high-quality education
1967	February 3	Roger Chaffee, Gus Grissom, Ed White	Apollo 1 fire
1967	April 7	The Pill	Oral contraceptives
1968	December 6	Race for the Moon	Space program
1969	January 3	William Anders, Frank Borman, Jim Lovell	Men of the Year (first around Moon)
1969	February 21	U.S. Medicine	Needed medical improvements
1969	March 14	Great Missile Debate	Rockets/nuclear technologies
1969	July 18	Lunar Exploration	Space program
1969	July 25	Neil Armstrong	First men on Moon

Table 11.9: Some science-related covers of *Time* magazine during the 1960s.

While the specific example of *Time* magazine covers has been cited here, this public praise and attention for scientists, engineers, and their accomplishments occurred throughout popular media during the 1940s–1960s. Hollywood made a film celebrating the scientific development of the U.S. atomic bomb (*The Beginning or the End*, 1947), with actors portraying J. Robert Oppenheimer, Enrico Fermi, Vannevar Bush, Albert Einstein, and other scientists and engineers. Countless other films, television shows, and books focusing on real or fictional scientists were produced during the 1940s–1960s. The national news was dominated by the latest plans and accomplishments of the Space Race throughout the late 1950s and the 1960s. In a 1960 speech to the American Association for the Advancement of Science, the British novelist and chemist C. P. Snow proclaimed [Snow 1961]:

> Scientists are the most important occupational group in the world today. At this moment, what they do is of passionate concern to the whole of human society.

This popular support for scientists went up to the highest levels. For example, President Franklin Roosevelt sent a letter to J. Robert Oppenheimer, the physicist in charge of the Manhattan Project, on 29 June 1943 [https://www.albuqhistsoc.org/source-documents/letter-fdr-oppenheimer/]:

> My dear Dr. Oppenheimer:
>
> I have recently reviewed with Dr. Bush the highly important and secret program of research, development and manufacture with which you are familiar. I was very glad to hear of the excellent work which is being done in a number of places in this country under the immediate supervision of General L.R. Groves and the general direction of the Committee of which Dr. Bush is Chairman. The successful solution of the problem is of the utmost importance to the national safety, and I am confident that the work will be completed in as short a time as possible as the result of the wholehearted cooperation of all concerned.
>
> I am writing to you as the leader of one group which is to play a vital role in the months ahead. I know that you and your colleagues are working on a hazardous matter under unusual circumstances. The fact that the outcome of your labors is of such great significance to the nation requires that this program be even more drastically guarded than other highly secret war development. I have therefore given directions that every precaution be taken to insure the security of your project and feel sure that those in charge will see that these orders are carried out. You are fully aware of the reasons why your endeavors and those of your associates must be circumscribed by very special restrictions. Nevertheless, I wish you would express to the scientists assembled with you my deep appreciation of their willingness to undertake the tasks which lie before them in spite of the dangers and the personal sacrifices. I am sure that we can rely on their continued wholehearted and unselfish labors. Whatever the enemy may be planning, American science will be equal to the challenge. With this thought in mind, I send this note of confidence and appreciation.

Although Roosevelt died before the Manhattan Project was completed, later presidents publicly awarded medals of honor to Oppenheimer and many of the other scientists who participated in that and other wartime projects.

As another example of support from the highest levels, President John F. Kennedy made revolutionary scientific and engineering goals the focus of his "Moon speech" at Rice University Stadium in Houston, Texas on 12 September 1962 [https://www.jfklibrary.org/archives/other-resources/john-f-kennedy-speeches/rice-university-19620912; see also Fig. 11.59]:

> Despite the striking fact that most of the scientists that the world has ever known are alive and working today, despite the fact that this Nation's own scientific manpower is doubling every 12 years in a rate of growth more than three times that of our population as a whole, despite that, the vast stretches of the unknown and the unanswered and the unfinished still far outstrip our collective comprehension. [...]
>
> Those who came before us made certain that this country rode the first waves of the industrial revolutions, the first waves of modern invention, and the first wave of nuclear power, and this generation does not intend to founder in the backwash of the coming age of space. We mean to be a part of it—we mean to lead it. For the eyes of the world now look into space, to the moon and to the planets beyond, and we have vowed that we shall not see it governed by a hostile flag of conquest, but by a banner of freedom and peace. We have vowed that we shall not see space filled with weapons of mass destruction, but with instruments of knowledge and understanding.
>
> Yet the vows of this Nation can only be fulfilled if we in this Nation are first, and, therefore, we intend to be first. In short, our leadership in science and in industry, our hopes for peace and security, our obligations to ourselves as well as others, all require us to make this effort, to solve these mysteries, to solve them for the good of all men, and to become the world's leading space-faring nation. [...]
>
> We choose to go to the moon. We choose to go to the moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one which we intend to win, and the others, too. [...]
>
> The growth of our science and education will be enriched by new knowledge of our universe and environment, by new techniques of learning and mapping and observation, by new tools and computers for industry, medicine, the home as well as the school. Technical institutions, such as Rice, will reap the harvest of these gains.

Like Roosevelt, Kennedy also died before he could see the revolutionary scientific programs he supported come to fruition, but again, later presidents gave public awards to many of the scientists, engineers, and astronauts who were instrumental in those programs.

Figure 11.59: Meeting between Wernher von Braun and President John F. Kennedy in Alabama on 19 May 1963.

Unfortunately, by the late 1960s and early 1970s, there was a decline in public interest in and support for science and for scientists in the United States. Some of the factors responsible for that decline included:

- Between the publication of Rachel Carson's book *Silent Spring* in 1962 and the creation of the U.S. Environmental Protection Agency in 1970, there was rising public concern about the personal and environmental risks of new chemicals and new materials that scientists had produced. With the founding of the U.S. Occupational Health and Safety Administration in 1971, there were also greatly increased concerns and lawsuits regarding the safety of new industrial processes, technologies, and products.

- The Space Race between the United States and the Soviet Union, which at the time was probably by far the most visible symbol of scientific progress, essentially came to an abrupt end in 1969 when the United States landed people on the Moon. The Soviet Union chose not to pursue the Space Race beyond that point (for example, by trying to be the first to land people on Mars), and the U.S. government and public rapidly lost interest in sending more people to the Moon or beyond. Without other national scientific goals that were as visible or as compelling as the Space Race, public interest in and support for science education and R&D dropped rapidly.

- By 1972, the majority of U.S. homes had color television, which tempted people with instant and endless gratification instead of applying those extra hours to learn and to create.

- The 1973 and 1979 energy crises and accompanying economic recessions made people, companies, and the government focus more on near-term economic survival than long-term science education and R&D. Later economic booms occurred in other areas of the economy, such as finance and entertainment, drawing further public prestige and interest away from science and engineering.

- Events such as 1970s lawsuits over the U.S. use of the Agent Orange defoliant in Vietnam and the 1979 Three Mile Island nuclear accident tended to create a very negative public perception of science in the United States.

By 2020 and beyond, the U.S. public's general views and treatment of scientists, medical professionals, teachers, other intellectuals, and even basic facts and principles seemed to have fallen very far from the heyday of the mid-twentieth century. Modern examples are too numerous, too well known, and too depressing to recite here.

Looking beyond just science, one could argue that during the 1940s–1960s, there appeared to be widely held U.S. beliefs in doing very high-quality work and in striving to make the world a better place. Millions of Americans worked to overcome the Depression, win World War II, build up U.S. industry, help rebuild Europe and Japan, and oppose the Soviet Union. In contrast, from the 1970s to the current time, it seems that many Americans have been less interested in spending their time and energy to do high-quality work and to improve the world, and more interested in trying to achieve fortune and fame as easily as possible, or in simply withdrawing to be entertained by their various video screens large and small.

11.2.2 Funding Levels

Research and development (R&D) spending is naturally a major factor affecting the performance of the innovation system in the United States or other countries.

Figure 11.60 shows early U.S. federal R&D spending, taken from a highly influential 1947 government report by economist John R. Steelman, who at that time was also the first presidential chief of staff (for Harry Truman) [Steelman 1947]. As shown in the graph, spending was minimal before WWII, reflecting the fact that there was essentially no government-funded research system in the United States, unlike in German-speaking central Europe. U.S. federal R&D spending increased exponentially during WWII, as the government-funded research system came into existence, hired large numbers of talented innovators, and launched programs on revolutionary technologies such as radar, nuclear fission, penicillin mass production, etc. The graph shows that the spending increased more slowly but still exponentially after WWII, with projected increases beyond the current year of 1947 well into the 1950s, as indeed proved to be the case. The figure also explicitly links each funding increase to an increase in the number of "the scientists to do the job."

As an overview of U.S. federal R&D spending from the early postwar period to the present, Fig. 11.61 shows the defense, nondefense, and total spending for government fiscal years (FY, starting October 1 before the corresponding calendar year) since FY 1953, in inflation-adjusted constant FY 2018 dollars. It is especially noteworthy that defense R&D spending doubled practically overnight in FY 1959—that was the first fiscal year of funding that was approved after the October 1957 launch of the Soviet Sputnik satellite. Similarly one can see the rapid increase in nondefense R&D during the early 1960s for the manned space program. There were also increases in military spending during the Reagan administration (1980s) and George W. Bush administration (early 2000s), but the graph shows that those were largely temporary.

To help provide more context for the spending levels, Fig. 11.62 regraphs the U.S. federal R&D spending as a percentage of the U.S. gross domestic product (GDP) for each year. This method can help give a better understanding of how large the research programs were relative to other aspects of the economy, and by extension how much talented labor, resources, and recognition would be drawn to research work versus other occupations in society. Fig. 11.62(a) presents an historical overview for the period 1949–2005, showing that by this measure the total federal R&D funding peaked in 1964 (the time of greatest development work for the space program), began a steep decline around 1967 (once most of the development work for the Apollo-Saturn program had been completed), and continued to decline slowly for decades thereafter. Figure 11.62(b) gives a more detailed graph for the period 1976–2018, showing that the funding has continued to decline to the present, apart from relatively small oscillations (the Reagan and George W. Bush temporary increases in defense spending). In fact, the current total federal R&D spending (approximately 0.7% of GDP) is only about one third of the peak 1964 spending (approximately 2.2% of GDP) and lower than any other post-Sputnik budget.

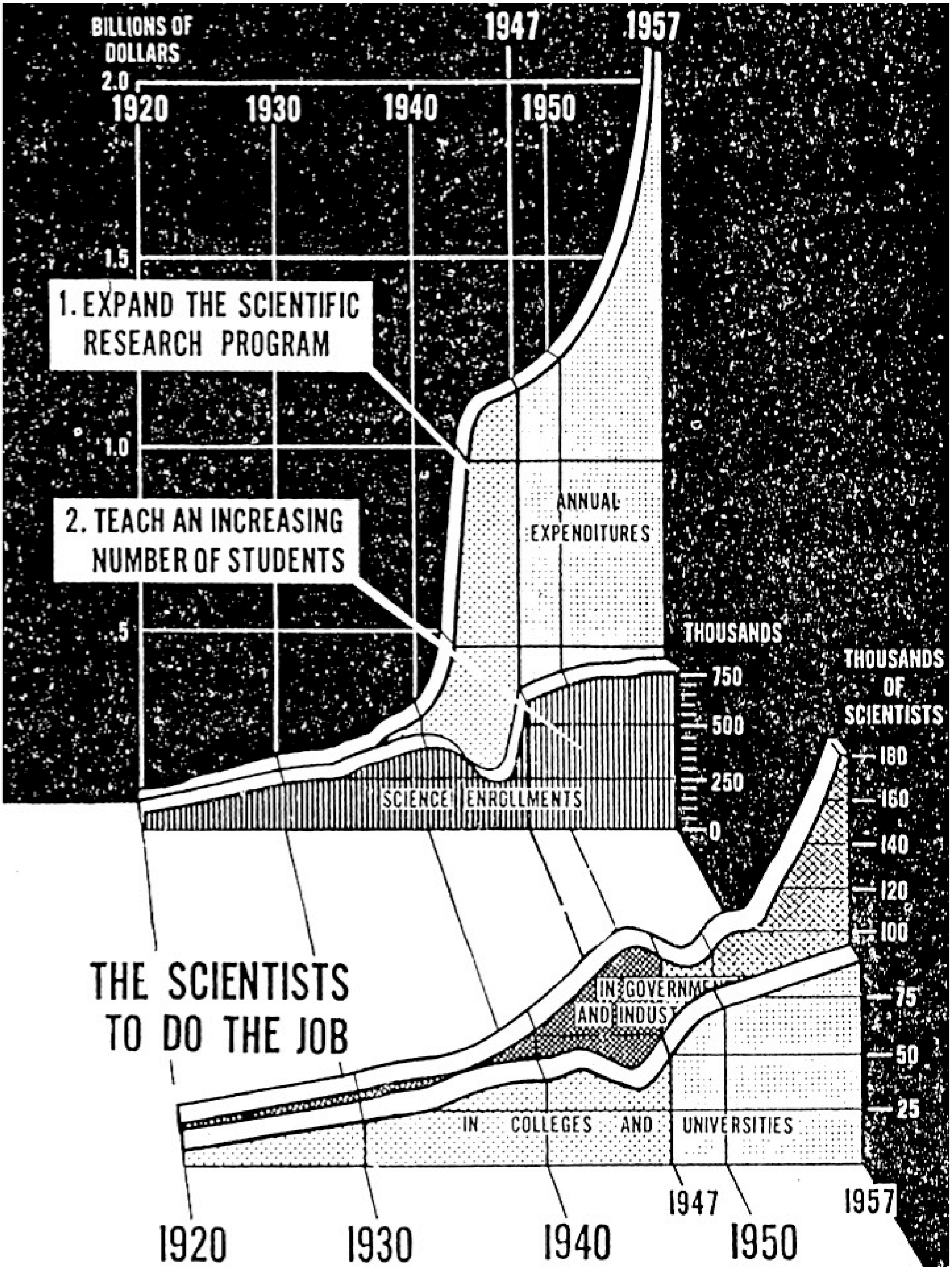


Figure 11.60: This 1947 graph shows that early U.S. federal R&D spending was minimal before World War II, increasing exponentially during the war, and increasing more slowly but still exponentially after the war [Steelman 1947].

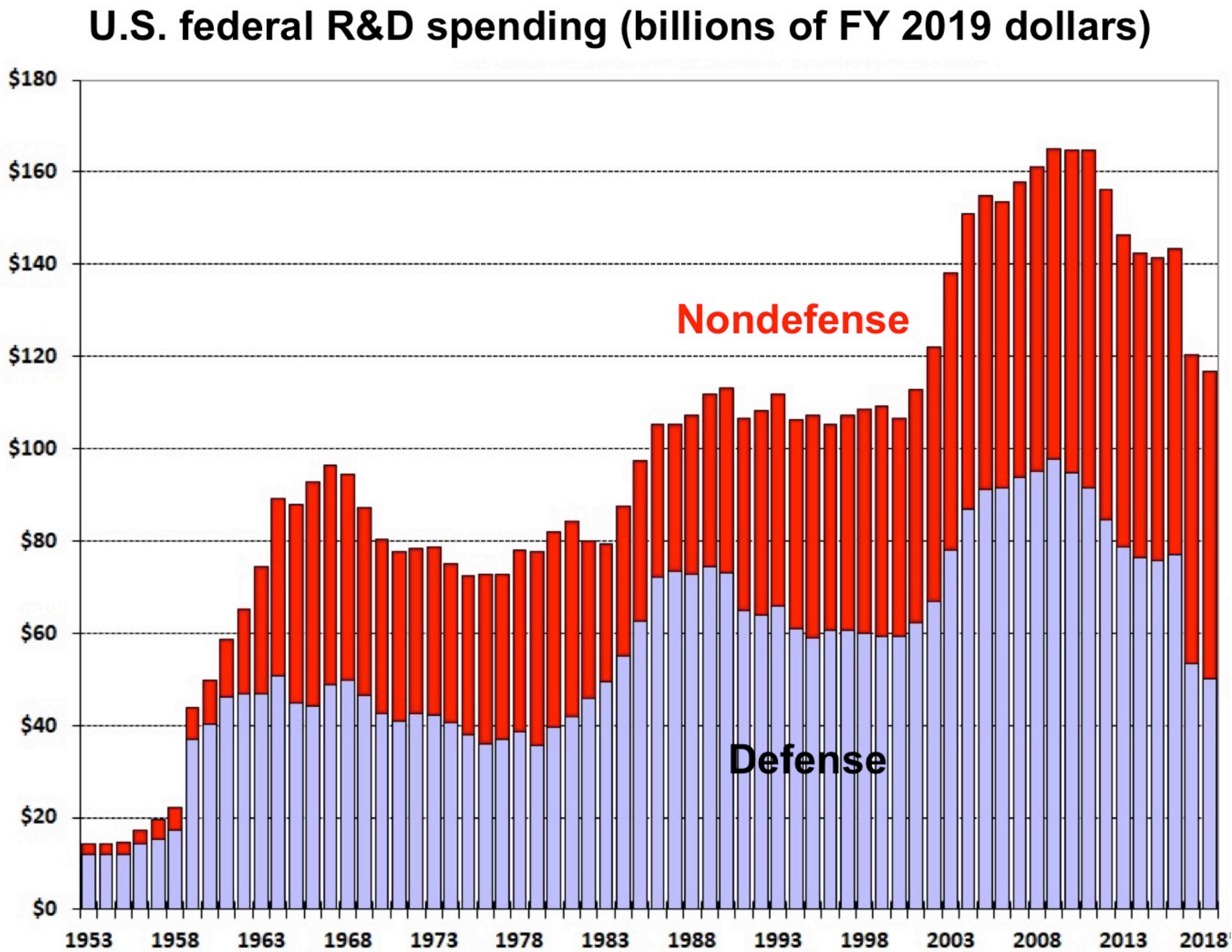


Figure 11.61: U.S. federal R&D spending for government fiscal years (FY, starting October 1 before the corresponding calendar year) since FY 1953, in inflation-adjusted constant FY 2019 dollars. Note the doubling of defense R&D in FY 1959, the first fiscal year of funding that was approved after the October 1957 launch of the Soviet Sputnik satellite, and the rapid increase in nondefense R&D during the early 1960s for the manned space program. Also note the temporary increases in military spending during the Reagan administration (1980s) and George W. Bush administration (early 2000s). The large apparent drop in defense funding in FY2017 is primarily due to a change in what programs were defined as "development" [https://www.aaas.org/programs/r-d-budget-and-policy/historical-trends-federal-rd].

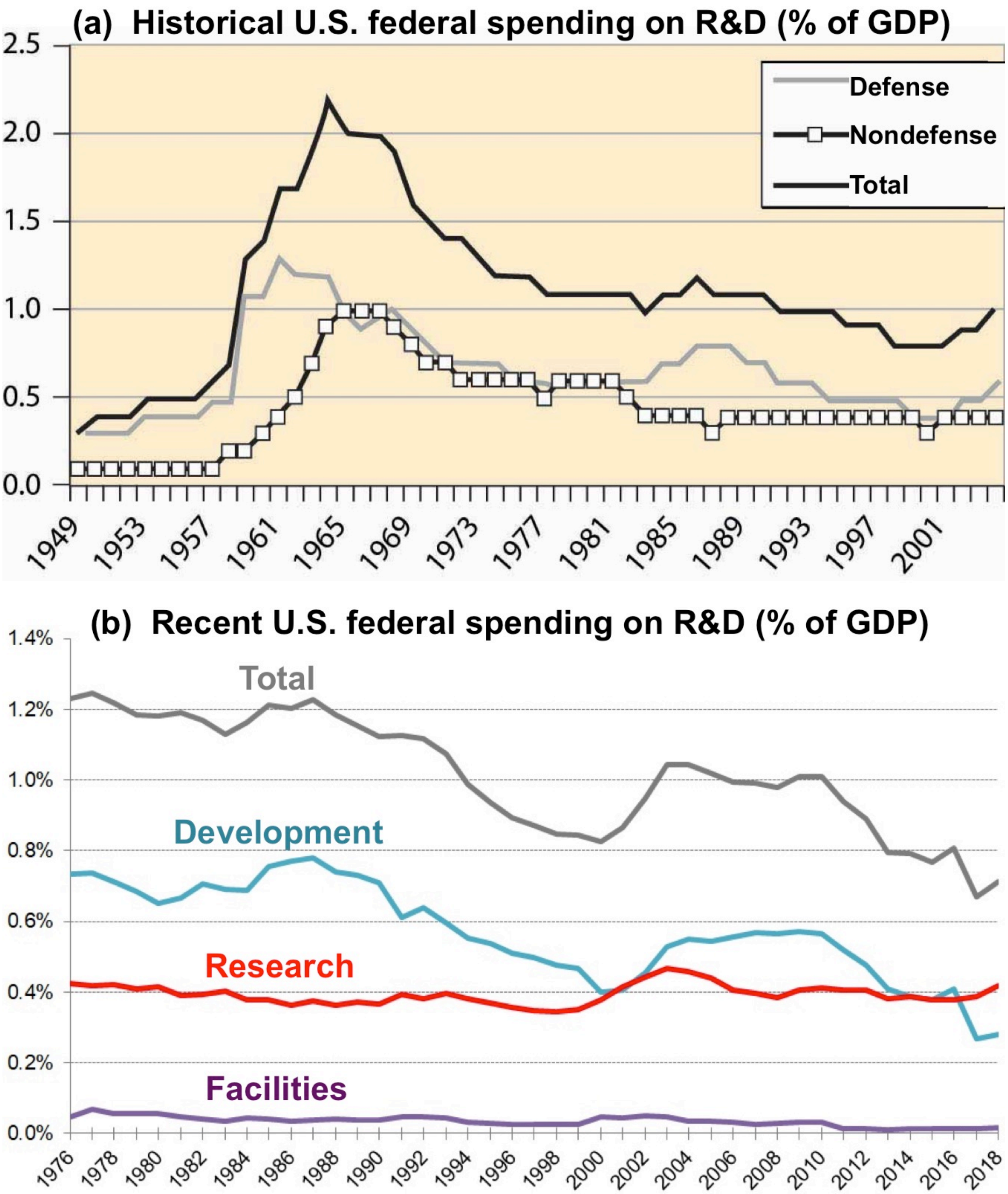


Figure 11.62: U.S. federal R&D spending regraphed as a percentage of the U.S. gross domestic product (GDP) for each year. (a) Historical overview for 1949–2005. (b) More detailed graph for 1976–2018. [https://saylordotorg.github.io/text_introduction-to-economic-analysis/s05-05-government.html#mcafee-ch04_s05_f10; https://www.aaas.org/programs/r-d-budget-and-policy/historical-trends-federal-rd].

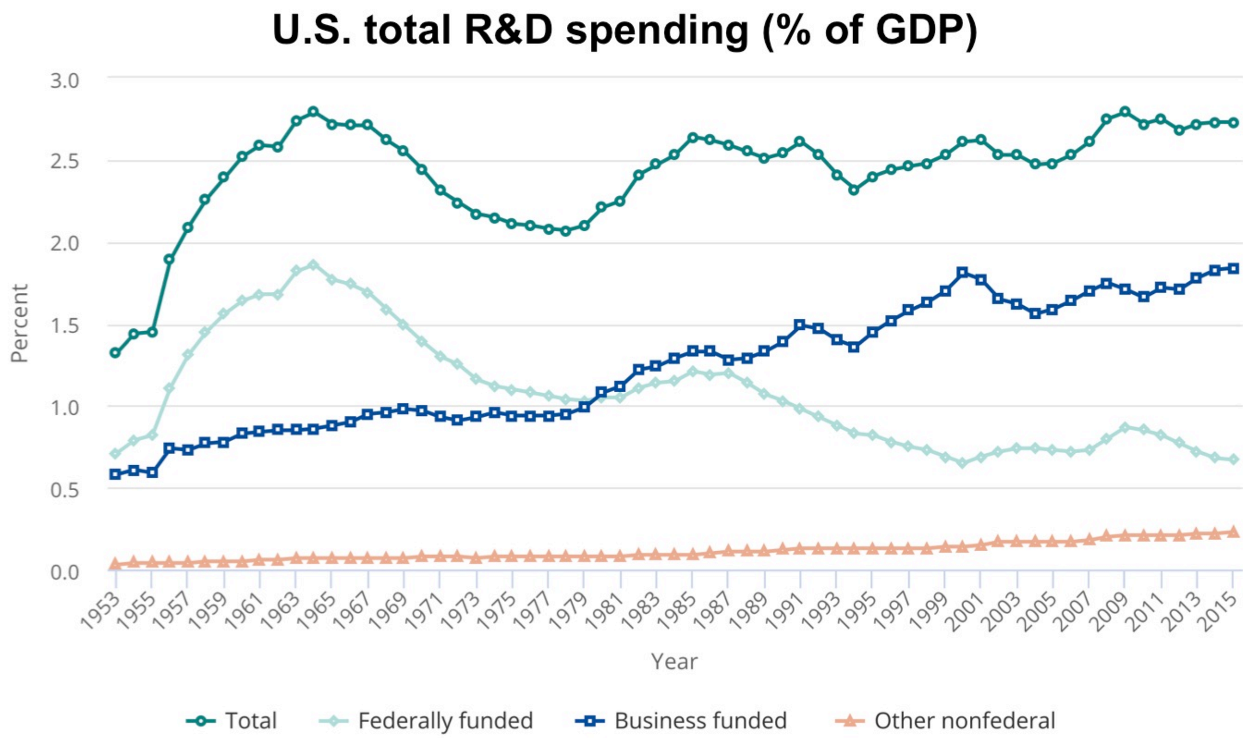


Figure 11.63: U.S. total R&D spending, including federally funded, business funded, and other non-federal funded work (e.g., by nonprofit foundations or state governments). All spending is expressed as a percentage of the GDP for each year. Taking the numbers at face value, the total U.S. R&D funding as a percentage of GDP has remained roughly constant since the early 1980s. Considering the shift in recent decades from longer-term to much shorter-term R&D, funding for innovative research has actually significantly declined [https://www.nsf.gov/statistics/2018/nsb20181/figures].

Of course, not all R&D spending comes from the federal government. Figure 11.63 shows U.S. total R&D spending, including federally funded, business funded, and other nonfederal funded work. All spending is expressed as a percentage of the GDP for each year:

- As previously shown in Fig. 11.62, the share of federal funding peaked in the 1960s space race and has generally been declining ever since, now down to approximately one third of its earlier peak value.

- Business funding has generally increased steadily, although the quantitative numbers do not indicate the qualitative shift in business R&D from longer-term development of major innovations such as integrated circuits and jet aircraft in the 1950s to immediately marketable products such as smart phone apps in the 2010s.

- Other nonfederal R&D funding (such as by nonprofit foundations and state governments) has been slowly increasing but is still much smaller than federal and business funding.

- Even accepting the numbers at face value, the total U.S. R&D funding as a percentage of GDP has remained roughly constant since the early 1980s. With flat funding, effectively the only way for newly graduated scientists and engineers to find a permanent position is to wait for someone older in an existing position to retire or to die. This fact creates pressures that greatly restrict how many new innovators can find employment, and how innovative they are allowed to be under such conservative, resource-limited conditions. Moreover, since over the last several decades more of the available government research jobs have shifted toward bureaucracy, more of the available academic jobs have shifted toward continuous paper and grant writing, and more of the business research jobs have shifted toward producing very short-term, low-risk products, one could argue that the funding for innovative research has significantly declined instead of stayed flat.

For comparison, Fig. 11.64 presents the total R&D spending (from government, industrial, and other sponsors) for a number of other countries, graphed as either purchasing power parity (PPP) dollars or a percentage of each country's GDP for each year. Note that just as R&D spending relative to GDP has been relatively flat in the United States for decades, it has also been fairly flat in most other countries for many years. (As noted for Fig. 11.63, by analyzing the types of R&D activities being supported now versus at earlier times, one might even argue that these apparently flat funding trends have actually been effective declines in innovative research.) From the graph, the most notable exceptions to this trend are China and South Korea, which have each significantly increased their R&D investments. China's R&D increase is especially dramatic, since both China's GDP and its ratio of R&D to GDP have been increasing relatively rapidly.

MIT economists Jonathan Gruber and Simon Johnson described the impact of funding changes on the rise and decline of innovation in the United States [Gruber and Johnson 2019, pp. 4–10]:

> In 1938, on the eve of world war, federal and state governments spent a combined 0.076 percent of national income on scientific research, a trivial amount. By 1944, the US government was spending nearly 0.5 percent of national income on science—a sevenfold increase, most of which was channeled through [Vannevar] Bush's organization from 1940. The effects of this unprecedented surge were simply incredible and, for America's enemies, ultimately devastating.

Then, in 1945, Vannevar Bush had what may be considered his most profound insight. [...]

What was needed next, Bush argued, was a redirection to focus on winning the peace. [...]

From 1940 to 1964, federal funding for research and development increased twentyfold. At its peak in the mid-1960s, this spending amount was around 2 percent of annual gross domestic product—roughly one in every fifty dollars in the United States was devoted to government funding of research and development (equivalent, relative to GDP, to almost $400 billion today). The impact on our economy, on Americans, and on the world was simply transformational. [...]

It is hard to find any aspect of modern life that has not been profoundly affected by innovation that can be traced back either to the Bush-era efforts or to inventions that were supported by various government programs in the years that followed. [...]

Unfortunately, we failed to maintain the [innovation] engine. From the mid-1960s onward, based on concerns about the environmental, military, and ethical implications of unfettered science, compounded by shortsighted budget math, the government curtailed its investments in scientific research. Economic difficulties during the 1970s, followed by the Reagan Revolution and the anti-tax movement, resulted in an even broader retreat from federally funded activities. Most recently, the impact of a global financial crisis in 2008 and consequent economic pressures—known as the Great Recession—have further squeezed investments in the scientific future.

Federal spending on research and development peaked at nearly 2 percent of economic output in 1964 and over the next fifty years fell to only around 0.7 percent of the economy. Converted to the same fraction of GDP today, that decline represents roughly $240 billion per year that we no longer spend on creating the next generation of good jobs.

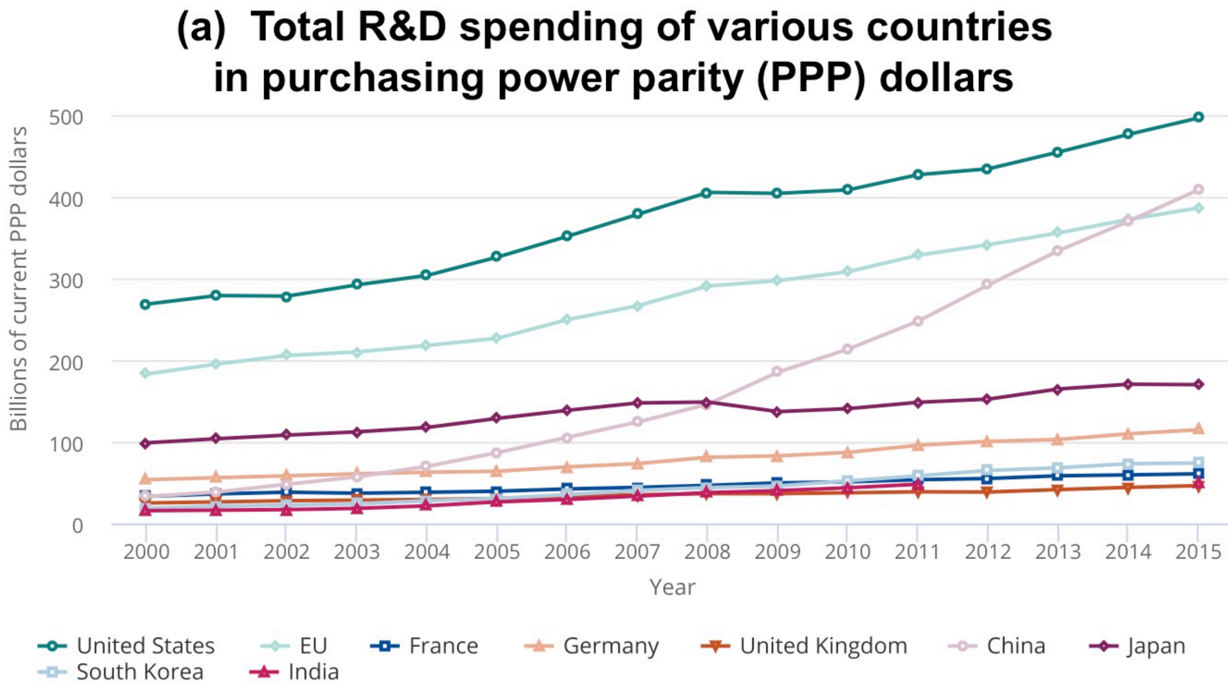
Should we care? If there is socially beneficial research and product development to be done, surely the innovative companies of today will take this on?

In fact, they won't. [...]

The venture capital sector that has created so many high-tech success stories has, at the same time, avoided the type of very-long-run and capital-intensive investments that lead to technological breakthroughs—and create new industries and jobs.

As a result, the government retreat from research and development has not been fully offset by the private sector.

While we have retreated from Vannevar Bush's innovation engine, the rest of the world is picking up the slack. Total research funding is growing at a much faster rate, relative to the economy, in the rest of the world than it is in the United States, led in many countries by active government policies.



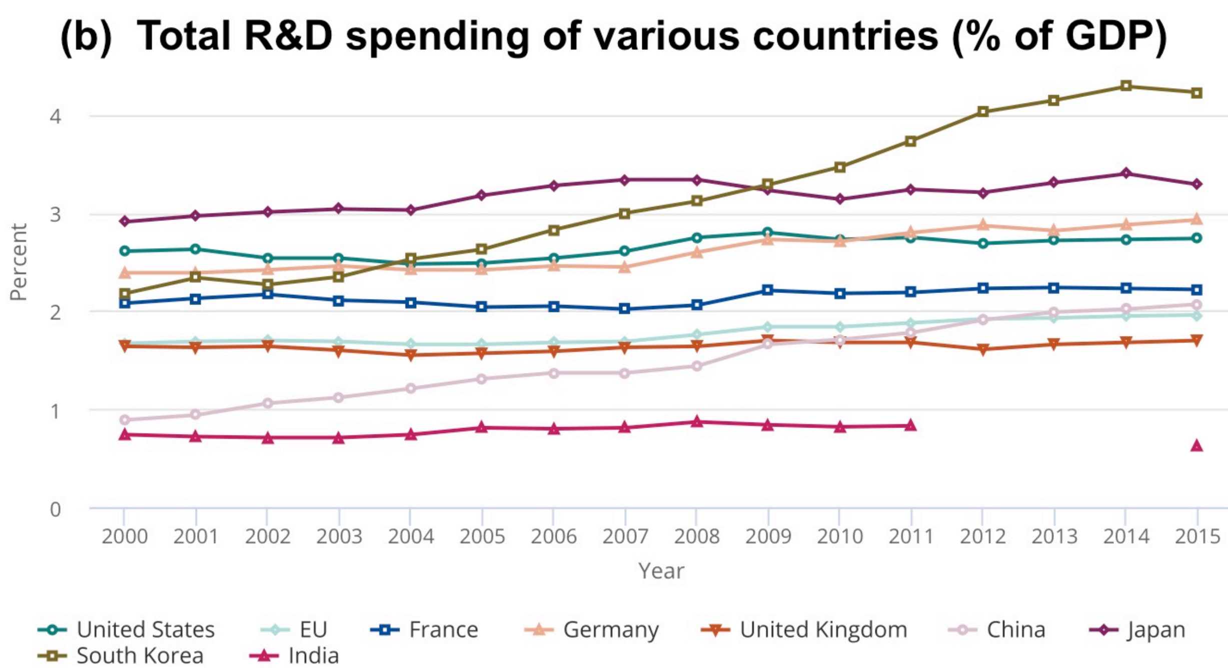


Figure 11.64: Total R&D spending for various countries, graphed as (a) purchasing power parity (PPP) dollars, and (b) a percentage of each country's GDP for each year. Note that relative to GDP, R&D spending has been relatively flat for most countries for many years, with the exception of significant investments by China and South Korea [https://www.nsf.gov/statistics/2018/nsb20181/figures].

11.2.3 Mentoring Style

As described in Section 10.2.3, many (though certainly not all) Ph.D. students in the German-speaking world were actively encouraged to independently propose and conduct their own thesis research, thereby honing their skills as highly creative and independent innovators. A number of German-speaking creators described similar experiences during their doctoral research; Section 10.2.3 quoted just a few illustrative examples.

In the early U.S. research system, it is more difficult to find many examples of students who were given such freedom to innovate in pursuing their Ph.D. thesis research. Most thesis topics appear to have been assigned by the Ph.D. advisor, or selected from among a short list of possible topics offered by the advisor, and then closely supervised by the advisor throughout the thesis research. Thus the U.S. students seem to have had fewer opportunities than their German-speaking counterparts to acquire and practice skills at independent innovation early in life.

When biographical and autobiographical accounts of U.S. scientists do reveal that they enjoyed remarkable independence in their Ph.D. thesis research, that independence was often a result of being supervised or assisted by someone who had come from the German-speaking scientific world. For example, historians Lillian Hoddeson and Vicki Daitch described John Bardeen's experiences as a Ph.D. student at Princeton in the 1930s; Bardeen later became the only person to ever win two Nobel Prizes in physics [Hoddeson and Daitch 2002, pp. 50–52, 54–55]:

> Princeton followed suit in 1930, hiring two Hungarian members of the Berlin circle of physics and mathematics, John von Neumann and Eugene Wigner, who were old friends. [...]
>
> Bardeen later wrote that of all his professors at Princeton he was "most stimulated by the two young Hungarians." [...]
>
> In shopping around for a thesis advisor, Bardeen spoke first with [U.S. physicist Edward] Condon, but he found that all of Condon's suggestions concerned filling gaps in the textbook he was then completing with G. H. Shortley, *The Theory of Atomic Spectra.* That "didn't sound too interesting" to Bardeen. [...]
>
> Bardeen decided to throw in his lot with Wigner and never regretted it. He found he needed only occasional meetings to keep his thesis on track. Wigner later told Seitz "that he rarely communicated with Bardeen." But what Bardeen remembered about Wigner was that he always had ways to motivate him with his penetrating questions. Most importantly, Bardeen felt that Wigner instructed him in the art of choosing crucial problems. "He could see what was essential and what the important problems were."
>
> Bardeen also felt that Wigner taught him how to go about attacking problems. The first step was to decompose the problem, either into smaller problems with less scope or into simpler problems that contained the essence of the larger problem. Bardeen said that Wigner stressed reducing to "the simplest possible case, so you can understand that before you go on to something more complicated."

Unfortunately, most Ph.D. thesis advisors in the United States apparently preferred the approach of Condon over that of Wigner (as described by Bardeen), using students as cogs in the machinery to advance the advisors' own research and publications rather than encouraging the students to be as innovative and independent as possible. To succinctly summarize the difference, one might say that the best early German-speaking advisors viewed their roles as *mentors* to offer advice to their students, whereas most native U.S. advisors viewed their roles as *masters* to harness the labor of their students.

In fact, it is remarkable how many creative U.S. scientists studied under German-speaking advisors. In addition to John Bardeen, Eugene Wigner supervised or co-supervised Ph.D. theses for Frederick Seitz, Richard Feynman, and many others. As other examples, Hans Bethe supervised the studies of Jeffrey Goldstone, Roman Jackiw, Freeman Dyson, and others; Victor Weisskopf supervised Ph.D. theses for John David Jackson, Murray Gell-Mann, and other physicists.

Judging from the scarcity of accounts, as the early U.S. research system matured into the modern system, advisors who advocated for students to be as creative and self-directed as possible apparently became ever more scarce. As discussed in the next section, the ages at which students received their Ph.D. also became older. Due to the combination of these two factors, scientists had fewer and fewer opportunities to learn and practice innovation during their formative years.

It should be noted that these problems extend far beyond the United States. The astrophysicist Martin López-Corredoira, who has worked in Spain and Switzerland and gathered information on the academic system worldwide, reported on the common experiences of Ph.D. students in the modern scientific world [López-Corredoira 2013, pp. 62–65]:

> The first contact with research takes place when a graduate student prepares a Ph.D. thesis. [...] If the student wants financial as well as departmental support, then his or her role is to be obedient to, and assimilate, the traditions of the department. [...]
>
> In some cases, the students that do most of the work are not able to write a paper containing their results; the bosses do it instead, as first authors of the paper. Students are told that they do not know how to write their own work. In other cases, when the supervisor sees that things will not have the outcome he or she wants, the supervisor will abandon the student. In some cases, the supervisor steals the student's ideas. In other cases, a student's time as a Ph.D. student is over before the thesis is finished because he or she was exploited by having to carry out other work aside from their thesis, or the boss had no time to attend to the explanations produced by the student. In such cases, the student must struggle to survive while writing up.
>
> Few bosses sit down and work with students. Normally, they spend some time during the early days explaining how to do things. After that, the student must carry out the routine tasks. The boss just provides the ideas, if they have them; otherwise, they just make minor corrections. The student spends weeks or months with the monotonous tasks in the laboratory, observatory, or in front of a computer with annoying calculations or simulations that consume a lot of time, or with analytical calculations, or carrying out bibliographical research or whatever. Students closer to an empirical branch of the sciences spend a long time with the instruments. The boss is usually present as well, but only to initially explain to the student how the machine works, or when something

> unusual happens, or there are extraordinary observations unrelated to the usual routine. Meanwhile the boss manages and generates ideas. [...]
>
> However, spending time thinking about one's own ideas, without permission, is something that is really not encouraged by the system; quite the opposite. Initiative is discouraged with arguments such as what is established is established. Workers for science are created instead of thinkers. [...]
>
> What is wrong with this situation, I continue to ask. Mainly, that [it is] industrial (mass-produced) science, rather than creativity being encouraged, and the period of optimum creativity of a scientist is exhausted with these ups and downs. We must take into account that, in the long history of science, the majority of great ideas were produced by young scientists. If young students, who could potentially produce new ideas, are used as slaves (or perhaps it is better to say "science workers"), then perpetuation of old ideas and intellectual stagnation are rife.

Even though doctoral educational and research programs worldwide were founded based on the model of the earlier German-speaking world, they appear to have strayed further and further from the fundamental principles that made the original German-speaking academic programs so successful at cultivating revolutionary scientific innovators.

11.2.4 Average Age for Final Degree

To compare the ages at which people received their final degree for the brightest American scientists and the brightest German-speaking scientists of the same era, one can use data from Nobel Prize winners. Scientists who were educated in the United States and won a Nobel Prize in Physiology or Medicine, Chemistry, or Physics prior to 1991 are listed in Tables 11.10, 11.11, and 11.12 respectively. The ages at which the scientists received their final degrees are shown in the tables.

In order to keep the data set focused on the U.S. educational system, scientists who had some of their training in that system but a significant part of their training outside that system (e.g., Americans such as Irving Langmuir who completed their education in Germany, or German speakers such as Konrad Bloch who completed their education in the U.S. system) are omitted from these tables.

Unless otherwise noted, all of the individuals in these three tables graduated with a Ph.D. As shown in Table 11.10, many of the winners of a Nobel Prize in Physiology or Medicine had an M.D. instead of a Ph.D. As indicated in the tables, two Nobel Prize winners graduated with a final degree that was not a doctorate. As also noted, a few individuals were delayed in receiving their final degree, due to military service, war disruptions, serious illness, or work obligations.

Students could graduate at any time of year, depending on when their doctoral thesis was completed and approved. In most cases only the year of graduation and not the exact date was readily available. In such cases, the graduation was assumed to have occurred on average in the middle of the year, and the students' ages at graduation calculated accordingly. Any errors caused by this assumption should mostly cancel each other out when averages are taken over entire groups of people.

Nobel Prize	**Name**	**Born**	**Graduated**	**Age**
1933	Thomas Hunt Morgan	25 September 1866	1890	24
1934	George Whipple	28 August 1878	1905	26 (M.D.)
1934	George Minot	2 December 1885	1912	26 (M.D.)
1934	William Murphy	6 February 1892	1922	30 (M.D.)
1943	Edward Doisy	13 November 1893	1920	26
1944	Joseph Erlanger	5 January 1874	1899	25 (M.D.)
1944	Herbert Gasser	5 July 1888	1915	26 (M.D.)
1946	Hermann Muller	21 December 1890	1960	25
1950	Philip Hench	28 February 1896	1920	25 (M.D.)
1950	Edward Kendall	8 March 1886	1910	25
1954	John Enders	10 February 1897	1930	33 (war)
1954	Frederick Robbins	25 August 1916	1940	24 (M.D.)
1954	Thomas Weller	15 June 1915	1940	25 (M.D.)

Table 11.10: Ages at final degree for scientists who were educated primarily or entirely in the United States and won a Nobel Prize in Physiology or Medicine prior to 1991. (Continued on next page.)

Nobel Prize	Name	Born	Graduated	Age
1956	Dickinson Richards	30 October 1895	1923	27 (M.D., war)
1958	George Beadle	22 October 1903	1931	27
1958	Edward Tatum	14 December 1909	1934	24
1958	Joshua Lederberg	23 May 1925	1947	22
1959	Arthur Kornberg	3 March 1918	1941	23 (M.D.)
1962	James Watson	6 April 1928	1950	22
1966	Peyton Rous	5 October 1879	1905	25 (M.D., illness)
1966	Charles Huggins	22 September 1901	1924	23 (M.D.)
1967	Haldan Hartline	22 December 1903	1927	23 (M.D.)
1967	George Wald	18 November 1906	1932	25
1968	Robert Holley	28 January 1922	1947	25
1968	Marshall Nirenberg	10 April 1927	1957	30
1969	Alfred Hershey	4 December 1908	1934	25
1970	Julius Axelrod	30 May 1912	1955	43 (work)
1971	Earl Sutherland	19 November 1915	1942	26 (M.D.)
1972	Gerald Edelman	1 July 1929	1954	24 (M.D.)
1975	David Baltimore	7 March 1938	1964	26
1975	Howard Temin	10 December 1934	1959	24
1976	Baruch Blumberg	28 July 1925	1951	25 (war)
1976	D. Carleton Gajdusek	9 September 1923	1946	22 (M.D.)
1977	Rosalyn Yalow	19 July 1921	1945	23
1978	Daniel Nathans	30 October 1928	1954	25 (M.D.)
1978	Hamilton Smith	23 August 1931	1956	24 (M.D.)
1980	George Snell	19 December 1903	1930	26
1981	Roger Sperry	20 August 1913	1941	27
1983	Barbara McClintock	16 June 1902	1927	25
1985	Michael Brown	13 April 1941	1966	25 (M.D.)
1985	Joseph Goldstein	18 April 1940	1966	26 (M.D.)
1986	Stanley Cohen	17 November 1922	1948	25
1988	Gertrude Elion	23 January 1918	1941	23 (no doctorate)
1988	George Hitchings	18 April 1905	1933	28
1989	J. Michael Bishop	22 February 1936	1962	26 (M.D.)
1989	Harold Varmus	18 December 1939	1966	26 (M.D.)
1990	Joseph Murray	1 April 1919	1944	25 (M.D.)
1990	E. Donnall Thomas	15 March 1920	1946	26 (M.D.)

Table 11.10 (continued): Ages at final degree for scientists who were educated primarily or entirely in the United States and won a Nobel Prize in Physiology or Medicine prior to 1991.

Nobel Prize	**Name**	**Born**	**Graduated**	**Age**
1914	Theodore Richards	31 January 1868	1888	20
1946	James Sumner	19 November 1887	1914	26
1946	John Northrop	5 July 1891	1915	23
1946	Wendell Stanley	16 August 1904	1929	24
1949	William Giauque	12 May 1895	1922	27 (work)
1951	Edwin McMillan	18 September 1907	1933	25
1951	Glenn Seaborg	19 April 1912	1937	25
1954	Linus Pauling	28 February 1901	1925	24
1955	Vincent du Vigneaud	18 May 1901	1927	26
1960	Willard Libby	17 December 1908	1933	24
1961	Melvin Calvin	8 April 1911	1935	24
1965	Robert Woodward	10 April 1917	1937	20
1966	Robert Mulliken	7 June 1896	1921	25 (war)
1972	Christian Anfinsen	26 March 1916	1943	27
1972	Stanford Moore	4 September 1913	1938	24
1972	William Stein	25 June 1911	1938	26
1974	Paul Flory	19 June 1910	1934	23
1976	William Lipscomb	9 December 1919	1946	26
1979	Herbert Brown	22 May 1912	1938	26
1980	Paul Berg	30 June 1926	1952	25
1980	Walter Gilbert	21 March 1932	1957	25
1984	Robert Merrifield	15 July 1921	1949	27
1985	Herbert Hauptman	14 February 1917	1955	38 (work)
1985	Jerome Karle	18 June 1918	1944	25
1986	Dudley Herschbach	18 June 1932	1958	25
1987	Donald Cram	22 April 1919	1947	28
1987	Charles Pedersen	3 October 1904	1927	22 (no doctorate)
1989	Thomas Cech	8 December 1947	1975	27
1990	E. J. Corey	12 July 1928	1950	22

Table 11.11: Ages at final degree for scientists who were educated primarily or entirely in the United States and won a Nobel Prize in Chemistry prior to 1991.

Nobel Prize	Name	Born	Graduated	Age
1923	Robert Millikan	22 March 1868	1895	27
1927	Arthur Compton	10 September 1892	1916	23
1936	Carl Anderson	3 September 1905	1930	24
1937	Clinton Davisson	22 October 1881	1911	29
1939	Ernest Lawrence	8 August 1901	1925	23
1944	I. I. Rabi	29 July 1898	1926	27
1946	Percy Bridgman	21 April 1882	1908	26
1952	Edward Purcell	30 August 1912	1938	25
1955	Willis Lamb	12 July 1913	1938	25
1955	Polykarp Kusch	26 January 1911	1936	25
1956 & 1972	John Bardeen	23 May 1908	1936	28
1956	Walter Brattain	10 February 1902	1929	27
1956	William Shockley	13 February 1910	1936	26
1959	Owen Chamberlain	10 July 1920	1949	28
1960	Donald Glaser	21 September 1926	1950	23
1961	Robert Hofstadter	5 February 1915	1938	23
1964	Charles Townes	28 July 1915	1939	24
1965	Richard Feynman	11 May 1918	1942	24
1965	Julian Schwinger	12 February 1918	1939	21
1968	Luis Alvarez	13 June 1911	1935	25
1969	Murray Gell-Mann	15 September 1929	1951	21
1972	Leon Cooper	28 February 1930	1954	24
1972	John Schrieffer	31 May 1931	1957	26
1975	Leo Rainwater	9 December 1917	1946	28 (war)
1976	Burton Richter	22 March 1931	1956	25
1976	Samuel Ting	27 January 1936	1962	26
1977	Phillip Anderson	13 December 1923	1949	25 (war)
1977	John Van Vleck	13 March 1899	1922	23
1978	Arno Penzias	26 April 1933	1962	29 (war)
1978	Robert Wilson	10 January 1936	1962	26
1979	Sheldon Glashow	5 December 1932	1959	26
1979	Steven Weinberg	3 May 1933	1957	24
1980	James Cronin	29 September 1931	1955	23
1980	Val Fitch	10 March 1923	1954	31 (war)
1981	Arthur Schawlow	5 May 1921	1949	28 (war)
1982	Kenneth Wilson	8 June 1936	1961	25
1983	William Fowler	9 August 1911	1936	24
1988	Leon Lederman	15 July 1922	1951	28
1988	Melvin Schwartz	2 November 1932	1958	25
1988	Jack Steinberger	25 May 1921	1948	27 (war)
1989	Norman Ramsey	27 August 1915	1940	24
1990	Jerome Friedman	28 March 1930	1956	26
1990	Henry Kendall	9 December 1926	1955	28

Table 11.12: Ages at final degree for scientists who were educated primarily or entirely in the United States and won a Nobel Prize in Physics prior to 1991.

Table 11.13 summarizes the average ages at graduation from Tables 11.10–11.12 for the U.S. system, excluding those whose education was delayed by war, work, or illness. For comparison, the corresponding average ages from Tables 10.3–10.6 for the German-speaking world are also included. As may be seen, on average those U.S.-educated scientists took approximately two years longer to complete their education than their contemporary counterparts from the German-speaking world. [For related issues, see Dahlgreen 2016.]

Category of people	**Age at graduation from German-speaking world**	**Age at graduation from U.S. system**
Ph.D., Physics Nobel 1901–1990	23.2 years	25.1 years
Ph.D., Chemistry Nobel 1901–1990	22.4 years	24.7 years
Ph.D., Medicine Nobel 1901–1990	23.6 years	25.2 years
M.D., Medicine or Chemistry Nobel	23.8 years	25.0 years
Final degree, all science Nobelists	23.0 years	24.9 years
Ph.D., non-Nobel sample	22.4 years	—
Ph.D., Nobel + non-Nobel sample	22.7 years	25.0 years
M.D., Nobel + non-Nobel sample	23.8 years	25.0 years
Final degree, Nobel + non-Nobel sample	22.9 years	24.9 years

Table 11.13: Ages at final degree for selected scientists educated in German-speaking and U.S. systems.

As a further comparison, the current situation in the U.S. educational system is even worse. For those receiving a doctorate in 2017, the median age at graduation was 31.6 [https://ncses.nsf.gov/pubs/nsf19301/data]. That is nearly a decade older than students who received a Ph.D. from the earlier German-speaking world.

Each increase in the average age at which scientists and engineers receive their final degree means fewer years for their research careers, especially fewer available years when they are youngest, most creative, most energetic, and least distracted by other factors in their lives (family obligations, serving on committees, etc.):

- By this criterion, scientists in the early U.S. research system graduated approximately two years behind their contemporary German-speaking peers, which might be one factor explaining why those U.S. scientists may have created fewer revolutionary innovations per person than their German-speaking peers.

- Yet scientists in the modern U.S. research system graduate approximately 6.5 years behind even those early U.S. scientists, and nearly a decade behind the early German-speaking creators, which might help explain why the modern system may create even fewer revolutionary innovations per person.

The problem is even worse than those numbers indicate. In general, many (though certainly not all) of the German-speaking creators and the early U.S. scientists were able to conduct truly independent research as soon as they obtained their doctoral degrees, if not before. In contrast, scientists who receive a Ph.D. or M.D. in the modern U.S. system typically then have to spend many years following older supervisors' instructions in postdoctoral jobs, residencies, or entry-level positions at corporate or government laboratories. In 2020, the average age at which Ph.D. scientists received their first National Institutes of Health (NIH) research project grant was 43, and the average age at which M.D. scientists received their first NIH research grant was 46 [https://nexus.od.nih.gov/all/2021/11/18/long-term-trends-in-the-age-of-principal-investigators-supported-for-the-first-time-on-nih-r01-awards/]. Thus many German-speaking creators and early U.S. scientists achieved similar independence on average two whole decades in life earlier than scientists in the modern U.S. system.

As discussed in Chapter 12, this data suggests that one way to improve the modern innovation system would be to eliminate redundancies between high school and undergraduate education, streamline the graduate school educational process, greatly lower the average ages at which scientists receive their final degrees and their first financial grants, and give young scientists much more independence during their most energetic and creative years.

11.2.5 Interdisciplinary Approach

A significant fraction of the German-speaking creators were individuals who had demonstrated that they could be productive in multiple scientific fields in Europe (Section 10.2.5), and that continued to be true for many of the German-speaking creators who moved to the United States before, during, or after the Third Reich. Many examples could be cited; here are just a few of the better known cases:

- Hans Bethe was a vigorous force in fields from astrophysics to international politics [Bethe 1991].

- Carl Djerassi not only helped to develop oral contraceptives, new methods for analytical chemistry, and safer pesticides, but also wrote novels and plays that received worldwide recognition [Carr 2009; http://www.djerassi.com].

- Krafft Ehricke made major advances in rocket design, nuclear engineering, orbital mechanics, and planetary science [Freeman 2008].

- George Gamow advanced our knowledge of both the Big Bang and the genetic code [Gino Segrè 2011].

- John von Neumann made major contributions to everything from nuclear weapons design to computers to economics to political policy [Macrae 1992].

- Leo Szilard was responsible for the beginnings of both the Manhattan Project and molecular biology research in the United States [Lanouette and Silard 1992].

- Herbert Wagner developed jet engines, guided missiles, and nuclear engineering projects [p. 4203; Christopher 2013; Constant 1980].

- Fritz Zwicky was known for his exceptional creativity in fields ranging from jet propulsion to astrophysics [John Johnson, Jr., 2019; Stöckli and Müller 2008].

Among the American-born creators who were active during the golden age of the U.S. system, there appear to have been fewer truly interdisciplinary individuals, although there were a few notable cases; for example:

- John Bardeen made Nobel-prize-winning contributions to both transistors and superconductivity [Hoddeson and Daitch 2002].

- Linus Pauling contributed to quantum physics, chemistry, protein structure, DNA research, and international politics [Serafini 1989].

- Simon Ramo was instrumental in national programs ranging from air defense systems to ballistic missiles, and he was as skilled at business and politics as he was at science and engineering [Ramo 1988].

In modern peer-reviewed committee decisions for research grants and academic tenure, very long lists of papers in the same narrow specialty are especially valued, and it is difficult to find examples of revolutionary innovators who are making major contributions in several very different fields. There are probably still some who have survived within the modern system, but the trend seems to be that interdisciplinary creators were most valued, and therefore most prevalent, in the earlier German-speaking world, still in evidence in the 1940s–1960s U.S. system, and increasingly rare in the decades since.

One might object that modern scientific fields have advanced so far that it is no longer feasible for individuals to acquire sufficient multidisciplinary expertise. However, that objection does not seem valid when one examines the enormous knowledge, expertise, and accomplishments of earlier scientists such as John von Neumann or Enrico Fermi, or when one considers that revolutionary innovations in many fields seem to have matured and stagnated at the level that was created by those same interdisciplinary creators. In other words, if those earlier multidisciplinary creators were revived from the dead today, they would probably be able to quickly catch up on the few truly important developments they had missed, and then continue their work in multiple fields. If individuals could be so successful studying and working in multiple disciplines in the twentieth century, modern students should be able to acquire the same breadth and depth of expertise now.

Certainly most scientists and engineers can be rather specialized and still contribute fully to the system. Nonetheless, there is great value if some small but significant fraction of individuals possesses a much broader interdisciplinary expertise. With that broader view of the entire scientific landscape, they can help to:

1. Guide the system toward more revolutionary areas that might otherwise be overlooked by those with only microspecialized views of known areas.

2. Take successful methodologies, discoveries, and inventions from one area and apply them to make advances in a completely different area.

3. Spot areas that for certain fundamental reasons are scientific dead ends.

4. Effectively communicate the state of scientific fields to scientists in other fields, government leaders, business leaders, students, and the general public.

11.2.6 Scientific Leadership and Decision-Making Style

Just as certain high-level scientific managers in the earlier German-speaking world seem to have operated as enlightened despots in identifying and funding promising creators and creations, a large number of enlightened despots appear to have greatly contributed to the successes of the U.S. research system from the 1940s through the 1960s. Without in any way attempting an exhaustive list, this section provides examples illustrating the impact that individual enlightened despots had on the U.S. research system.

Like the earlier German-speaking enlightened despots, these U.S. enlightened despots had different individual styles, various opportunities, and differing levels of success; they were all imperfect in their scientific judgment and/or personal character (some more than others), and most if not all of them made some strong enemies along the way. Nonetheless, also like their earlier German-speaking counterparts, each of these U.S. despots had:

- The strong and direct support of very high authorities (in many cases actually the U.S. President).
- A keen eye for revolutionary innovators and innovations.
- The ability to directly offer steady employment and funding for any innovators and innovations they deemed worthy, by circumventing the much slower and more risk-averse normal bureaucratic processes for application, review, approval, renewal, etc.

Vannevar Bush (1890–1974), shown in Fig. 11.65, may be viewed as the political father of the U.S. research world,[10] just as Friedrich Althoff may be viewed as the political father of the earlier German-speaking research world (p. 2013). Like Althoff, Bush also installed or aided a number of other enlightened despots, such as those shown in the lower half of Fig. 11.65. Bush was an electrical engineering professor and vice president at the Massachusetts Institute of Technology (MIT) as World War II approached and U.S. government funding for R&D was minimal. Bush became president of the Carnegie Institution for Science in Washington, DC (1939–1955), as well as chair and member of the advisory board of the National Advisory Committee for Aeronautics (NACA, the predecessor of NASA, 1938–1948). In 1940 he successfully lobbied President Franklin Roosevelt to create the National Defense Research Committee (NDRC) and Office of Scientific Research and Development (OSRD), which Bush ran until 1947 and in which capacity he reported directly to the President. Bush's NDRC and OSRD were in charge of creating, funding, and managing all military scientific R&D in the United States during these years, including U.S. developments in nuclear fission reactors and weapons, radar systems, proximity fuses, penicillin mass production, and other innovations. After the war, Bush proposed and successfully lobbied for the establishment of the major U.S. government research sponsoring agencies, including the creation of the National Science Foundation, the Atomic Energy Commission (now called the Department of Energy), and the military Research and Development Board (RDB, predecessor of later Department of Defense research sponsoring offices), as well as major expansions of NACA and the National Institutes of Health (NIH). Bush also strongly promoted corporate research while serving on the board of directors for American Telephone and Telegraph (AT&T, 1949–1962), Merck (1949–1962), and other companies.

[10] Baxter 1946; Burchard 1948; Bush 1946, 1949, 1960, 1967, 1970; James Conant 1970; Jennet Conant 2002; Schrage 1990; Wiesner 1979; Zachary 1997a, 1997b, 2022.

Vannevar Bush

Figure 11.65: Examples of scientific "enlightened despots" who had a large impact on the U.S. system. Above: Vannevar Bush established the entire government-funded research system during and immediately after World War II. Below: March 1940 meeting of Ernest Lawrence, Arthur Compton, Vannevar Bush, James Conant, Karl Compton, and Alfred Loomis (from left to right).

Bush laid out some of his views on scientific innovation in an allegorical essay entitled "The Builders" [Bush 1967, pp. 11–12]:

> The process by which the boundaries of knowledge are advanced, and the structure of organized science is built, is a complex process indeed. It corresponds fairly well with the exploitation of a difficult quarry for its building materials and the fitting of these into an edifice[...]
>
> In these circumstances it is not at all strange that the workers sometimes proceed in erratic ways. There are those who are quite content, given a few tools, to dig away, unearthing odd blocks, piling them up in the view of fellow workers, and apparently not caring whether they fit anywhere or not. Unfortunately there are also those who watch carefully until some industrious group digs out a particularly ornamental block, whereupon they fit it in place with much gusto and bow to the crowd. Some groups do not dig at all, but spend all their time arguing as to the exact arrangement of a cornice or abutment. Some spend all their days trying to pull down a block or two that a rival has put in place. Some, indeed, neither dig nor argue, but go along with the crowd, scratch here and there, and enjoy the scenery. Some sit by and give advice, and some just sit.
>
> On the other hand there are those men of rare vision, who can grasp well in advance just the block that is needed for rapid advance on a section of the edifice to be possible, who can tell by some subtle sense where it will be found, and who have an uncanny skill in cleaning away dross and bringing it surely into the light. These are the master workmen.

Historian G. Pascal Zachary gave an excellent overview of Bush's personality and legacy [Zachary 1997a, pp. 4–5, 7–8]:

> [...] Bush believed Americans should freely give public-spirited experts ultimate authority over the nation's security. He ranked the engineer as first among equals, a sort of super-citizen who could master virtually every activity essential to the smooth functioning of a modern nation. What distinguished the engineer from other experts was his breadth. Bush saw the engineer as a pragmatic polymath; the engineer, he once wrote, "was not primarily a physicist, or a business man, or an inventor but [someone] who would acquire some of the skills and knowledge of each of these and be capable of successfully developing and applying new devices on the grand scale."
>
> This realization that the engineer was the *engine* of 20th-century capitalism qualified Bush as the godfather of high technology and a leading proponent of industrial vitality through innovation, not intrigue. [...] At midcentury, he was among the few who realized the curative power of new ventures. The best way to limit monopoly economic power, he insisted, was through "the advent of small new industrial units, for if these latter have half a chance they can cut rings around the great stodgy concern."
>
> Such contrarian views made Bush a divisive figure. His personality didn't always help either. His philosopher-king aura smacked of arrogance, even meanness to some. He struck his critics as imperious, intimidating and at times even a bully who harbored "a relentless, perhaps insatiable, drive for power." Still he had redeeming qualities. His wit and charm prompted comparisons with the folksy Will Rogers. His intelligence,

> vitality and candor impressed many. He enjoyed a good tussle, refused to back down from anyone and, when opposed, could explode in anger. He rubbed people in authority the wrong way, but he was principled about it. He felt he never angered anyone without good reason. Aware that his penchant for battle cost him good will, he still never shied away from a fight, and he took as much ground as his opponents ceded. "My whole philosophy . . . is very simple," he told a few generals during the war. "If I have any doubt as to whether I am supposed to do a job or not, I do it, and if someone socks me, I lay off." [...]
>
> Acts of importance were the measure of Bush's life, and they are the reason his life deserves study today. His was a political life, wrapped in the enigma of science and invention. An apostle of expertise, he transcended the labels of "liberal" or "conservative" and pursued the progressive ideal of public betterment through the private efforts of people of good will and merit. [...]
>
> In an age of complexity, Bush's habits of mind transcended easy categorization and prefigured the postmodern embrace of contradictions. He was a contrarian, skeptical of easy solutions yet willing to tackle tough problems without a compass. He looked askance at social status based on wealth, but fervently believed that mass opinion should be directed by a "natural aristocracy" of meritorious Americans. He was a pragmatist who thought that knowledge arose from a physical encounter with a stubborn reality. The mathematician Norbert Wiener called him "one of the greatest apparatus men that America has ever seen—he thinks with his hands as well as with his brain." Despite being drenched in a world of particulars, Bush was ultimately a moral thinker whose grand themes were individual self-reliance, democracy with a small *d* and the absolute necessity for thinking men and women to build—with the help of technology—meaningful patterns from the confusing buzz of facts, ideas and emotions that compose the discourse of any era.
>
> Suspicious of big institutions, whether run by public servants, the military or corporations, Bush objected to the pernicious effects of an increasingly bureaucratized society and the potential for mass mediocrity long before such complaints became conventional wisdom. [...]
>
> His great failure and his enduring triumph was his realization that the course of modern history would be shaped by large hierarchical institutions, making plans and settling scores behind closed doors, working best when insulated from public opinion. That these institutions lost their energy and legitimacy as the 20th century waned would not have surprised Bush. Whether overseeing the creation of the atomic bomb or lobbying to fund "pure" research without utilitarian purpose, he believed the beleaguered individual was still of paramount importance.
>
> "The individual to me is everything," he wrote on the eve of World War II. "I would circumscribe him just as little as possible." In the murderous years that followed, he never lost his faith in the power of one.

As Zachary pointed out, a tragic irony is that Bush, who was probably the most powerful enlightened scientific despot in the history of the United States and who empowered or assisted other enlightened despots, helped to set up the key institutions of the U.S. innovation system that ultimately, over the course of the following decades, replaced the individual far-sighted enlightened despots with a faceless bureaucratic system of myopic, risk-averse peer review.

William M. Allen (1900–1985), shown in Fig. 11.66, ran Boeing 1945–1972 when it developed the 707 through 747 jet airliners. As exemplified by those products, he championed major technological steps, large R&D budgets, and long development timelines [Clive Irving 2014; Serling 1992]. *Fortune* magazine named him one of the "10 greatest CEOs of all time" [Collins 2003]:

> "Don't talk too much," Boeing's new chief admonished himself. "Let others talk."
>
> Its planes helped win the war—yet victory in 1945 looked like death for Boeing. Revenues plummeted more than 90% as orders for bombers vanished overnight. And bombers, everyone knew, were what Boeing was all about.
>
> Everyone, that is, but its new leader. An understated lawyer who said he wasn't qualified for the job, Bill Allen never saw Boeing as the bomber company. It was the company whose engineers built amazing flying machines. In 1952 he bet heavily on a new commercial jet, the 707. At the time, Boeing had no business being in the commercial market, or at least that's what potential customers said. ("You make great bombers up there in Seattle. Why don't you stick with that?") Yet Allen's time frames were bigger too. He saw that Boeing could compete by changing the industry. Under his leadership, Boeing built the 707, 727, 737, and 747—four of the most successful bets in industrial history. At a board meeting described by Robert Serling in *Legend & Legacy*, a director said that if the 747 was too big for the market to swallow, Boeing could back out. "Back out?" stiffened Allen. "If the Boeing Aircraft Co. says we will build this airplane, we will build it even if it takes the resources of the entire company." Like today's CEOs, he endured the swarming gnats who think small: short time frames, pennies per share, a narrow purpose. Allen thought bigger—and left a legacy to match.

(Army) Air Force General Henry "Hap" Arnold (1886–1950), shown in Fig. 11.66, was a very strong supporter of developing revolutionary technologies during and after World War II [Henry Arnold 1945, 1949; Bower 1987; Lasby 1971]. He played an especially important role in getting the United States to acquire a large number of creators and creations from the German-speaking world and to support the employment of those innovators and technologies for U.S. military applications. Historian Clarence Lasby described the extent of Arnold's vision [Lasby 1971, pp. 102–103]:

> Henry "Hap" Arnold, Commanding General of the Air Forces, was determined to capitalize on German advances. A stocky, broad-shouldered West Point graduate and former aide to General Billy Mitchell, Arnold had been the most devoted partisan of airpower throughout the 1930's. He was also a visionary, and was fortunate to find a man who appreciated his new concepts for air warfare in Professor Theodore von Kármán, a Hungarian Jew who in 1929 had left the directorship of the Aeronautical Institute of Aachen, Germany, to assume the same position at the Aeronautical Laboratory at Cal Tech. In 1939 Arnold contracted with von Kármán to construct a 40,000-horsepower wind tunnel, the first of its kind, and to develop rockets to assist the takeoff of heavy aircraft. In September 1944 he called upon his ally again, this time to prepare a blueprint for air research for the next twenty to fifty years. When he addressed the scientist's advisory group, he asked them to free their imaginations. "I see a manless Air Force," he said. "I see no excuse for men in fighter planes to shoot down bombers." Unlike the aviators in the Navy, Arnold had no fear of novel weapons. In May 1945 he had sent von Kármán on a special mission to study the Germans' latest developments, and when his own officers proposed the exploitation of the enemy scientists through Overcast, he approved.

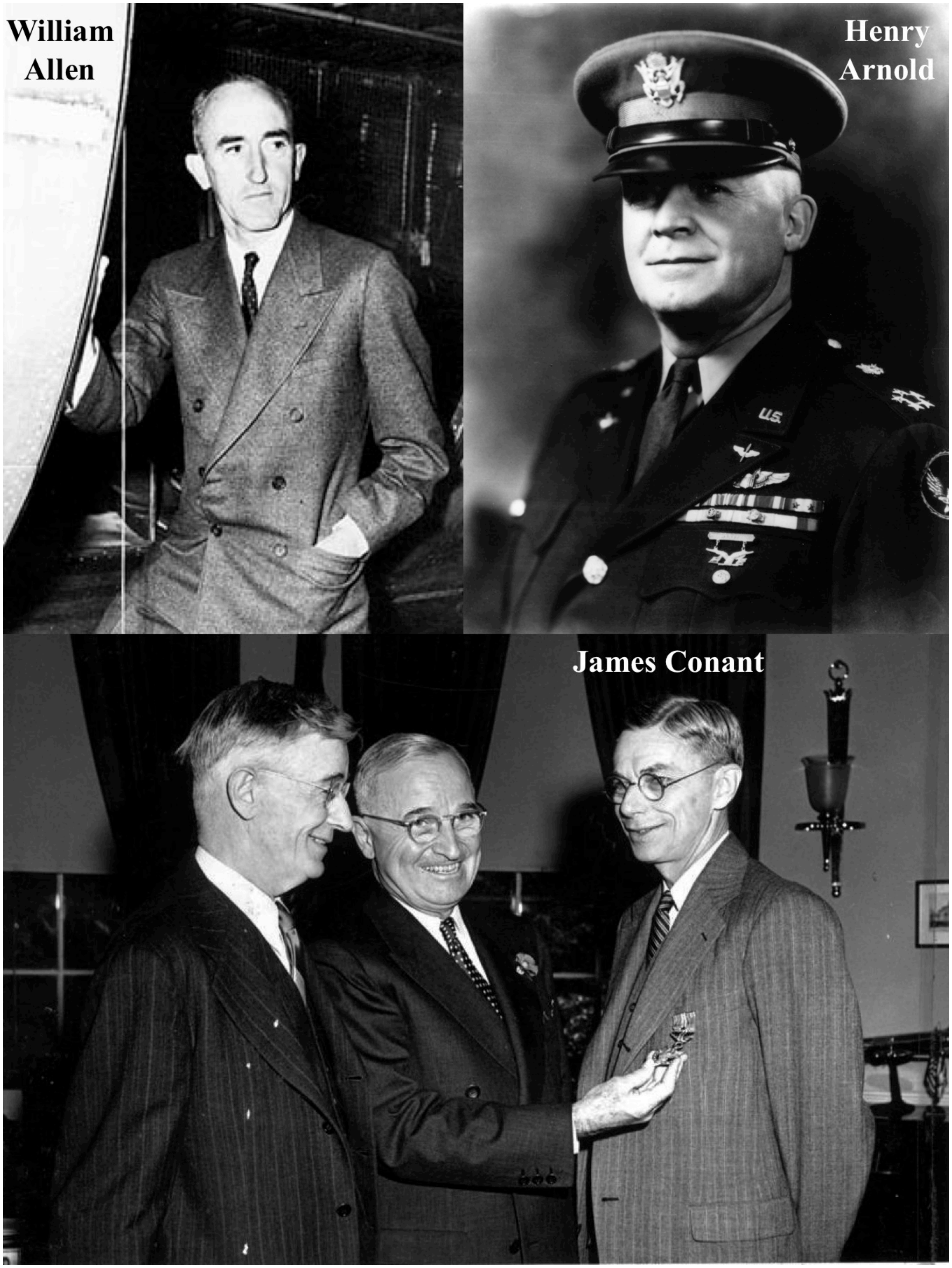


Figure 11.66: More examples of scientific “enlightened despots” who had a very large impact on the U.S. system: William M. Allen ran Boeing 1945–1972 when it developed the 707 through 747 jet airliners. Army Air Forces General Henry Arnold strongly supported revolutionary technologies during and after World War II. James Conant (lower right, with Vannevar Bush and Harry Truman) modernized Harvard University, helped Vannevar Bush run national research during World War II, and was the first U.S. Ambassador to West Germany after the war.

James Conant (1893–1978), shown in Fig. 11.66, modernized Harvard University, helped Vannevar Bush run national research during World War II, and was the first U.S. Ambassador to West Germany after the war [Baxter 1946; James Conant 1970; Jennet Conant 2002, 2017; Zachary 1997a]. According to his obituary [NYT 1978-02-12 p. 1]:

> Dr. Conant led Harvard for 20 years, but the lean, self-effacing six-footer was never in a rut, then or after. He left a brilliant career in chemistry to accept the university's presidency and his resignation in 1953 at the age of 60 marked only the beginning of distinguished roles as diplomat and almost single-handed reformer of, and schoolmaster to, American public education.
>
> As a prelude to his diplomatic service Dr. Conant had served in World War II as a scientific adviser to the Government on the atomic bomb project and was one of those involved in the selection of the target in Japan for the first bomb, which was dropped over Hiroshima Aug. 6, 1945.
>
> Dr. Conant, who spent the major part of his life in the leadership of higher education, perhaps will be best remembered in popular lore as the man who warned of the "social dynamite" accumulating in the cities and who tried to chart a course of improvement for the nation's elementary and secondary schools.
>
> In whatever task he had at hand, he stressed the relevant, the immediate and the practical. He dealt largely in ideas but he liked to see them translated into action, and his habit of sliding back his cuff and glancing at his watch was due more to planning the next step than to impatience.
>
> As an educator Dr. Conant was indifferent to the pressures of politics and consensus and, although he did not seek out controversy, he was unintimidated by it.
>
> He would cling obstinately to his opinions if he thought them right. On the wall of his office at Harvard he kept a framed cartoon with the caption: "Behold the turtle, he makes progress only when his neck is out."

James Conant succinctly summed up his philosophy of scientific management [Jennet Conant 2002, p. vii]:

> To advance scientific knowledge, pick a man of genius, give him money, and let him alone.

Lee DuBridge (1901–1994), shown in Fig. 11.67, directed the MIT Radiation Laboratory 1940–1946 and the California Institute of Technology (Caltech) 1946–1969 [Baxter 1946; Burchard 1948; Jennet Conant 2002; Greenstein 1997; Guerlac 1987]. He facilitated the great wartime successes of the Radiation Laboratory in radar development both by being a strong lobbyist to government for funding and independence for the Laboratory, and also by creating an extraordinarily productive research environment for the scientists working there [Guerlac 1987, p. 297]:

> No full understanding of the administrative eccentricities of the Radiation Laboratory is possible without recognizing that one of its outstanding merits, in the eyes of its own management, was that it was a physicist's world, run for, and as completely as possible by, physicists. Everything was subordinated to producing an environment for research as free and untrammeled as in a university and to preventing research from becoming entangled or impeded by the growing responsibilities thrust upon the organization. [...N]o policy could have been better designed to rid the research man of unwise interference, and to give him unsurpassed opportunities for creative work. The Radiation Laboratory came close to realizing a scientist's dream of a scientific republic, whose only limitation was the supply of scientists.

Jesse Greenstein, a Caltech astronomer, provided more details about DuBridge's personality and accomplishments [Greenstein 1997]:

> In November 1940, under pressure from Lawrence and Loomis, Lee became the founding director of the Radiation Laboratory (RadLab) centered at the Massachusetts Institute of Technology. It did not disband until January 1946. His first helpers, recruited on a crash basis, included a dozen from the nuclear physics community, Alex Allen, Ken Bainbridge, Ed McMillan, I. I. Rabi, Norman Ramsey, Stan Van Voorhis, and Milton White; some of the staff later won Nobel Prizes. By 1945 the lab employed 4,000 scientists and engineers. Lee's style, one that he retained all his life, was one of showing leadership rather than exerting authority. He listened and understood the problems well, but he could be finally decisive. Their first project was to design and build a radar for air interception, which took three months plus a year to mount on the Northrup Black Widow airplanes.
>
> Also designed and built were radar to detect ships and submarines at sea, for night bombing, and to point guns. Over 100 types of microwave radar were created. For each there were training programs, service instructions, and manuals for field maintenance. Many prospective users were trained at MIT. RadLab personnel fanned out over the world to train users and improve field operations. The annual budget reached $50 million. The lab and its products (the theory of high-frequency circuits and the many uses of microwaves) were described in an unclassified twenty-seven-volume series published at the end of the war. [...]
>
> He was in many ways an ideal college president for the twenty-three years he held that office. He was soft-spoken, responsive, and persuasive. He somehow knew how to say "no" and still retain the friendship of a faculty member. He visited faculty offices to ask what was new in a member's field. As senior professor of astronomy I enjoyed Lee's questions as to what had been found recently at Palomar. His broad physical insight gave him quick understanding and he savored what remained puzzling. A further extraordinary ability was to repeat a story, with background and speculation about its future, to a meeting of the Board of Trustees or to the Associates. Sometimes the solution was only money, which he provided at once in small amounts and in large amounts after some effort. Lee spoke very well in public and was under constant pressure to explain Caltech science and education to organizations and the public.

Crawford Greenewalt (1902–1993), shown in Fig. 11.67, helped Du Pont build the plutonium-producing Hanford fission reactors during World War II, and he ran Du Pont 1948–1967 when it introduced its most innovative chemical products [Greenewalt 1959; Hounshell and Smith 1988; Zilg 1984]. In their landmark book on the history of R&D at Du Pont, historians David Hounshell and John Smith, Jr. described Greenewalt's approach [Hounshell and Smith 1988, pp. 358–361]:

> In the twentieth century history of the Du Pont Company, there was perhaps never a more perfect fit between corporate objectives and the career, style, and philosophy of the company's president than during the presidency of Crawford H. Greenewalt. [...]
>
> Starting from virtually no knowledge of fission in October 1942, he rapidly acquired a deep knowledge of reactor physics—deep enough to keep a check on Chicago physicists and not to be cowed by them. [...] Greenewalt so impressed Fermi and Compton that both offered him positions in their postwar research enterprises. [...]
>
> The Manhattan Project's success and the elder du Ponts' continued concerns about family management of the company quickly propelled Greenewalt to the top. [...]
>
> Not long after assuming the presidency, Greenewalt articulated what he believed to be the Du Pont Company's two fundamental principles of growth and development that had served in the past and would continue to govern in the future. Writing in his first annual report as president, Greenewalt noted, "The first of these has been to seek diversification in any chemical field to which it can make a substantial technical contribution." Such a principle meant that "research results have been applied over a wide commercial area." But Du Pont had not done research and development in just any area of the chemical industry. Rather, as Greenewalt stressed, "the second principle has been to direct the Company's research and manufacturing efforts primarily to the large and difficult tasks which inherently require great resources in technical ability and finances." Greenewalt's second principle was a corollary to the one laid down some forty years earlier by Pierre du Pont, who said that the company should always have a few really big, high-risk research projects going because the company stood to benefit both from potentially large payoffs and from keeping an expert force of researchers continually engaged by the company. Greenewalt, the chemical engineer turned executive, envisioned the company developing and managing large, integrated, continuous-process chemical plants that would be the embodiment of his principles. In the future, Du Pont would marshal its resources to do what most other companies could not. From these efforts, "new nylons" would emerge.
>
> The rapid and strong impact that nylon's success had on the Du Pont Company's strategy of growth and its concomitant R&D policies is perhaps best expressed in the phrase "new nylons." By 1945, these two words had become shorthand for the whole paradigmatic shift in Du Pont's research program whereby all the industrial departments, not just the Chemical Department, would undertake fundamental research at the expanded Experimental Station. From a policy level, Crawford Greenewalt's widely circulated report, "Fundamental Research: Definition and Justification," stated the matter succinctly: "We are interested primarily in fundamental research studies which are likely to produce new nylons." [...] Greenewalt often pondered the statistical basis of research and concluded that it was but a form of gambling where the odds were greatly improved through the conduct of fundamental research within a widely diversified company such as Du Pont.

Figure 11.67: More examples of U.S. scientific “enlightened despots”: Lee DuBridge directed the MIT Radiation (radar) Laboratory 1940–1946 and the California Institute of Technology 1946–1969. Crawford Greenewalt oversaw the plutonium-producing Hanford fission reactors during World War II and ran Du Pont 1948–1967 when it introduced its most innovative chemical products. Army General Leslie Groves and J. Robert Oppenheimer were the military and scientific directors, respectively, for the WWII U.S. nuclear weapons program, and helped establish the postwar program.

Army General Leslie Groves (1896–1970) and J. Robert Oppenheimer (1904–1967), shown in Fig. 11.67, were the military and scientific directors, respectively, for the WWII U.S. nuclear weapons program, and helped to establish the postwar program.[11]

Colonel Kenneth Nichols, who oversaw the construction and operation of all Manhattan Project facilities under Groves, described Groves [Nichols 1987, p. 108]:

> First, General Groves is the biggest S.O.B. I have ever worked for. He is most demanding. He is most critical. He is always a driver, never a praiser. He is abrasive and sarcastic. He disregards all normal organizational channels. He is extremely intelligent. He has the guts to make timely, difficult decisions. He is the most egotistical man I know. He knows he is right and so sticks by his decision. He abounds with energy and expects everyone to work as hard, or even harder, than he does... if I had to do my part of the atomic bomb project over again and had the privilege of picking my boss, I would pick General Groves.

Nuclear historian and policy analyst Robert Norris described the working relationship between Groves and Oppenheimer [Norris 2002, pp. 242–243]:

> That Oppenheimer and Groves should have worked so well together is really no mystery. Groves saw in Oppenheimer an “overwhelming ambition” that drove him. He understood that Oppenheimer was frustrated and disappointed; that his contributions to theoretical physics had not brought him the recognition he believed he deserved. This project could be his route to immortality. Part of Groves’s genius was to entwine other people’s ambitions with his own. Groves and Oppenheimer got on so well because each saw in the other the skills and intelligence necessary to fulfill their common goal, the successful use of the bomb in World War II. The bomb in fact would be the route to immortality for both of them.
>
> They treated each other in special ways. Oppenheimer could at times be sarcastic with students or colleagues who could not keep up with his quick mind. Not so with Groves. He patiently answered whatever query the general asked. On Groves’s part he treated Oppenheimer delicately, like a fine instrument that needed to be played just right. Groves’s normal approach with most of his subordinates was to push them as hard as he could. The pressure was a test to see what they were made of. The more they took, the tougher they were. The good ones would make it through, and those who broke would be transferred, demoted, or replaced. The general saw that this approach would not work with Oppenheimer. Some men if pushed too hard will break.

[11] Bird and Sherwin 2005; Jennet Conant 2005; Coster-Mullen 2012; Davis 1968; Groves 1962; Chuck Hansen 1988, 2007; Hawkins et al. 1983; Hoddeson et al. 1993; Jungk 1958; Kelly 2007; Nichols 1987; Norris 2002; Oppenheimer 1984; Bruce Cameron Reed 2015a, 2019; Rhodes 1986, 1995; Serber 1992; Smyth 1945; Sublette 2019.

Army Colonel Ernest Gruhn (1897–1994), shown in Fig. 11.68, the first director of the Joint Intelligence Objectives Agency, was a very strong supporter of developing revolutionary technologies during and after World War II. He played a vital role in getting the United States to import a large number of creators and creations from the German-speaking world and to harness those innovators and technologies for U.S. military applications. In his history of Operation Overcast/Paperclip, Tom Bower wrote [Bower 1987, pp. 137–138]:

> The detailed management of Overcast had by then been transferred from Bissell to Colonel Ernest Gruhn, who had been appointed director of the Joint Intelligence Objectives Agency. Operating from a few rooms in the Munitions Building in Washington, Gruhn and successive directors of JOIA would become passionate advocates of America's need to recruit the Germans and deny them to other powers. More sinisterly, they would deliberately conceal their irregular and unauthorized activities from civilian government departments.

Clarence "Kelly" Johnson (1910–1990), shown in Fig. 11.68, created and ran the Lockheed "Skunk Works" 1943–1975. His operation produced a large number of highly innovative aircraft, including the first U.S. jet fighters such as the P-80 and F-104, the U-2 high-altitude spy plane, the hypersonic SR-71 Blackbird spy plane, and stealth aircraft technology [Johnson and Smith 1989; Pace 2016; Rich 1994, 1995; Tirpak 2018; Yenne 2014]. Ben Rich, Johnson's right-hand man and successor, described Johnson's approach [Rich 1995]:

> Be quick, be quiet, be on time.
>
> That was the credo of Clarence L. (Kelly) Johnson, the aeronautical innovator who founded Lockheed's supersecret "Skunk Works" where he designed the world's fastest and highest-flying aircraft—the SR-71 Blackbird.
>
> Johnson played a leading role in the design of more than forty aircraft and set up a Skunk Works-type operation to develop a Lockheed satellite—the Agena-D—that became the nation's workhorse in space. His achievements over almost six decades captured every major aviation design award and the highest civilian honors of the U.S. government and made him an aerospace legend. [...]
>
> Johnson achieved international recognition for the highly successful Skunk Works operation—"a concentration of a few good people . . . applying the simplest, most straightforward methods possible to develop and produce new products" with minimum overhead and outside oversight—and for his unparalleled management style. [...]
>
> Johnson was known for his hard adherence to principles. On several occasions he turned back development contracts to the U.S. Department of Defense after initial work indicated the proposed aircraft would not be effective, no matter how much money the DoD was willing to provide. [...]
>
> The secret of Kelly Johnson's success was really no secret. He was not only one of the world's foremost designers, but he was an innovative manager who gave people who worked for him challenges to constantly create better products.

> Many of us in the Skunk Works turned down promotions to other Lockheed organizations to stay with Kelly. And uppermost for Kelly was to stay with the Skunk Works. He was offered a company presidency at Lockheed three times—and three times he declined it. "To me," said Kelly, "there was no better job within the corporation than head of Advanced Development Projects—the Skunk Works."
>
> Even when he retired from Lockheed as a corporate senior vice president in 1975, Johnson continued at the Skunk Works as a senior advisor. His influence continues in the Skunk Works. "Our aim," he said, "is to get results cheaper, sooner, and better through application of common sense to tough problems. If it works, don't fix it."
>
> "Reduce reports and other paperwork to a minimum."
>
> "Keep it simple, stupid—KISS—is our constant reminder."
>
> Johnson instinctively knew how to select people for his organization. He knew how to get the most out of the fewest people and how to get the job done—well. He let his managers run their programs with a minimum of interference. He not only gave you the authority but also the responsibility.

Ben Rich gave more information on Johnson and his Skunk Works approach [Rich 1994, p. 7]:

> Most Skunk Workers were handpicked by our just retired leader, Kelly Johnson, one of the reigning barons of American aviation, who first joined Lockheed in 1933 as a twenty-three-year-old fledgling engineer to help design and build the Electra twin-engine transport that helped put the young company and commercial aviation on the map. By the time he retired forty-two years later, Kelly Johnson was recognized as the preeminent aerodynamicist of his time, who had created the fastest and highest-flying military airplanes in history. Inside the Skunk Works, we were a small, intensely cohesive group consisting of about fifty veteran engineers and designers and a hundred or so expert machinists and shop workers. Our forte was building a small number of very technologically advanced airplanes for highly secret missions. What came off our drawing boards provided key strategic and technological advantages for the United States, since our enemies had no way to stop our overflights. Principal customers were the Central Intelligence Agency and the U.S. Air Force; for years we functioned as the CIA's unofficial "toy makers," building for it fabulously successful spy planes, while developing an intimate working partnership with the agency that was unique between government and private industry. Our relations with the Air Force blue-suiters were love-hate—depending on whose heads Kelly was knocking together at any given time to keep the Skunk Works as free as possible from bureaucratic interlopers or the imperious wills of overbearing generals. To his credit Kelly never wavered in his battle for our independence from outside interference, and although more than one Air Force chief of staff over the years had to act as peacemaker between Kelly and some generals of the Air Staff, the proof of our success was that the airplanes we built operated under tight secrecy for eight to ten years before the government even acknowledged their existence.

Figure 11.68: More examples of U.S. scientific "enlightened despots": Army Colonel Ernest Gruhn ran the Joint Intelligence Objectives Agency that transferred German scientists and technologies to the United States after World War II. Mervin Kelley created and led breakthrough research programs at AT&T Bell Laboratories 1936–1959. Kelly Johnson (left, with pilot Francis Gary Powers in front of a U-2 spy plane) created and ran the Lockheed "Skunk Works" 1943–1975.

Mervin Kelly (1895–1971), shown in Fig. 11.68, built and led the highly innovative research programs at AT&T Bell Laboratories during the period 1936–1959, occupying positions ranging from director of research to president.[12] John Pierce, a research manager under Kelly at Bell Laboratories, gave a detailed description of Kelly's personality [Pierce 1975]:

> [...] Kelly's greatest contribution lay in creative technical management. It is no more than just to say that Kelly made Bell Laboratories the foremost industrial laboratory in the world. He recognized and inspired good men and good work. He assessed and drove to completion important technical potentialities and opportunities. He shaped and managed a complex organization. And, he inspired the confidence and won the support of the management of AT&T and of the operating telephone companies of the Bell System. As Frederick R. Kappel, former board chairman of AT&T said after Kelly's death:
>
> "He was a great fellow for the Bell System. Mervin was always and forever pushing the operating management, and the heads of AT&T as well, to get on with new things. His aggressiveness got him in a lot of hot arguments, but I always sat back and said, 'Give it to them, Mervin, that's what we need.' Every place needs a fireball or sparkplug, and he was it."
>
> Kelly was not only a sparkplug; he combined determination and showmanship. Twice he submitted his resignation to the president of AT&T, stating that important work at Bell Laboratories was not being adequately funded. In each case, he got the funds. Surely, he was sincere, but he was dramatic as well. [...]
>
> Kelly's greatest accomplishments lay in the Bell Laboratories. He valued talent sincerely, as his warm biographical sketch of C. J. Davisson shows. He wanted, found, appreciated, and encouraged the sort of men who invented the transistor. [...]
>
> When the transistor had been invented, Kelly recognized its worth. As a foreign member of the Swedish Academy of Sciences, he pressed for the award of the Nobel Prize to Bardeen, Brattain, and Shockley. And, for years at Bell Laboratories nothing was any good unless it was "new art" (solid state).
>
> Kelly fostered or launched ambitious programs in nationwide dialing, in automation of maintenance and testing, in microwave communication, in coaxial cable transmission, in transoceanic cables, and in electronic switching. All were timely, and, in the end, all were successful. [...]
>
> After Kelly retired from Bell Laboratories, he acted as a consultant to a number of companies, but chiefly to International Business Machines Incorporated. In this capacity, his energy and enthusiasm were no less than in his leadership of Bell Laboratories, but he wisely realized that his role was that of counsellor to the management, including Thomas Watson, Jr., the chairman of the board, and not that of a boss. According to E. R. Piore, vice president and chief scientist of IBM:
>
> "He traveled to all technical locations in IBM that stretch across this country north and south and east and west and which are located in six countries in Europe. Once in the laboratory, he would [as he used to do at Bell Laboratories] spend time with the people at the bench, stimulating discussion and thinking, constantly evaluating the person and

[12] Bernstein 1984; Gertner 2012; Kelly 1950; Pierce 1975; Rhoads 2005; Riordan and Hoddeson 1997; Wolff 1983.

> the program. Thus he acquired possibly more than any other person, a judgment of men, of programs, and the methods in use. This quality of conversing with the man at the bench, making the man feel at home with Kelly, in no way inhibited him with similar conversations with men up the ladder, including Tom Watson, Jr., and the rest of the group that had oversight over the whole IBM enterprise. Thus he would report to me after his trip and report to Tom Watson also. Mervin was not making a career for himself in IBM. Thus he never fought for his convictions but quietly gave his views—strong, moderate, or negative. This is one reason why his influence was great whether talking to me or to those above me. These conversations dealt with technology, people and management.
>
> "His evaluation and identification of people had a profound effect on their careers. He was after the best technical people, and recommended that they be placed in jobs of ever-increasing responsibility. I would judge that this was his greatest accomplishment in IBM." [...]
>
> Continually pressing for higher achievement, Kelly always prized and promoted ability wherever he found it. Conversely, he was uniformly impatient with mediocrity and almost ruthlessly intolerant of incompetence. [...]

Pierce also provided numerous examples of Mervin Kelly's views on how industrial research and development should be managed [Pierce 1975]:

> Kelly had no doubt as to the place of science and technology in man's life. He wrote: "So completely have they dominated the pattern of our growth that when the man in the street speaks of 'progress,' he usually means scientific and technological progress."
>
> Kelly was equally clear concerning the source of such progress: "Basic research is the foundation on which all technologic advances rest."
>
> What is the source, the generating force behind new ideas? Kelly said: "But with all the needed emphasis on leadership, organization and teamwork, the individual has remained supreme—of paramount importance. It is in the mind of a single person that creative ideas and concepts are born."
>
> Where should basic research be carried out? Kelly noted that " . . . the academic community has been the principal home of basic research for more than a century. . . ." However, he looked toward industry for substantial contributions to research: "The author believes that at least 10 per cent of most research and development budgets can be profitably employed in basic research. Any company that has 50 or more members of professional staff, that will dedicate 10 per cent of them to basic research, can build a strong, productive, and profitable effort." [...]
>
> Using the Bell Laboratories as an example of organized technology, Kelly delineated three areas that preceded the manufacture of complicated technological systems:
>
> "The first includes all of the research and fundamental development. This is our non-scheduled area of work. It provides the reservoir of completely new knowledge, principles, materials, methods, and art that are essential for the development of new communications systems and facilities.

> "The second we call 'systems engineering'. Its major responsibility is the determination of the new specific systems and facilities development projects—their operational and economic objectives and the broad technical plan to be followed. 'Systems engineering' controls and guides the use of the new knowledge obtained from the research and fundamental development programs in the creation of new telephone services and the improvement and lowering of cost of services already established.
>
> "The third encompasses all specific development and design of new systems and facilities. The work is most carefully programmed in conformity with the plan established by the systems engineering studies. Our research and fundamental development programs supply the new knowledge required in meeting the objectives of the new specific developments."
>
> In addition to these three technical areas, Kelly referred to another, the management of buildings, shops, and services:
>
> "The nonscientific duties of management should be minimized for all levels of the research supervision. Through proper organization, direct responsibility for people can be limited to scientists and their aides. Budget preparation, management of shops, services, secretaries and typists, for example, can be done by an intimately associated professional management staff of non-scientists. There should be the very minimum of diversion of the attention of the research leadership and the individual researchers from their scientific programs. This can be accomplished by organizational structures and operations fashioned to free all scientists from nonresearch supervisory duties which, at the same time, provide excellent and economical service in all areas that support the direct scientific endeavor." [...]
>
> Concerning the three functions into which he divided technological endeavor, Kelly made a number of observations. About research, he said:
>
> "Inspired and productive research in industry requires men of the same high quality as is required for distinguished pure research in our universities.
>
> "They must be given freedoms that are equivalent to those of the research man in the university." [...]

Pierce later summarized four aspects of the mid-twentieth-century Bell Laboratories management style that he thought could and should be implemented in other times and places in order to promote revolutionary innovation [Gertner 2012, p. 351]:

> A technically competent management all the way to the top.
>
> Researchers didn't have to raise funds.
>
> Research on a topic or system could be and was supported for years.
>
> Research [on a particular project] could be terminated without damning the researcher.

Before leaving the subject of early management at Bell Laboratories, one should also note (among other examples there) the earlier and partially overlapping contributions of Frank Jewett (1879–1949), who was the first president of Bell Laboratories 1925–1940, chairman of the Bell Laboratories Board of Directors 1940–1944, president of the U.S. National Academy of Sciences 1939–1947, and a member of the National Defense Research Committee during World War II [Buckley 1952].

George W. Merck (1894–1957), shown in Fig. 11.69, ran the U.S. company Merck 1925–1957. His father, Georg(e) Merck, had come to the United States in 1891 to found an American branch of the German pharmaceutical company Merck, but the U.S. government forced the American branch to become a fully independent U.S.-owned company during World War I. George W. Merck succeeded his father as the leader of the American company. During his tenure, he greatly expanded research in a wide variety of areas, and was known for focusing more on producing useful new products than pursuing the highest profits. *Fortune* magazine named him one of the "10 greatest CEOs of all time" [Collins 2003]:

> The Merck & Co. boss didn't worry about Wall Street—and grew profits 50-fold.
>
> Late one afternoon in 1978, Dr. William Campbell did what all great researchers do: He wondered at the data. While testing a new compound to battle parasites in animals, he was struck with the idea that it might be effective against another parasite—one that causes blindness and itching in humans so horrific that some victims have committed suicide. Campbell might have simply scribbled a note in the files and gone to lunch. After all, the potential "customers"—tribal people in remote tropical locations—would have no money to buy it. Undaunted, Campbell penned a memo to his employer, Merck & Co., urging pursuit of the idea. Today 30 million people a year receive Mectizan, the drug inspired by his observation, largely free of charge.
>
> The most exceptional part of the story is that it wasn't an exception. "Medicine is for people, not for the profits," George Merck II declared on the cover of Time in August 1952—a rule his company observed in dispensing streptomycin to Japanese children following World War II. Yet fuzzy-headed moralistic fervor wasn't George Merck. Austere and patrician, he simply believed that the purpose of a corporation is to do something useful, and to do it very well. "And if we have remembered that, the profits have never failed to appear," he explained. "The better we remembered, the larger they have been." It's the mirror image of CEOs whose unhealthy fixations with Wall Street have served neither people nor profits: Merck served shareholders so well precisely because he served others first.

(Army) Air Force General Donald Putt (1905–1988), shown in Fig. 11.69, was a very strong advocate for developing revolutionary technologies after World War II. He played an especially important role in helping the United States acquire a large number of creators and creations from the German-speaking world and employ them for U.S. military applications. For example, Wolfgang Samuel, a retired Air Force colonel and military historian, summarized the contributions of Donald Putt [Samuel 2004, pp. 7–8]:

> Putt determined to go after the intellectual capital of the former Third Reich, the scientists who had designed the jet and rocket planes and other advanced weapons never brought to bear against the Allies simply because the Nazis ran out of time. More than any of his peers, Putt clearly grasped the importance of the German scientist to the technological future of the United States and wanted as many of them as possible, and as soon as possible, brought to Wright Field, the research, development, and test center for the Army Air Forces. There, he thought, the scientists should resume work, making up the technological deficit America had allowed itself to accumulate in the prewar years. [...H]e persisted relentlessly, and in time his efforts were crowned with success.

Figure 11.69: More examples of U.S. scientific "enlightened despots": George W. Merck ran the U.S. company Merck 1925–1957. Air Force General Donald Putt recruited German and Austrian scientists at the end of World War II and funded their work in the United States after the war. Simon Ramo directed innovative corporate research for military applications at GE, Hughes Aircraft, and TRW from the 1940s to the 1970s. Navy Admiral Hyman Rickover shepherded the development of fission power for submarines and ships from 1945 onward.

Simon Ramo (1913–2016), shown in Fig. 11.69, ran a very innovative electronics program at General Electric (1936–1946), then created and ran the highly innovative research program at Hughes Aircraft (1946–1953), and then co-founded and managed research at TRW (Thompson Ramo Wooldridge, 1953–1978) [Dyer 1998; Ramo 1980a, 1980b, 1983, 1988, 2005]. Along the way, Ramo reported directly to U.S. presidents and led development of the first U.S. electron microscopes, long-range air defense systems, intercontinental ballistic missiles, interplanetary space probes, and other technologies. The *New York Times* obituary summarized Ramo's accomplishments [NYT 2016-06-30 p. A25]:

> Dr. Ramo, who advised a string of presidents, legislators and cabinet officials on science and technology, was a pioneering force in the aerospace and electronics industries throughout the postwar period.

Navy Admiral Hyman Rickover (1900–1986), shown in Fig. 11.69, shepherded the development of fission power for submarines and ships from 1945 onward [Allen and Polmar 2007; Kruse 2015; Oliver 2014; Rockwell 1995]. *Time* magazine featured Rickover on the cover of its 11 January 1954 issue and described his personality:

> Sharp-tongued Hyman Rickover spurred his men to exhaustion, ripped through red tape, drove contractors into rages. He went on making enemies, but by the end of the war he had won the rank of captain. He had also won a reputation as a man *who gets things done.*

Kevin Kruse described Rickover's methods [Kruse 2015]:

> Rickover was careful to assemble a staff that could build the Navy he envisioned, even though that staff did not always fit the Navy mold. He was the first Navy admiral to bring women on to a submarine (in the 1950s) not because he was a Civil Rights leader but because, as Oliver writes in the book, "we needed brains to make the submarine force successful ... and women possessed half of the available resource."
>
> Rickover went so far as to invent his own selection process, one that bucked Naval practice and policy but was more suited to his needs. Children of the influential were not selected as a matter of course, nor were people with political connections. The Bureau of Personnel did not control the process and the admiral interviewed every new recruit.
>
> Once selected, Rickover allowed his sailors the leeway to try new things and the power to change established practice if a new process was better. He encouraged his staff to do what worked, regardless of preconceived ideas.
>
> Rickover was, himself, an odd choice to change the Navy. He never saw combat, and did not wear the standard uniform at all if he could help it. He was small of stature, a Jewish refugee from Poland and, for all his work altering perceptions, was not the consummate politician top military leaders often are.
>
> He was also the longest-serving naval officer in U.S. history, with 63 years active duty. Which, by itself, says a lot.

Even shortly before the end of his life, Rickover was still creating new programs to nurture young scientists and engineers. In 1983–1984, he helped establish the Center for Excellence in Education and the Research Science Institute, which host 80 high school students at MIT for research mentoring each summer, invite middle- and high-school teachers to participate in research laboratories, and offer other programs to promote scientific innovation [https://www.cee.org/about-us/history/history].

Air Force General Bernard Schriever (1910–2005), shown in Fig. 11.70, was a protégé of General Henry Arnold. Following the path originally laid out by Arnold, Schriever was a strong champion for the development of missiles, rockets, and spacecraft in the U.S. Air Force from his initial appointment to that area in 1954 until his retirement in 1966 [Stephen Johnson 2002; Jacob Neufeld 2004; Sheehan 2009].

Air Force historian Jacob Neufeld gave an excellent overview of Schriever's career and impact [Jacob Neufeld 2004]:

> After the war, Schriever's leadership and accomplishments attracted the attention of senior officers, notably "Hap" Arnold, now the Commanding General of the Army Air Forces. Recognizing his protégé's rare combination of engineering training and operational experience, Arnold assigned Schriever the delicate job of maintaining the close ties forged during the war between the Air Force and nation's leading scientists. Working with the world famous Dr. Theodore von Kármán, chairman of the Scientific Advisory Board (SAB), and with RAND Corporation staffers, Schriever focused on long-range scientific planning. He helped to refine a methodology that matched long-range military requirements with ongoing research and development. Plans were drawn for all major elements of air power—strategic and tactical warfare, air defense, intelligence, and reconnaissance; RAND, the SAB, and university researchers performed the systems analysis studies. As a result, the Air Force did not have to wait for technological change to mature, but could lead and direct it. Put another way, Schriever's staff combined operational requirements with technologies, strategies, and objectives to establish objectives for future systems. "Technology push" thus prevailed over "requirements pull." [...]
>
> In its February 1954 report, the Teapot committee recommended that the Air Force initiate a crash program to produce an ICBM. In May, the Air Force made the Atlas ICBM its top priority and Gardner selected Brigadier General Schriever to head the program.
>
> Activated on 1 July 1954, in Inglewood, a suburb of Los Angeles, Schriever's Western Development Division (WDD), was housed in a former parochial school. It began with twelve officers and three enlisted men, and eventually grew to some 1,500 personnel. Schriever had to create an organization to manage extremely varied and novel science and technology, build facilities for testing and production, integrate the missile systems, fit together the nuclear weapons they would carry, and provide the launching sites, equipment, and ground support necessary to bring the missiles to operational status. Moreover, he had to accomplish all of this within six years and before the Soviets could themselves build, deploy, and target their missiles against the United States! It was a deadly serious, real-life contest of "beat the clock." [...]

Even as he was preoccupied with acquiring ICBMs and IRBMs, Schriever foresaw the potential of outer space systems and the need to extend the Air Force's interests into the "high frontier." While many of his achievements in the space field remain classified, we can acknowledge his pivotal role in developing the requirements for intelligence and reconnaissance satellites and manned space flight. Schriever's enthusiasm for space exploration tapped his fortitude in sometimes standing up alone to his superiors. Indeed, although some people tried to muzzle him, Schriever never shrank back from what he believed in. [...]

Promoted to four-star rank and head of AFSC General Schriever conceived and effected the consolidation of Air Force technical and logistical efforts into a single organization. More significantly, he transformed the concept of materiel development and acquisition from a functional to a systems approach—the focal point for virtually all-new weapons.

Schriever's role in this transformation was pivotal with respect to his insistence on technologically superior performance standards, adherence to pre-established production schedules, and reliance on cost-control measures. While AFSC commander, he fostered research and oversaw the acquisition of systems that provided strategic deterrence; early detection, warning, and air defense; advanced aircraft and spacecraft designs; command, control, and communication systems; and aerospace medicine. By 1963, AFSC organization employed some 27,000 military and 37,000 civilians, operated an annual budget of over $7 billion (about 40 percent of the USAF's total), and managed eighty major weapons systems. General Schriever defined and institutionalized the acquisition process by demonstrating the interrelationship between technology, strategy, organization, and politics. [...]

In 1963, in response to Air Force Secretary Eugene Zuckert's request for a futuristic study, Schriever launched Project Forecast—one of the most comprehensive long-range assessments ever undertaken of the nation's position in military science and technology. Participants included 40 government agencies, 26 colleges and universities, 70 corporations and 10 non-profit organizations. Published in 1964, this landmark report concluded that rather than leveling off, technology was only beginning its exponential growth. Project Forecast identified several promising areas of exploration that would lead to quantum improvements in air and space weapons: notably in the fields of advanced composite materials, computers, flight design, and propulsion.

For twenty years, from the end of World War II until his retirement in 1966, General Schriever was at the locus of events as the Air Force developed its organization and processes for complex technology. [...] In the Development Planning Office, he helped establish systems analysis as the procedure to set requirements for new technologies.

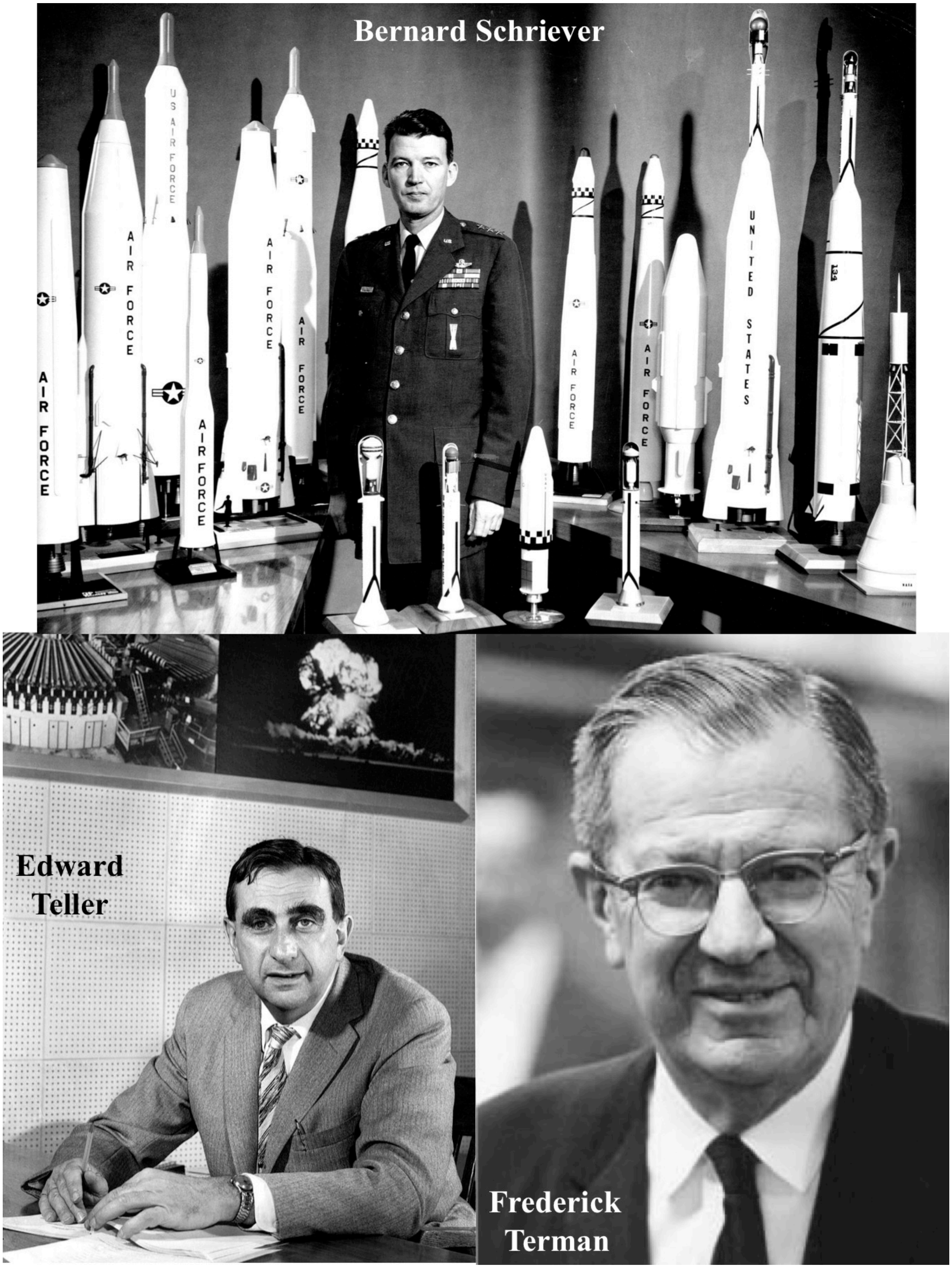


Figure 11.70: More examples of U.S. scientific "enlightened despots": Air Force General Bernard Schriever championed the development of missiles, rockets, and spacecraft 1954–1966. Edward Teller was the scientific head of the U.S. program to develop the hydrogen bomb, and founded and directed the Lawrence Livermore National Laboratory 1958–1975. Frederick Terman was instrumental in establishing Silicon Valley in California 1946–1965.

Edward Teller (1908–2003), shown in Fig. 11.70, one of the German-speaking creators who emigrated to the United States during the Third Reich, was the scientific head of the U.S. program to develop the hydrogen bomb, and founded and helped to direct the Lawrence Livermore National Laboratory 1952–1975 [Blumberg and Panos 1990; Broad 1985, 1992; Teller 1979, 1987, 2001]. While Teller's scientific contributions to the wartime Manhattan Project and postwar H-bomb program are described in Section 8.7, what is especially significant for this section is Teller's political position as an enlightened despot directing major parts of the U.S. research system.

Historian of science István Hargittai summed up Teller's personality [István Hargittai 2010, p. 456]:

> Edward Teller, who survived three exiles, contributed to the way the twentieth century played out on a worldwide stage, even if the extent of his influence is debatable. He had extraordinary willpower and triumphed over many obstacles, including his physical handicap. He waged struggles that many of his peers would have refrained from. He thrust himself into battles that often engulfed him as they would have engulfed anybody. He seemed at times invincible, and he was a dedicated fighter for the containment of communism to an extent few others were. His dedication often appeared as obsession and his schemes as irrational. While he was attempting to save the Free World, he was also trying to impose his will upon it. John A. Wheeler, who was friendly with him throughout his life, noted of him that "he fought obstinately for what he believed in. I may have disagreed with his tactics but never with his goals."

For over half a century and with enormous energy and success, Teller lobbied the government for political and financial support for revolutionary scientific research, while at the same time continually recruiting and mentoring countless young scientists to work on a variety of highly innovative projects. The Lawrence Livermore National Laboratory is the most visible result of those efforts, as described by biographers Stanley Blumberg and Louis Panos [Blumberg and Panos 1990, pp. 211–213]:

> The Lawrence Livermore National Laboratory sits in a valley an hour's drive east of San Francisco. [...]
>
> In 1952, Teller sold Washington on the need for a new weapons lab, and Ernest O. Lawrence sold Teller on Livermore as the place for it. [...]
>
> In time, the laboratory took on distinct signs of Teller's influence. He continued to champion its original purpose as a source of new weapons design and was instrumental in attracting talented young physicists to Livermore. [...]
>
> By 1988 the laboratory employed about 8,000 scientists and other employees on projects costing more than $1 billion a year. Official secrecy shrouds much of their work, inevitably arousing public curiosity concerning the tidbits occasionally dropped about such exotic projects as the X-ray laser, particle beams, kinetic energy, and the like. Lost in the fanfare over these is other, more fundamental work, such as environmental and biomedical research projects seeking answers to vital questions: How do plants respond to chronic low levels of pollutants in the atmosphere? How will chemicals discharged into oceans and streams affect fisheries? How do energy by-products and discharges work their way through the environment and the food chain to affect humans? In looking for the answers, scientists analyze damage to reproductive cells, develop bioassays to detect genetic injury, and do molecular studies on damage and repair of human genes.

Frederick Terman (1900–1982), shown in Fig. 11.70, received his Ph.D. under Vannevar Bush in 1924 and became an electrical engineering professor at Stanford. During World War II he led the Radio Research Laboratory at Harvard University in developing important radar techniques such as radar jammers and chaff countermeasures. After the war, he returned to Stanford as Dean of Engineering and then Provost. During that period (1946–1965), he focused on attracting and supporting talented individuals and new companies to that region, establishing Silicon Valley [Gillmor 2004; Lécuyer 2007; Lowen 1997; Villard 1998].

One of Terman's former students, Stanford electrical engineering professor O. G. Villard, Jr. described Terman's impact [Villard 1998]:

> Frederick Emmons Terman—author, teacher, mentor, university administrator and maker of policy par excellence—was beyond any reasonable doubt responsible for the concentration of economic accomplishment in what has come to be known as California's Silicon Valley, as well as for important innovations in engineering. [...]
>
> [Terman's father] was inventor and co-developer of the Stanford Binet intelligence (or IQ) test[...] This circumstance may well have had an influence in forming Fred Terman's personal philosophy concerning the importance to any organization of truly gifted individuals, who with their followers could be said to form "steeples of excellence."

Richard Atkinson, who taught at Stanford under Terman's leadership for nearly 25 years and ultimately became the president of the University of California, described Terman [Gillmor 2004, p. vii]:

> "Father of Silicon Valley": these words seem to leap from the page. Invariably this is the only description now applied to Fred Terman in newspaper and magazine articles. It is not an inaccurate title, but it hardly begins to do justice to the genius that was Frederick Emmons Terman. It is difficult to know where to begin when describing him. He was without doubt a brilliant electrical engineer, a learned scholar who authored groundbreaking textbooks on radio engineering and electronics, an inspiring teacher who kindled the spirit of discovery in his students, and an academic administrator whose devotion to excellence and visionary leadership firmly set a university on the path toward greatness. It was the latter, coupled with the extraordinary depth of his vision that I find the most compelling and enduring of Fred's many accomplishments.

Thomas J. Watson, Jr. (1914–1993), shown in Fig. 11.71, built the innovative research programs at IBM (International Business Machines) during the period 1946–1971, first as vice president and then as president of the company [Thomas Watson 1963, 2000]. The research programs he established greatly advanced computer technologies, microelectronics, and solid state physics applications.

Investors Business Daily wrote [Scott Smith 2016]:

> Watson is credited with moving IBM into the age of electronics at this time, taking it from a manufacturer of adding machines and typewriters to the forefront of the computer industry. In the 1950s, IBM not only invented the first electronic computer and the magnetic hard drive, but designed intercontinental missiles and developed the first artificial intelligence – a machine that could learn from its own experience.
>
> In 1957, IBM revolutionized programming with the FORTRAN language, and the next year it built the SAGE computer to run North American Air Defense. Watson also raised the company's investment in research and development from 3% of annual sales to 6%–9%.
>
> "He invested a lot of money on research and development," said Goldsby, "and it usually paid off."
>
> IBM continued to soar under Watson's leadership in the 1960s, creating the SABRE system for airline reservations, working with NASA on the lunar landing and launching the revolutionary System/360. This offered a range of commercial and scientific uses with the ability to upgrade without having to rewrite applications. Fortune magazine called it "IBM's $5 billion gamble," and it was massively profitable, the major contributor to the 500% increase in company revenue and earnings through the decade.
>
> In this era, IBM also changed its marketing approach from one that only sold hardware, services and software together as one package to one that offered them "unbundled" – a model for later tech companies.
>
> IBM was now the largest computer maker in the world, with 270,000 employees by 1970 and a corporate headquarters in Armonk, N.Y. But the next year, Watson had to step down because of a heart condition. [...]
>
> As the 1990s ended, *Time* magazine named Watson to its list of the "100 most influential people of the 20th century."

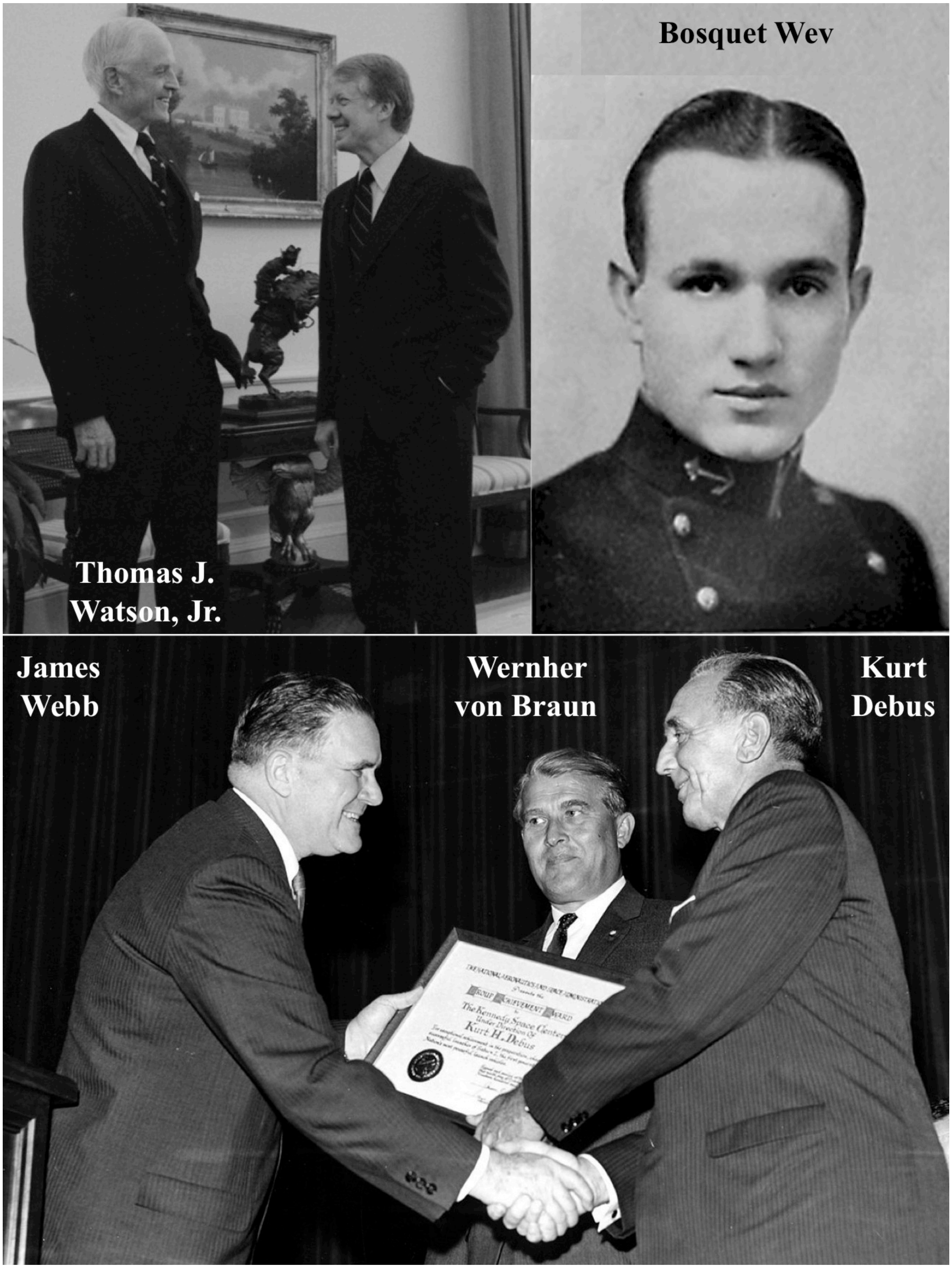


Figure 11.71: More examples of U.S. scientific "enlightened despots": Thomas J. Watson, Jr. (shown with President Jimmy Carter) built the innovative research programs at IBM during the period 1946–1971. Navy Captain Bosquet Wev (for whom only a very early photo is available) of the Joint Intelligence Objectives Agency strongly advocated for the acquisition of German and Austrian scientists and technologies after World War II. James Webb (lower left, shown with Wernher von Braun and Kurt Debus) ran NASA during its most productive period, 1961–1968.

James Webb (1906–1992), shown with Wernher von Braun and Kurt Debus in Fig. 11.71, ran NASA during its heyday of 1961–1968 [Bizony 2006; Lambright 1995]. He was responsible for all manned and unmanned missions during that time, as well as the Apollo-Saturn technology that had been perfected by the end of his tenure. Webb answered directly to the President, worked with von Braun, Debus, and other German-speaking rocket engineers, and coordinated the vast amount of U.S. industry required to produce all of the necessary hardware. W. Henry Lambright, a professor of political science and public administration at Syracuse University, described Webb's skills [Lambright 1995, pp. 216–217]:

> Management innovation was both a reality and public relations strategy for Webb. Above all, he understood the importance of power: its nurture, use, and loss. With this understanding he showed what a public executive with the right mix of energy, conviction, skill, wide-ranging contacts, and experience can do when conditions are ripe. He was cunning, guileful, manipulative, and hyperbolic—a lot like Lyndon Johnson. If he did not cross the line of administrative accountability, he surely edged up against it. But unlike Johnson, whose orientation was to legislation, Webb cared deeply about the effective administration of public affairs and was able to inspire those under him to new heights. He pushed a vast army of specialists in a common direction, at breakneck speed. A bold risk taker, he confronted pressures from astronauts, the president's science adviser, the air force, the defense secretary, other NASA executives, Congress, media, industry, universities, and many others, and did not flinch. Rather than break under political pressure, he used rhetorical and coalition-building techniques to impose pressures and coopt others. Organizing and reorganizing NASA as circumstances changed, using the resources at his disposal to reward and punish, he kept reign on his internal forces while orchestrating external support. Throughout, he focused on Apollo's goal and what it took to get there.

Space historian Piers Bizony [Bizony 2006, pp. ix–x] added:

> It was a smart operator from North Carolina, James E. Webb, who steered the expansion of NASA from a minor collection of research labs into one of the grandest enterprises the world has ever seen. Aided by a cadre of Southern-born businessmen and politicians, Webb established a colossal network of influence in the service of space. For all its recent setbacks, NASA still commands influence today because of the legacy he created. He knew how to persuade not one, but two presidents in succession to give him what he wanted. [...]
>
> We think of space administrators as dull, colourless bureaucrats. Webb was nothing of the kind. He was a powerful personality, combative, manipulative and driven. You underestimated him at your peril. He was a big, stocky bruiser of a man. When he walked into a room, people knew about it. His broad North Carolina accent and verbose way of speaking sometimes made him come across like a good ol' boy, a 'blabbermouth', as Bobby Kennedy once described him. Yet under all the down-home bluster, one of the sharpest and shrewdest political minds in American history was at work. He took hold of the space age and ran it just the way he wanted.
>
> Webb knew everyone in Washington, and pretty much everyone in the business world. He understood what they wanted, and where his interests and theirs might converge.

> During his leadership of the space efforts in the Kennedy and Lyndon Johnson years, he dispensed largesse, called in favours and occasionally strong-armed people who were foolish enough to oppose him. He was not a man to take 'no' for an answer. His enemies believed he was on a personal crusade to gain power and influence through his running of the space agency. And indeed he was. He was a visionary 'technocrat' whose ambitions stretched far beyond merely landing a man on the moon. By 1964 he held sway over 5 per cent of the entire US federal budget. The potential of that great wealth on the ground was just as important to him as the missions it could pay for in space. Here was a dyed-in-the-wool Democrat idealist who believed in personal honour, moral duty and national responsibility. He had come of age in the Depression years, and worked with Roosevelt during the New Deal era of national reconstruction. He believed passionately in the benefits of good government.

Navy Captain Bosquet Wev (1903–1979) of the Joint Intelligence Objectives Agency (JIOA) was a very strong supporter of developing revolutionary technologies after World War II. He played an especially important role in aiding the United States to acquire a large number of creators and creations from the German-speaking world and to support the employment of those innovators and technologies for U.S. military applications [Bower 1987; Crim 2018; Linda Hunt 1991]. Because Wev and his work were so secretive, the only available photo of him was taken very early in his Navy career and is shown in Fig. 11.71.

In his early book on the Paperclip program, Tom Bower gave a brief description of Wev [Bower 1987, p. 169]:

> Appropriately, with the new era the operation was given a new name: Overcast was replaced by Paperclip. [...]
>
> Equally appropriately, the new era began with the arrival of a new deputy director of JIOA. Captain Bosquet Wev, a conspiciously zealous naval officer, treated his responsibilities at the newly reconstituted JIOA with chauvinistic passion, unwavering obedience, and obsessive secrecy.

Historian Brian Crim described Wev's aims and methods in a much more recent book on Paperclip [Crim 2018, pp. 101–102]:

> Wev regarded the JIOA as a clearing house for intelligence, targeting, and document collection. Paperclip was vital to America's evolving national security concerns, and the more scientists the JIOA could identify, secure, and exfiltrate from Europe before the Soviet Union did the same, the better. Wev's intransigence and dismissive attitude toward rules and regulations reflected the War Department's privileged position, a point he reiterated frequently in meetings.

As shown in Section 10.2.6 and in this section, tremendous numbers of the revolutionary innovations both in the German-speaking research world and in the early decades ($\sim$1940s–1960s) of the U.S. research system can be linked to the enlightened despot scientific management style that was common in those places and times. It is difficult to imagine that all of those revolutionary innovations would have occurred in the modern research system, in which consensus-based bureaucratic competition for limited funding favors very short-term, very low-risk work and eschews new innovations and new innovators.

Indeed, most of the enlightened despots listed in this section retired in the late 1960s or early 1970s, right around the time that the U.S. research system appeared to shift from long-term work on revolutionary innovations to short-term work on incremental progress:

- William Allen retired from Boeing in 1972.
- Vannevar Bush was active on scientific advisory boards until the 1960s.
- James Conant was active on various fronts until the 1960s.
- Lee DuBridge stepped down from Caltech in 1969.
- Crawford Greenewalt left Du Pont in 1967.
- Leslie Groves and Robert Oppenheimer were both active in different ways into the 1960s.
- Kelly Johnson retired from the Lockheed Skunk Works in 1975.
- Mervin Kelly was active until he died in 1971.
- Donald Putt retired from the Air Force in 1957 and from United Technology Center in 1962.
- Simon Ramo stepped down from TRW in 1978.
- Hyman Rickover remained a formidable force through the 1970s.
- Bernard Schriever left the Air Force in 1966.
- Edward Teller retired from managing Lawrence Livermore National Laboratory in 1975.
- Frederick Terman retired from Stanford in 1965.
- Thomas Watson Jr. retired from IBM in 1971.
- James Webb and Wernher von Braun left NASA in 1968 and 1972, respectively.

It is difficult to find examples of enlightened scientific despots who were so numerous or so successful in the United States after that period of time.

This finding suggests that one way to increase the amount of revolutionary innovation in the modern research system would be to find enlightened despots with good judgment, strongly support them from a very high level, and allow them to allocate at least some fraction of the research budget over a sustained period of time to those they consider the most promising innovators and innovations. This approach has been advocated by people such as Pierre Azoulay [Azoulay et al. 2019], Sydney Brenner (p. 2260), and Donald Braben [Braben 2004, 2008, 2014], and is discussed in Chapter 12 .

It is also interesting to note that many enlightened despots who were not strong scientists themselves chose to lead jointly with a very talented scientist. These duos could operate very effectively for years, typically with the less scientific partner carrying most of the burden of advocating for the program "upward" with government officials who were above that program, and the more scientific partner primarily directing "downward" the research of scientists under that program. Examples of these upward/downward management duos included:

- General Henry Arnold and Theodore von Kármán in the U.S. Air Force.
- General Walter Dornberger and Wernher von Braun in Germany.
- James Webb and Wernher von Braun at NASA.
- General Leslie Groves and Robert Oppenheimer in the Manhattan Project.
- Dean Wooldridge and Simon Ramo at Hughes Aircraft and TRW.
- Various pairings of Edward Teller (in either role) over a forty-year period with others such as Ernest Lawrence, Herbert York, and Lowell Wood.

11.2.7 Systems Analysis

Just as systems analysis methods enabled scientists and sponsors in the earlier German-speaking world to explore all possible creations in a given area and identify the best ones, those same methods also guided research and development in the United States, especially during the 1940s–1960s. In fact, the United States directly appropriated the systems analysis methods from the German-speaking world via two routes:

- Importing a wide range of German creations (such as prototype missiles covering all possible categories, or jet engines covering all possible types), which had already been conceived, developed, and categorized by the systems analysis approach.

- Importing German-speaking creators who championed systems analysis methods and employed them in the service of the U.S. government, especially creators such as Theodore von Kármán, Fritz Zwicky, John von Neumann, and Leo Szilard.

A good example of the influence of systems analysis on early U.S. research and development is General Henry Arnold's 12 November 1945 *Third Report of the Commanding General of the Army Air Forces to the Secretary of War* (see p. 5538):

> [...] We must look at the future of aerial warfare in the light of the following considerations:
>
> 1. Aircraft, piloted or pilotless, will move at speeds far beyond the velocity of sound, well over 700 miles per hour.
>
> 2. Improvements in aerodynamics, propulsion, and electronic control will enable unmanned devices to transport means of destruction to targets at distances up to many thousands of miles. However, until such time as guided missiles are so developed that there is no further need for manned aircraft, research in the field of "conventional" aircraft of improved design must be vigorously pursued.
>
> 3. Small amounts of explosive materials, as in atomic bombs, will cause destruction of many square miles.
>
> 4. Defense against present day aircraft may be perfected by target-seeking missiles.
>
> 5. Only aircraft or missiles moving at extreme speeds will be able to penetrate enemy territory protected by such defenses.
>
> 6. A communications system between control center and each individual aircraft will be established.
>
> 7. Location and observation of targets, take-off, navigation and landing of aircraft, and communications will be independent of visibility or weather.
>
> 8. Fully equipped airborne task forces will be able to strike at far distant points and will be totally supplied by air.

> [...] Further, the great unit cost of the atomic bomb means that as nearly as possible every one must be delivered to its intended target. This can be done in one of several ways, all of which involve air power. For example, the following evolution may be suggested:
>
> a. Today, our Army Air Forces are the recognized masters of strategic bombing. Until others can match the present efficiency of our own antiaircraft defenses, we can run a large air operation for the sole purpose of delivering one or two atomic bombs. Our experience in the war suggests that the percentage of failures in an operation of this kind would be low.
>
> b. When improved antiaircraft defenses make this impracticable, we should be ready with a weapon of the general type of the German V-2 rocket, having greatly improved range and precision, and launched from great distances. V-2 is ideally suited to deliver atomic explosives, because effective defense against it would prove extremely difficult.
>
> c. If defenses which can cope even with such a 3,000-mile-per-hour projectile are developed, we must be ready to launch such projectiles nearer the target, to give them a shorter time of flight and make them harder to detect and destroy. We must be ready to launch them from unexpected directions. This can be done from true space ships, capable of operating outside the earth's atmosphere. The design of such a ship is all but practicable today; research will unquestionably bring it into being within the foreseeable future.
>
> [...] Complete dispersal of our cities and moving vital industries underground on a sufficiently large scale would be overwhelmingly expensive. [...]
>
> Although there now appear to be insurmountable difficulties in an active defense against future atomic projectiles similar to the German V-2 but armed with atomic explosives, this condition should only intensify our efforts to discover an effective means of defense. [...]
>
> Jet propulsion is in its infancy despite the fact that this war has evolved six distinct methods of utilizing atmospheric oxygen for propulsion, such as (1) *motorjet*—or reciprocating engine plus ducted fan, (2) *turboprop*—a gas turbine plus propeller, (3) *turbofan*—a gas turbine plus ducted fan, (4) *turbojet*—a gas turbine plus jet, (5) *ramjet*—a continuous jet with compression by aerodynamic ram, and (6) *pulsojet*—or intermittent jet. These new and strange sounding words will be familiar ones in our speech in the near future, and right now they carry more meaning for Americans than any other six words I know.

The above quote, which was clearly heavily influenced by Arnold's chief scientific advisor, Theodore von Kármán (see p. 5508), applied systems analysis first to aerial warfare, then to atomic bomb delivery methods, and finally to aircraft propulsion.

Under the guidance of Theodore von Kármán [Gorn 1992], John von Neumann [Macrae 1992], and others, the entire 1940s–1960s U.S. national defense system was based on systems analysis. All three parts of the nuclear triad (intercontinental jet bombers, land-based intercontinental ballistic missiles, and submarine-launched missiles) were borrowed directly from wartime German programs; see Appendix E for more information. Government-funded think tanks sprang up to apply systems analysis to the remaining details of the defense system; some prominent examples included:

- RAND Corporation (initiated in 1945, finalized in 1948) [Jardini 2013; Kaplan 1991].
- MIT Lincoln Laboratory (founded in 1951) [Grometstein 2011].
- Institute for Defense Analyses (IDA, founded in 1956) [Finkbeiner 2006].
- MITRE Corporation (founded in 1958) [Shearman 2008].
- JASON advisory group (founded in 1959) [Finkbeiner 2006].
- The Analytic Sciences Corporation (TASC, founded in 1966) [http://www.fundinguniverse.com/company-histories/analytic-sciences-corporation-history/].

However, that systems analysis methodology was primarily applied to the U.S. national defense system, not other areas of research and development. By around 1970, the Cold War had relaxed, the national defense system had assumed essentially the form that it still has, and there was little motivation to apply systems analysis to new problems. Moreover, the imported German creations that were steeped in systems analysis (missiles of all possible types, jets of all possible types, etc.) had been developed to a very mature state, and the imported German-speaking masters of systems analysis had mostly retired or died. Thus much of the research performed in the decades since around 1970 has been conducted without the insights that systems analysis could offer both to individual scientists and also to the sponsors of scientific research programs.

11.2.8 Limited Natural Resources

Whereas the earlier German-speaking world was very limited in the natural resources that it possessed on its own lands or that it could import, the United States had a wealth of natural resources on its own territory, and even more that it could import from willing suppliers around the world. As a result, the German-speaking world had a strong incentive to invent revolutionary new synthetic materials and processes, but the United States did not. With the assistance of the U.S. government, American companies commercialized synthetic innovations that had been developed in the German world, ranging from new plastics to food substitutes [Gimbel 1990a]. Unfortunately they do not appear to have made the same proportionally large investments that the German-speaking world had made in creating new generations of revolutionary synthetic products and processes.

Now that the United States and the rest of the world are more concerned about dwindling natural resources and accumulating amounts of greenhouse gases, pollution, and waste, these newfound concerns could potentially be used as strong forces to drive a large amount of fresh innovation for synthetic and/or recycled materials.

11.2.9 International Rivalry

Just as military and industrial competition with other countries was a strong driver of innovation in the German-speaking world throughout the entire period 1800–1945 (Fig. 10.15), international competition also strongly motivated innovation in the United States during the 1940s, 1950s, and 1960s (Fig. 11.72).

During World War II, political and military leaders in the United States were deeply concerned about German domination in Europe and German development of revolutionary new technologies such as nuclear weapons, long-range rockets, and jets that could entrench or further spread that domination. As a result, they strongly supported Vannevar Bush's new innovation system, as discussed in Section 11.2.6. Large numbers of immigrant German-speaking scientists and American scientists were rapidly mobilized in the United States to develop nuclear weapons, perfect radar systems, mass-produce penicillin, and accomplish other feats.

Before World War II had even ended, the United States had started to turn its attention to the coming Cold War with the Soviet Union. In 1945, the United States scrambled to extract as many creators, creations, and resources as possible from the former German Reich before those could fall into Soviet hands, although a large fraction did nonetheless. From 1945 onward, the United States was in a race to adopt and perfect as many German-created military technologies as possible, or to develop new ones, before the Soviet Union could do the same. Among the revolutionary technologies that were fielded were improved nuclear weapons, jet fighters and bombers, ground-to-air and air-to-air missiles and smart bombs, advanced air defense networks, nuclear submarines and nuclear aircraft carriers, intermediate range and intercontinental ballistic missiles, nerve gases, and biological warfare agents. Those technologies were arrayed against their Soviet counterparts throughout the Cold War standoff, and some of them were tested on the battlefield in proxy wars between the two superpowers such as those in Korea and Vietnam. In addition to direct military competition, the United States and the Soviet Union also engaged in the space race as an alternative way to display their prowess with closely military-related technologies to each other and to the rest of the world. Buttressing all of those Cold War programs (and heavily subsidized by them) were rapid industrial developments in aerospace technologies, microelectronics, nuclear power, chemical engineering, biomedical research, and other areas.

The journalist David Beers, who grew up surrounded by his father's Cold-War research at Lockheed, described the enormous impact on research and development [Beers 1996, pp. 29–31]:

> It was the government mobilizing and funding technology with a zeal that would burn even hotter once LBJ and John F. Kennedy rode their *Sputnik* scare strategy to the White House in 1960.
>
> It was the state commanding, in a sense, that not only technology but *places* come into being.
>
> Blue sky metropolises, nurtured by federal dollars, would be commanded to rise out of orange groves and scrublands and prairies and deserts and other former boondocks to industrial America. The money would flow to the Northwest of Boeing, to the Texas of Bell Aviation and Mission Control, to the Rocky Mountains of the North American

> Air Defense Command, to the Florida of Martin-Marietta and Cape Canaveral, to the Alabama of Wernher von Braun's U.S. Army Redstone rocket works. [...]
>
> The money would go, as well, to certain centers of technological innovation, the realms, for example, of Boston's MIT and Pasadena's CalTech, universities that made a specialty of military contracts. A basic rule of thumb is that the money flowed to where life could be made affordably good for the blue sky professional and family. [...]
>
> The biggest of them all, of course, was and is Southern California, home to Aerojet and Convair and Ford Aerospace and Hughes and Litton and Lear Siegler and McDonnell-Douglas and Northrop and Rockwell and RAND and TRW and the United States Air Force Space Division and all the hundreds of subcontractors that serve them as well as many key military bases and universities. The San Fernando Valley of Southern California is home as well to Lockheed, and a time came in the late 1950s when Lockheed was commanded to build an answer to *Sputnik*.

However, the Cold War competition dramatically slowed around 1970. After beating the United States to launch the first satellite and the first person in Earth orbit, the Soviet Union lost the moon race when the United States landed the first people on the moon on 20 July 1969; the Soviet Union then cancelled its own manned lunar program and chose not to continue the space race toward even grander goals. With no further competition, the United States discontinued its advanced space program after only six manned lunar landings and billions of dollars spent to develop those technologies, and has only sent astronauts to low Earth orbit with much less capable rockets in the many decades since then.

At almost the same time, the Strategic Arms Limitation Talks (SALT) between the United States and the Soviet Union began in November 1969, effectively marking the end of the fierce competition to develop ever more powerful weapons and delivery systems for them. In general, Soviet Premier Leonid Brezhnev and his successors were significantly less militarily aggressive than Joseph Stalin and Nikita Khrushchev had been. With greatly decreased competition from the Soviet Union, and no other serious rivals in sight, beginning around 1970 the U.S. government started to lose interest in rapid and revolutionary innovation, and its research and development system and industries tended to follow suit.[13]

David Beers wrote about the dramatic shift that he observed in 1970 [Beers 1996, pp. 132–133]:

> "This," President Nixon declared of the lunar landing, "is the greatest week since the beginning of the world, the creation." My tribe, certainly, assumed Apollo's success would secure our dominance. Having been placed in charge of the future, we had delivered as promised a man on the moon on television. As scripted by our tribe's father, Wernher von Braun, the moon shot was to be but a way station on the path to Mars, a warm-up for the building and launching of a "flotilla" of manned spaceships to the red planet.

[13]The United States did feel some sense of economic and technological rivalry with Japan during the 1980s, but that was nowhere near as strong or as sustained as the military rivalry with the Soviet Union had been, and therefore was much less motivational for the U.S. innovation system [LaFeber 1997].

> Yet almost at the moment *Eagle* landed, blue sky icons seemed to lose their mojo powers. Environmentalists, utterly unmoved by the sleek loveliness of the SST [supersonic transport], painted it loud and rude, shot it down. The B-70 superbomber program had already crashed in Congress as the antiwar movement challenged the notion that the Pentagon, NASA, or any state authority should be the revered and unchallenged steward of a people's imagination about the future. Few (except for my tribe) took seriously Vice President Agnew's call for a Mars mission. [...]
>
> One year after the greatest week since the beginning of the world, a slowing in weapons spending, coinciding with a slump in commercial jet sales, caused mass aerospace layoffs across the country. [...]
>
> That was a time when some of my father's peers went from designing satellites to perfecting alloy backpack frames (surely Dad hadn't been a compatriot of Neil Armstrong's only to make camping gear!) I remember, while watching the Jetsons suburbanize the Milky Way on TV, reading newspaper stories about out-of-work Lockheed men killing themselves.
>
> That was a time when the tribe clung to hubris nevertheless. One year after the greatest week in the history of the world, members of the blue sky tribe convened the West Coast's First Aerospace Congress to take up the issue of where next to apply the methods used to conquer the moon. Let us now turn aerospace engineers loose, speakers urged, on the problems of pollution, crime, urban blight, racism, poverty. Let us fix society with systems engineering. It fell to Vernon L. Grose, vice president of Tustin Institute of Technology in Santa Barbara, to counsel some caution.

Any remaining Cold War motivation that could drive revolutionary scientific innovation was lost when the Soviet Union disintegrated in 1991. By the time military or economic threats from Islamic terrorism, China, and a resurgent Russia became apparent in the 2000s, the U.S. government was too distracted by bitter internal political battles, and the U.S. research and development system had become too dysfunctional and calcified in the intervening several decades, to seriously rise up to properly deal with any new international innovation challenges.

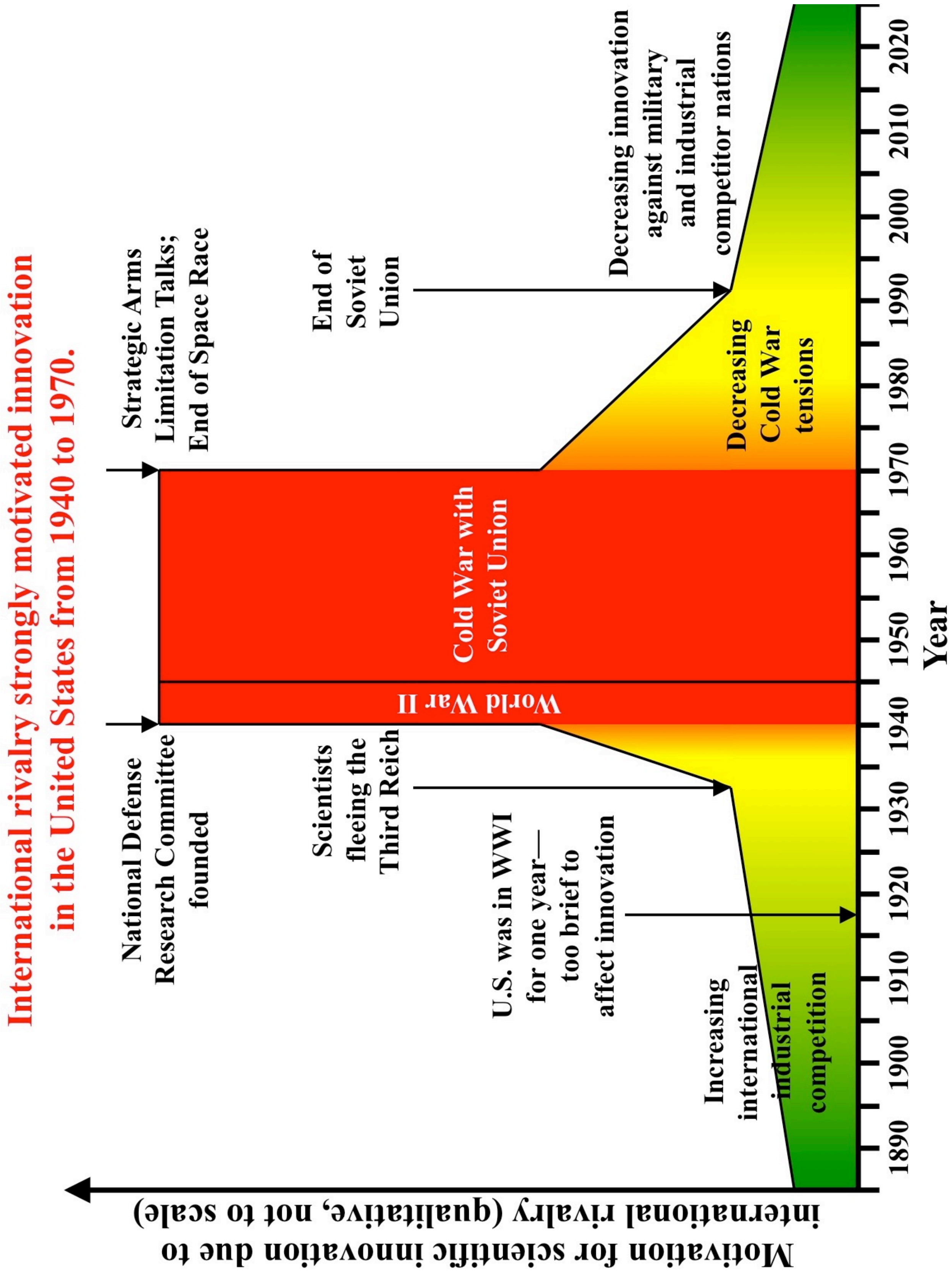


Figure 11.72: International rivalry strongly motivated innovation in the United States from 1940 to 1970.

11.2.10 Industrial Unity of Purpose

Paradoxically, competition between companies can decrease the incentive for innovation, rather than increase it, as shown in Fig. 11.73. Bell Laboratories developed transistors but other companies made fortunes based on that technology [Riordan and Hoddeson 1997]. Hughes Aircraft publicly announced the first laser yet it was other companies that profited by producing and selling lasers [Bromberg 1991]. IBM and Xerox PARC created versatile computers, but lost out when such computers were mass-produced by other companies like Apple and Dell [Isaacson 2014]. Apple developed the iPhone yet lost most of its market share to other companies that rapidly produced similar smart phones [Isaacson 2011]. Pharmaceutical companies have spent billions of dollars to develop new drugs, only to have their patents expire within just a few years after the lengthy drug development and approval process, allowing other companies to manufacture generic versions of those drugs [Alberts 2014; Begley 2009; Hsueh 2015; Mittra 2009; O'Neill 2012].

As a result of this historical pattern, modern companies have learned that it is much more lucrative not to innovate. It is much less profitable to invest a large amount of money in developing an innovative new product that is rapidly copied by competitors, and much more profitable not to invest in research and simply to copy innovations that are developed by someone else.

In the German-speaking world from around 1800 to 1945, these negative forces of competition among domestic companies were counteracted by the much greater sense of competition with foreign governments and industries (Section 10.2.10). The leaders of different German-speaking companies were united by a common sense of purpose, such as beating industrial competition from the United Kingdom or trying to win World Wars I and II. That industrial unity of purpose was cultivated and rewarded by the federal government.

Similarly, from the 1940s to the 1960s, U.S. companies received a much stronger positive incentive for innovation from foreign military competition, first with Germany and then with the Soviet Union, than any domestic negative incentive against innovation. As with the earlier German model, this industrial unity of purpose was nurtured and even dictated by the federal government. Throughout World War II, the Cold War, and the space race, the U.S. government invited bids from companies to develop revolutionary technologies, selectively funded those companies with the most attractive bids, and stipulated when and how companies would collaborate with each other when different parts of a system would be built by different companies (Fig. 11.74).

With the end of the space race and the easing of the Cold War around 1970, there was no longer strong incentive for this industrial unity of purpose, either from the U.S. government or from foreign competition. Companies were left to pursue their individual best economic interests using their own strategies. After a few very public examples (such as those cited above) that it was much more lucrative to take advantage of other companies' innovations than to invest in creating their own innovations, companies fell into a pattern that emphasized very short term, very low risk, very lucrative products. That pattern has continued to the present day.

Without enough government protection, companies that invested in developing innovative products lost most of the market share to other companies that simply copied those products.

Transistors

Lasers

Pharmaceuticals

Personal computers

Smartphones

Companies should view very innovative, longer-term R&D as:

- **A worthwhile investment in staying ahead of competitors.**
- **Not a financial liability whose resulting products could be copied by competitors that did not fund their own R&D.**

Figure 11.73: Without enough government protection, companies that invested in developing innovative products lost most of the market share to other companies that simply copied those products, creating a strong disincentive for companies to fund R&D.

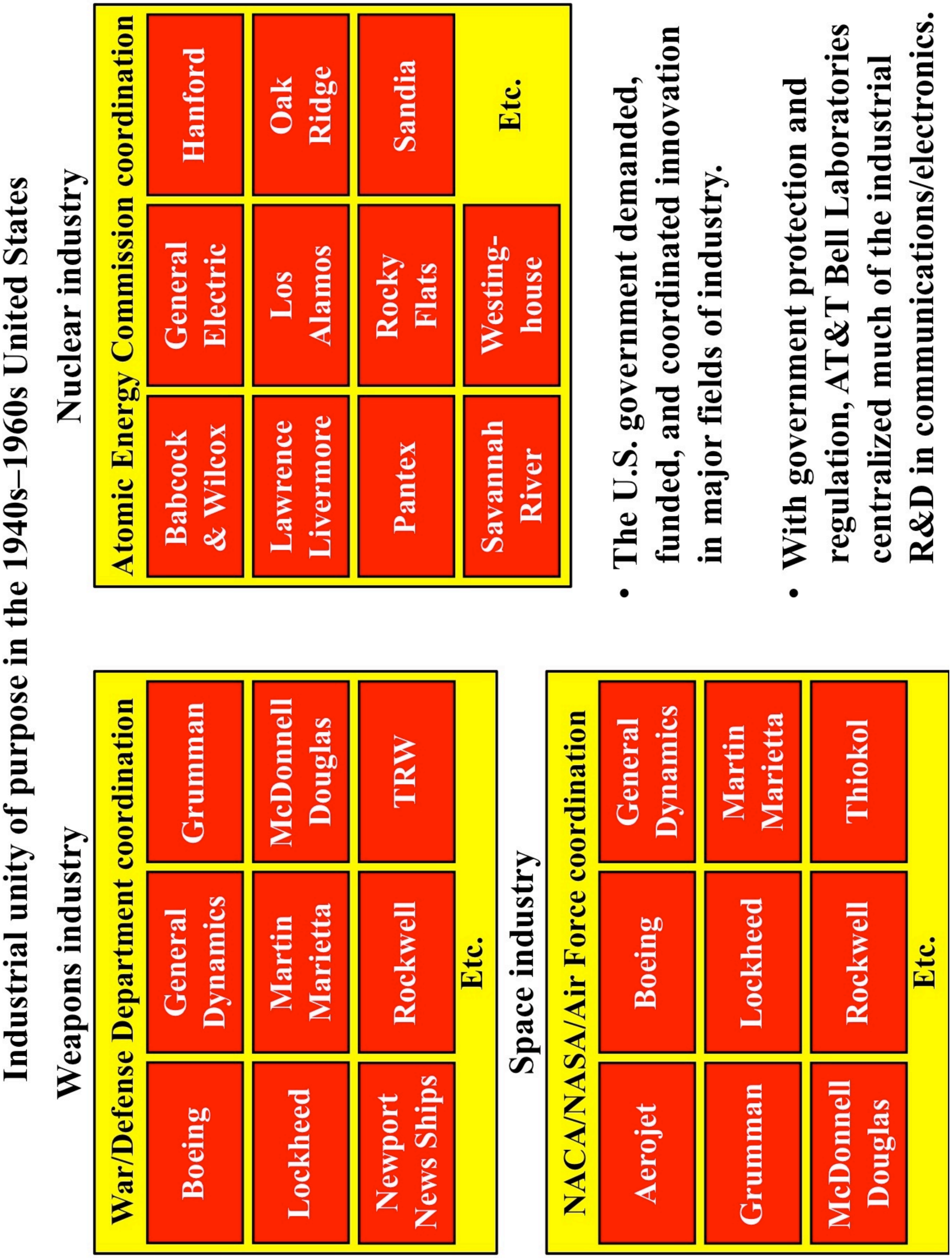


Figure 11.74: In the United States from 1940 to 1970, companies were less afraid of losing their innovations to each other than of losing to foreign countries, strongly motivating them to innovate (with strong support and coordination by government agencies).

Another strong incentive that the U.S. government could use to alter and unify corporate behavior is taxes. U.S. corporate tax rates were extremely low prior to 1940, high during the 1940s–1960s, and then lower from the 1970s onward, as shown in Fig. 11.75. The high corporate tax rates during the 1940s–1960s were a strong incentive for executives to reinvest most of their company's income in research and development, infrastructure, and employees instead of trying to remove it from the company as cash profits and lose much of it. When those tax rates began to seriously decline from the 1970s onward, the culture of U.S. companies altered dramatically. Research and development programs were downsized or eliminated, U.S.-based laboratories and manufacturing facilities were neglected or closed and outsourced overseas, employees were considered easily replaceable and treated poorly, and more and more of the income generated by large corporate organizations was channeled to fewer and fewer people in those organizations. After those trends have continued for over half a century, the United States has reached a point where many of the largest companies pay no taxes at all on billions of dollars in profit [NYT 2021-04-02] and there are disastrous effects on revolutionary scientific innovation (Sections 1.1 and 11.3.1) and society in general.

Simon Ramo, cofounder of TRW, described how U.S. companies began to view R&D as more of a burden than an opportunity beginning in the 1970s—see p. 52.

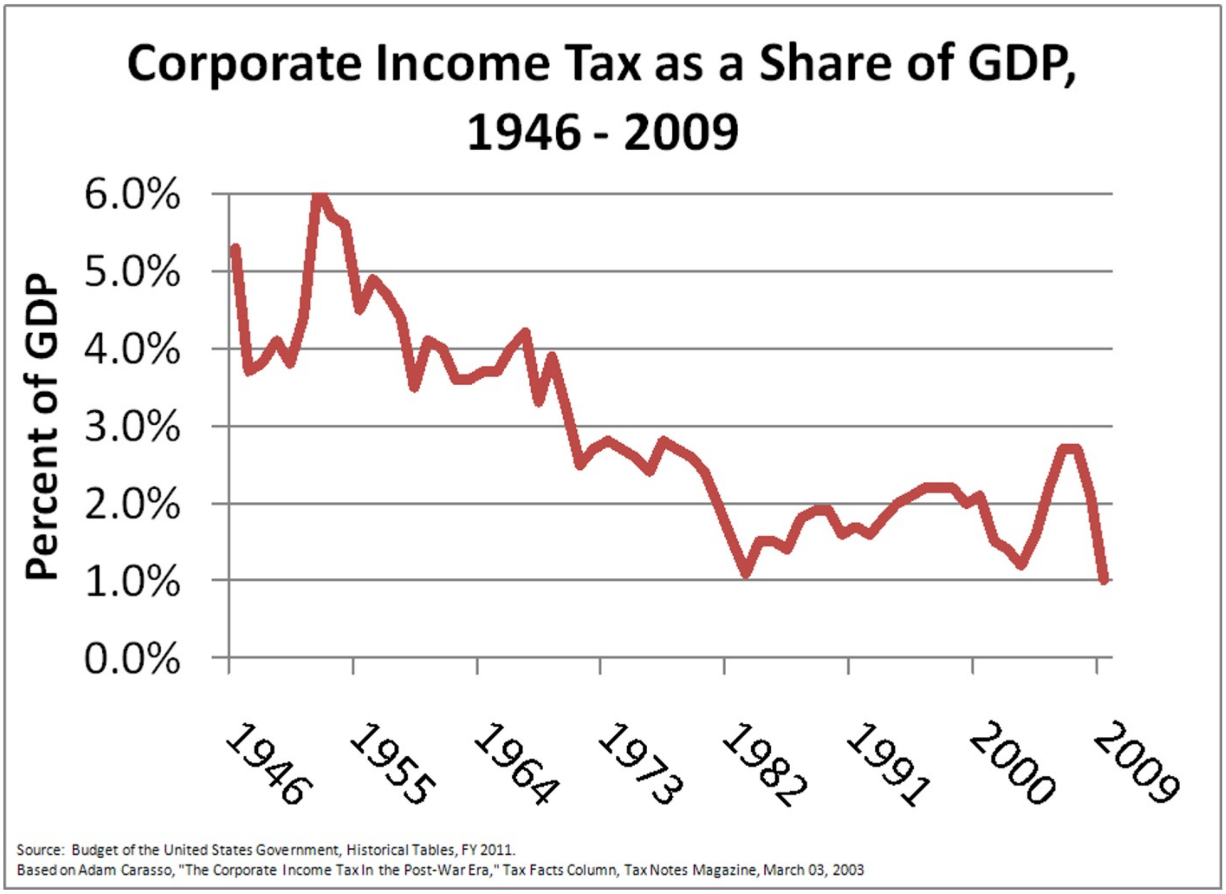
John Pierce, a research manager under Mervin Kelly at Bell Laboratories during its heyday, gave a very similar description of various external and internal forces that led Bell Laboratories to become less interested in innovative R&D after Kelly retired [Pierce 1975]:

> Kelly's concept of "organized creative technology," embracing research, fundamental (or exploratory) development, systems engineering, and final development for manufacture is persuasive. His concept of the place of basic research in industry is inspiring and appealing. What, however, are we to make of these in practice?
>
> There seems to be no avoiding Kelly's conclusion that industrial progress is based on the results of basic research. We can note that basic research is sometimes inspired by technological invention. Thermodynamics was inspired by the steam engine. But, whatever its inspiration, basic research lies behind the whole of modern technology. Kelly felt strongly that much basic research should be carried out in industrial laboratories.
>
> During Kelly's career at Bell Laboratories, he experienced (despite the years of the Depression) the relatively stable support derived from the provision of a service as opposed to the manufacture of products for the market place. The exception to this was defense work, but this was done during periods of close cooperation between government and industry in the national crises of World War II and the Korean War. These were circumstances far more favorable to research, or at least to the dedicated effort of first-rate men, than is work in a manufacturing industry where markets as well as revenues fluctuate.
>
> Further, in Kelly's time the effect on science of some government actions and attitudes was less clear than it is today. The consequences to science of antitrust actions that sever service from manufacture (in aircraft and airlines, for example), that render successful companies insecure in their operations and in cooperative relations with universities, and that prevent cooperative research toward common needs, were not yet clear. Further, in Kelly's time the attitude of government toward both science and industry was on the

> whole friendly and cooperative. Today, the attitude of government has, in many areas, become at once hostile, highly demanding, and minutely dictatorial through statutory and bureaucratic means.
>
> Thus, Kelly may have overestimated the amount and quality of research that could in the future be expected from industry, and perhaps from the nation.
>
> Some of Kelly's ideas concerning the organizational form most suitable for "organized creative technology" have hazards as well as power. The autonomy of research, the prerogatives of systems engineering, and the separation of the management of non-technological functions from the technological management depend for their success on inspired leadership.
>
> When leadership is uninspired or inadequate, it is easy for research to drift away from the overall purpose of an organization. It is easy for the rest of the organization to disregard research. It is easy for systems engineers to become stale and to lose their feel for the actual state of research on one hand and the current realities of development, manufacture, and operation on the other. It is easy for a large staff organization concerned with buildings, facilities, shops, libraries, and even computer services to put organizational order and budgetary neatness ahead of the real needs and problems of scientists and engineers.
>
> Above all, a technological organization must have the leadership to see and pursue real opportunities and real needs.

Thus beginning around 1970, U.S. companies became less and less supportive of innovative research and development, and that pattern continued for several decades. By the time another serious foreign competitor arose in China around 2000 or so, it became apparent that China could rapidly copy any U.S. innovation, mass-produce it, and sell it for less in U.S. and global markets. Therefore not only domestic but also foreign competition became a strong disincentive to invest in research and development of major new innovations.

High U.S. corporate tax rates during the 1940s–1960s were a strong incentive for executives to reinvest most of a company's income in research and development, infrastructure, and employees instead of trying to remove it from the company as cash profits and lose much of it.



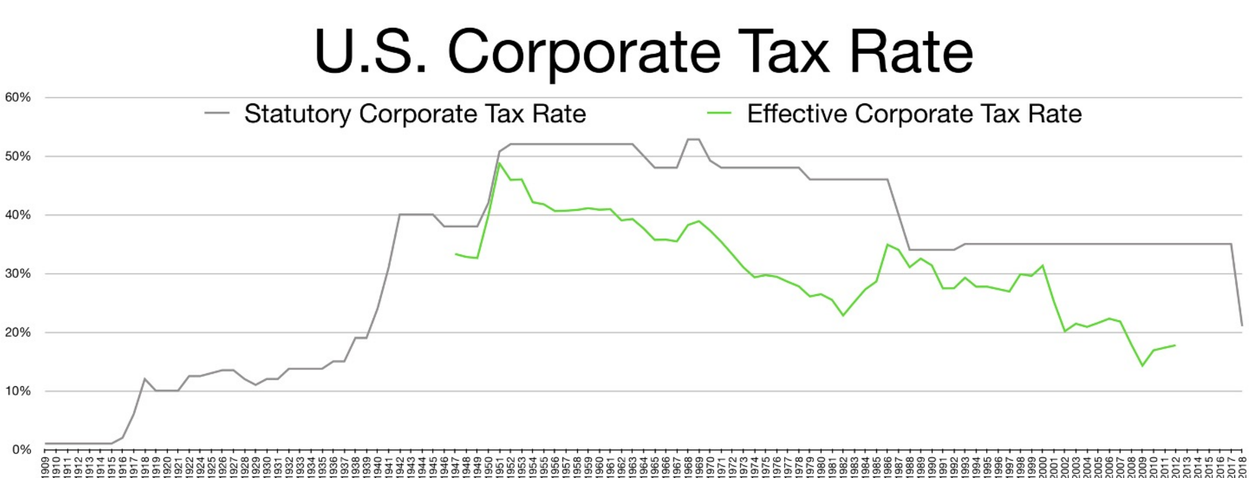


Figure 11.75: High U.S. corporate tax rates during the 1940s–1960s were a strong incentive for executives to reinvest most of a company's income in research and development, infrastructure, and employees instead of trying to remove it from the company as cash profits and lose much of it.

11.2.11 Other Factors

Family backgrounds of creators

Just as a disproportionate percentage of innovators in the German-speaking world was Jewish, a disproportionate percentage in the U.S. system has also been Jewish. Currently approximately 2% of the U.S. population is Jewish or of Jewish background. Yet from 1901 through 2013, 25% of all U.S. Nobel Prize winners in science were Jewish and born in the Unites States. Including both those born in the United States and also those who immigrated to the United States from other countries of origin, 38% of all U.S. Nobel Prize winners in science were Jewish [Gerstl 2014, p. 87]. Those statistics may indicate that certain family backgrounds place more emphasis on intellectual education and careers, or even more specifically on science-related education and careers.

However, this factor is not sufficient for producing revolutionary scientific innovations. There are currently approximately six million Jewish people in the United States, as well as millions of people from all sorts of other backgrounds, yet the rate of revolutionary innovations per year (certainly the rate of revolutionary innovations per year per person) seems far lower than in earlier times. What appears to be lacking are the systemic approaches (such as those listed in previous sections) that fostered, supported, and rewarded revolutionary innovators and innovations in the German-speaking world and in the early U.S. system, but that have subsequently been largely abandoned.

Other possible factors

In addition to the factors already considered in this chapter, it is possible that other factors helped or hindered scientific innovation in the United States. In the future, scholars who examine this topic further should evaluate factors such as those listed on p. 2042, and determine how much if any effect each factor has had on innovation.

11.3 Failure to Sustain Approaches Transferred from the German-Speaking World

The U.S. research system was highly productive during its early decades in the 1940s–1960s, when it largely focused on perfecting creations it had imported from the earlier German-speaking world (Section 11.1), using thousands of creators (Section 11.1) and some systemic approaches (Section 11.2) that it had also imported from the German-speaking world. Unfortunately, productivity apparently declined after that period, as the original creations reached complete technological maturity, the original German-speaking creators retired or died, and the system drifted further from the approaches that had originally facilitated the successes of those creators and creations. In particular, research funding stagnated or declined (Figs. 11.62–11.64), far-sighted enlightened despots were replaced by consensus-based bureaucracies, and research shifted from longer-term development of revolutionary innovations to extremely low-risk production of immediately marketable commercial products or immediately publishable academic papers. This section quotes some first-hand observations of the apparent decline of the modern research system, then examines potential explanations for that decline.

11.3.1 Observations of Decline

The following are personal accounts from several discerning experts who observed these changes as they happened in all three sectors of the U.S. research system:

A. The university-based academic research system (p. 2257).

B. The corporate research system based in private company laboratories (p. 2266).

C. The government research system based in government-run and/or government-funded laboratories (p. 2268).

A. Observations of decline in the academic research system

Philip Anderson (1923–2020, 1977 Nobel Prize in Physics) was part of the U.S. research system from the 1940s onward and described its decline [Laurie Brown et al. 1995, pp. 2027–2029]:

> The gigantic growth... took place to a large extent because of a perception both in industry and in government that the products created were economically useful. The result was funding on a scale which absorbed essentially all new recruits. Through the first three postwar decades this was unquestionably the case; we hardly need to repeat the litany of practically useful materials and devices which came out during these years.
>
> [...] The result was an increasing overcrowding of research as a profession. One may question—and leaders of various kinds did—how much research is too much, or even whether there *could* be too much research, research being viewed as an absolute good. But conditions within the profession, viewed objectively, made it quite clear that aside from the inevitable funding crunch there were dysfunctions in the system.

> There was a very sharp change in the nature of a research career. The 'promising' young scientist's publication rate grew by factors of five to ten; the number of applications a young researcher might make for postdoctoral work or an entry-level position from two or three to 50. Senior scientists were overwhelmed with receiving and sending reams of letters of recommendation, which thereupon became meaningless. The numbers of meetings in a given specialized subject, and the number of subjects with a formal meeting list, both grew by factors of ten or more. In many subjects one could 'meet' nearly 52 weeks in the year, somewhere in the world, and leaders in the field were invited to all. Meetings almost inevitably led to publications. Most publications became tactical in this game of jockeying one's way to the top; publications in certain prestige journals were seen as essential entry tickets or score counters rather than as serious means of communication. Great numbers of these publications were about simulations of dubious realism or relevance. Essentially, in the early part of the postwar period the career was science-driven, motivated mostly by absorption with the great enterprise of discovery, and by genuine curiosity as to how nature operates. By the last decade of the century far too many, especially of the young people, were seeing science as a competitive interpersonal game, in which the winner was not the one who was objectively right as to the nature of scientific reality but the one who was successful at getting grants, publishing in PRL [*Physical Review Letters*], and being noticed in the news pages of *Nature*, *Science*, or *Physics Today*.
>
> In many subjects the great volume of publications, the fragmentation into self-referential so-called schools who met separately, and a general deterioration in quality which came primarily from excessive specialization and from careerist sociology, meant that quite literally more was worse.

Note that Anderson described all of these problems in 1995, and they have only become even more pronounced in the decades since then.

As early as 1972, Albert Szent-Györgyi (Hungarian, 1893–1986), the winner of the 1937 Nobel Prize in Physiology or Medicine, noticed similar problems in the American research system. In a letter to the journal *Science*, he complained about how the system had come to discriminate against funding revolutionary innovators who pioneered entirely new research directions (whom he labelled "Dionysians") in favor of only funding scientists who made evolutionary, incremental progress in already known directions ("Apollonians") [Szent-Györgyi 1972]:

> In science the Apollonian tends to develop established lines to perfection, while the Dionysian rather relies on intuition and is more likely to open new, unexpected alleys for research. [...]
>
> The future of mankind depends on the progress of science, and the progress of science depends on the support it can find. Support mostly takes the form of grants, and the present methods of distributing grants unduly favor the Apollonian. Applying for a grant begins with writing a project. The Apollonian clearly sees the future lines of his research and has no difficulty writing a clear project. Not so the Dionysian, who knows only the direction in which he wants to go out into the unknown; he has no idea what he is going to find there and how he is going to find it. [...]

> A discovery must be, by definition, at variance with existing knowledge. During my lifetime, I made two. Both were rejected offhand by the popes of the field. Had I predicted these discoveries in my applications, and had these authorities been my judges, it is evident what their decisions would have been. [...]
>
> The problem is a most important one, especially now, as science grapples with one of nature's mysteries, cancer, which may demand entirely new approaches.

Sydney Brenner (1927–2019), who won the Nobel Prize in Physiology or Medicine in 2002 for his work on molecular biology, described similar problems with the modern academic research system [Dzeng 2014]:

> In America you've got to have credits from a large number of courses before you can do a PhD. That's very good for training a very good average scientific work professional. But that training doesn't allow people the kind of room to expand their own creativity. But expanding your own creativity doesn't suit everybody. For the exceptional students, the ones who can and probably will make a mark, they will still need institutions free from regulation. [...]
>
> I strongly believe that the only way to encourage innovation is to give it to the young. The young have a great advantage in that they are ignorant. Because I think ignorance in science is very important. If you're like me and you know too much you can't try new things. I always work in fields of which I'm totally ignorant. [...]
>
> Today the Americans have developed a new culture in science based on the slavery of graduate students. Now graduate students of American institutions are afraid. He just performs. He's got to perform. The postdoc is an indentured labourer. We now have labs that don't work in the same way as the early labs where people were independent, where they could have their own ideas and could pursue them.
>
> The most important thing today is for young people to take responsibility, to actually know how to formulate an idea and how to work on it. Not to buy into the so-called apprenticeship. I think you can only foster that by having sort of deviant studies. That is, you go on and do something really different. Then I think you will be able to foster it.
>
> But today there is no way to do this without money. That's the difficulty. In order to do science you have to have it supported. The supporters now, the bureaucrats of science, do not wish to take any risks. So in order to get it supported, they want to know from the start that it will work. This means you have to have preliminary information, which means that you are bound to follow the straight and narrow.
>
> There's no exploration any more except in a very few places. You know like someone going off to study Neanderthal bones. Can you see this happening anywhere else? No, you see, because he would need to do something that's important to advance the aims of the people who fund science.
>
> I think I've often divided people into two classes: Catholics and Methodists. Catholics are people who sit on committees and devise huge schemes in order to try to change

things, but nothing's happened. Nothing happens because the committee is a regression to the mean, and the mean is mediocre. Now what you've got to do is good works in your own parish. That's a Methodist. [...]

I am fortunate enough to be able to do this because in Singapore I actually have started two labs and am about to start a third, which are only for young people. These are young Singaporeans who have all been sent abroad to get their PhDs at places like Cambridge, Stanford, and Berkeley. They return back and rather than work five years as a post-doc for some other person, I've got a lab where they can work for themselves. They're not working for me and I've told them that. [...]

They can have some money, and of course they've got to accept the responsibility of execution. I help them in the sense that I oblige them and help them find things, and I can also guide them and so on. We discuss things a lot because I've never believed in these group meetings, which seems to be the bane of American life; the head of the lab trying to find out what's going on in his lab. Instead, I work with people one on one, like the Cambridge tutorial. Now we just have seminars and group meetings and so on.

So I think you've got to try to do something like that for the young people and if you can then I think you will create. That's the way to change the future. Because if these people are successful then they will be running science in twenty years' time. [...]

Even God wouldn't get a grant today because somebody on the committee would say, oh those were very interesting experiments (creating the universe), but they've never been repeated. And then someone else would say, yes and he did it a long time ago, what's he done recently? And a third would say, to top it all, he published it all in an un-refereed journal (The Bible).

So you know we now have these performance criteria, which I think are just ridiculous in many ways. But of course this money has to be apportioned, and our administrators love having numbers like impact factors or scores. Singapore is full of them too. Everybody has what are called key performance indicators. But everybody has them. You have to justify them.

I think one of the big things we had in the old LMB [Laboratory of Molecular Biology], which I don't think is the case now, was that we never let the committee assess individuals. We never let them; the individuals were our responsibility. We asked them to review the work of the group as a whole. Because if they went down to individuals, they would say, this man is unproductive. He hasn't published anything for the last five years. So you've got to have institutions that can not only allow this, but also protect the people that are engaged on very long term, and to the funders, extremely risky work.

I have sometimes given a lecture in America called "The Casino Fund." In the Casino Fund, every organisation that gives money to science gives 1% of that to the Casino Fund and writes it off. So now who runs the Casino Fund? You give it to me. You give it to people like me, to successful gamblers. People who have done all this who can have different ideas about projects and people, and you let us allocate it.

> You should hear the uproar. No sooner did I sit down then all the business people stand up and say, how can we ensure payback on our investment? My answer was, okay make it 0.1%. But nobody wants to accept the risk. Of course we would love it if we were to put it to work. We'd love it for nothing. They won't even allow 1%. And of course all the academics say we've got to have peer review. But I don't believe in peer review because I think it's very distorted and as I've said, it's simply a regression to the mean.
>
> I think peer review is hindering science. In fact, I think it has become a completely corrupt system. It's corrupt in many ways, in that scientists and academics have handed over to the editors of these journals the ability to make judgment on science and scientists. There are universities in America, and I've heard from many committees, that we won't consider people's publications in low impact factor journals.
>
> Now I mean, people are trying to do something, but I think it's not publish or perish, it's publish in the okay places [or perish]. And this has assembled a most ridiculous group of people. I wrote a column for many years in the nineties, in a journal called *Current Biology*. In one article, "Hard Cases," I campaigned against this [culture] because I think it is not only bad, it's corrupt. In other words it puts the judgment in the hands of people who really have no reason to exercise judgment at all. And that's all been done in the aid of commerce, because they are now giant organisations making money out of it. [...]
>
> I think that this has now just become ridiculous and it's one of the contaminating things that young people in particular have to actually now contend with. I know of many places in which they say they need this paper in *Nature*, or I need my paper in *Science* because I've got to get a post-doc. But there is no judgment of its contribution as it is.

In an obituary for Frederick Sanger (1918–2013), the only person to ever win two Nobel Prizes in Chemistry (1958 and 1980), Sydney Brenner continued his analysis of how the research system has changed [Brenner 2014]:

> A Fred Sanger would not survive today's world of science. With continuous reporting and appraisals, some committee would note that he published little of import between insulin in 1952 and his first paper on RNA sequencing in 1967 with another long gap until DNA sequencing in 1977. He would be labelled as unproductive, and his modest personal support would be denied. We no longer have a culture that allows individuals to embark on long-term—and what would be considered today extremely risky—projects.

As another example of the change in academia over the last several decades, the British newspaper *The Guardian* wrote about Peter Higgs (1929–), who won a Nobel Prize in Physics in 2013 for having predicted the existence and properties of a fundamental particle, the "Higgs boson," 50 years before it was finally discovered [Aitkenhead 2013]:

> Peter Higgs, the British physicist who gave his name to the Higgs boson, believes no university would employ him in today's academic system because he would not be considered "productive" enough. [...]

> He doubts a similar breakthrough could be achieved in today's academic culture, because of the expectations on academics to collaborate and keep churning out papers. He said: "It's difficult to imagine how I would ever have enough peace and quiet in the present sort of climate to do what I did in 1964." [...]
>
> By the time he retired in 1996, he was uncomfortable with the new academic culture. "After I retired it was quite a long time before I went back to my department. I thought I was well out of it. It wasn't my way of doing things any more. Today I wouldn't get an academic job. It's as simple as that. I don't think I would be regarded as productive enough."

Even though the primary product of the academic research system is published papers, with their quantity considered far more important than their quality, even the content of those papers ends up largely unread, unknown, and unused. In part, that is because of (1) the completely overwhelming flood of papers and journals; (2) the fact that most academic researchers are too busy frantically writing their own papers to spend much time reading and applying other researchers' papers; and (3) the unnecessarily microspecialized vocabulary that academics keep creating, resulting in a "tower of Babel" effect that makes academics in even slightly different fields unintelligible to each other, let alone to their sponsors or the general public. [For the history of these trends, see for example: Buranyi 2017; Francis 2020.]

Another reason that published papers tend to have so little effect is that the large majority of scientific papers are inaccessible to most of the population due to exorbitant online journal paywalls or the cost or obscurity of the printed volumes in which they appear. Sarah Kendzior, who has a Ph.D. in anthropology, used the JSTOR (Journal Storage) electronic journal database as an example to illustrate this general problem [Kendzior 2015, pp. 124–129]:

> Universities that want to use JSTOR are charged as much as $50,000 in annual subscription fees.
>
> Individuals who want to use JSTOR must shell out an average of $19 per article. The academics who write the articles are not paid for their work, nor are the academics who review it. The only people who profit are the 211 employees of JSTOR. [...]
>
> Today, publishing in an academic journal all but ensures that your writing will go unread. [...] If I wanted to download my [own] articles, I would have to pay $183. That is the total cost of the six academic articles I published between 2006 and 2012[...]
>
> New professors are awarded tenure based on their publication output, but not on the impact of their research on the world—perhaps because, due to paywalls, it is usually minimal. [...]
>
> The academic publishing industry seems poised to collapse before it changes. But some scholars are writing about the current crisis. Last month, an article called "Public Intellectuals, Online Media and Public Spheres: Current Realignments" was published in the *International Journal of Politics, Culture and Society.*
>
> I would tell you what it says, but I do not know. It is behind a paywall.

In an article in *The New Yorker*, Ronan Farrow presented examples of how some modern universities appear to pursue money above all else [Farrow 2019]:

> New documents show that the M.I.T. Media Lab was aware of Epstein's status as a convicted sex offender, and that Epstein directed contributions to the lab far exceeding the amounts M.I.T. has publicly admitted.
>
> The M.I.T. Media Lab, which has been embroiled in a scandal over accepting donations from the financier and convicted sex offender Jeffrey Epstein, had a deeper fund-raising relationship with Epstein than it has previously acknowledged, and it attempted to conceal the extent of its contacts with him. Dozens of pages of e-mails and other documents obtained by *The New Yorker* reveal that, although Epstein was listed as "disqualified" in M.I.T.'s official donor database, the Media Lab continued to accept gifts from him, consulted him about the use of the funds, and, by marking his contributions as anonymous, avoided disclosing their full extent, both publicly and within the university. Perhaps most notably, Epstein appeared to serve as an intermediary between the lab and other wealthy donors, soliciting millions of dollars in donations from individuals and organizations, including the technologist and philanthropist Bill Gates and the investor Leon Black. According to the records obtained by *The New Yorker* and accounts from current and former faculty and staff of the media lab, Epstein was credited with securing at least $7.5 million in donations for the lab, including two million dollars from Gates and $5.5 million from Black, gifts the e-mails describe as "directed" by Epstein or made at his behest. The effort to conceal the lab's contact with Epstein was so widely known that some staff in the office of the lab's director, Joi Ito, referred to Epstein as Voldemort or "he who must not be named." [...]
>
> Questions about when to accept money from wealthy figures accused of misconduct have always been fraught. Before his conviction, Epstein donated to numerous philanthropic, academic, and political institutions, which responded in a variety of ways to the claims of abuse. When news of the allegations first broke, in 2006, a Harvard spokesperson said that the university, which had received a $6.5-million donation from him three years earlier, would not be returning the money. Following Epstein's second arrest, in 2019, the university reiterated its stance.

Further articles revealed the corrosive effect on research when universities value the immediate pursuit of huge amounts of money above everything else. For example, *Business Insider* reported on one project in "MIT's Media Lab Has an Ambitious Project That Purports to Revolutionize Agriculture. Insiders Say It's Mostly Smoke and Mirrors" [Brodwin 2019]:

> The "personal food computer," a device that MIT Media Lab senior researcher Caleb Harper presented as helping thousands of people across the globe grow custom, local food, simply doesn't work, according to two employees and multiple internal documents that Business Insider viewed. One person asked not to be identified for fear of retaliation.
>
> Harper is the director of MIT's Open Agriculture Initiative and leads a group of seven people who work on transforming the food system by studying better methods of growing crops.

> The food computers are plastic boxes outfitted with advanced sensors and LED lights and were designed to make it possible for anyone, anywhere to grow food, even without soil, Harper has said. Instead of soil, the boxes use hydroponics, or a system of farming that involves dissolving nutrients in water and feeding them to the plant that way. [...]
>
> Harper forwarded an email requesting comment on this story to an MIT spokesperson. The spokesperson didn't provide a comment.
>
> The aim was to make it look like the devices lived up to Harper's claims, the employees said. Those claims, which included assertions that the devices could grow foods like broccoli four times faster than traditional methods, landed Harper and his team articles in outlets ranging from the Wall Street Journal to Wired and National Geographic. [...]
>
> Paula Cerqueira, a researcher and dietitian who worked as a project manager at the Open Agriculture Initiative for two years, told Business Insider that the personal food computers are "glorified grow boxes."
>
> Cerqueira was part of a team that, on several occasions, delivered the personal food computers to schools. She also helped demonstrate the boxes to big-name MIT Media Lab investors.
>
> During the organization's "Members Weeks"—once-a-semester events that drew donors including Google, Salesforce, Citigroup, and 21st Century Fox—Cerqueira and her coworkers would show investors how the technology worked.
>
> On one occasion, Cerqueira said, her coworkers were told to fetch basil grown from a nearby location and place it into the personal food computers to make it look like it had been grown inside the boxes.
>
> "They wanted the best looking plants in there," Cerqueira told Business Insider. "They were always looking for funding."
>
> In another instance, Harper told Cerqueira to buy edible lavender plants from a nearby flower's market and place them in the boxes for a photoshoot, she said. Before any photos were taken, she carefully dusted off the tell-tale soil on the plants' roots.
>
> The central problem with the personal food computer was that it simply didn't work, Cerqueira and another person with knowledge of the matter told Business Insider.

The technology investor Peter Thiel summed up some of the problems with the modern academic research system in a 27 April 2023 speech [Thiel 2023]:

> Start with the university. It's easy to focus on all the insanity in the humanities. But if you remember what universities themselves believe—that all their serious work, their cutting- edge research, is done in the sciences—the focus on the humanities begins to resemble an attention redirect, stifling the hard questions about what is actually going on in the sciences. Are they progressing as advertised? Are we still living in an accelerating world in which science is fundamentally healthy and critical, with diversity

> of thought? It shouldn't have required covid to be able to ask these questions, to notice that "science" has somehow gotten to be a very, very diseased thing. Most imagine a scientist to be an independent researcher who thinks for himself, and this figure may still appear in children's books, but in practice the occupation mostly entails the enforcement of a fixed set of dogmas.
>
> A few years after *The Diversity Myth* came out, a Stanford physics professor, Bob Laughlin, got a Nobel Prize. And he began to suffer from the supreme delusion that, now that he had a Nobel Prize in physics, he also had academic freedom and could investigate anything he wanted. Now, there are a lot of controversial topics in science. You could have a heterodox view on stem-cell research, or you could be a skeptic of climate change or Darwinism. But Laughlin hit on a topic that was far more taboo than any of the above. He had the idea that most of the scientists were doing no work at all. They were actually stealing money from the government, just creating all these fraudulent grant applications. Laughlin had done a lot of work studying the physics of super-high temperatures (superconductivity and the like), and he once told me that, of the roughly fifty thousand papers written on the subject, maybe twenty-five of them were any good at all.
>
> Laughlin's team started with the biology department at Stanford, launching a sort of inquiry into what, exactly, it was doing. They didn't actually publish the results—they just had a public hearing and generally denounced all the professors as having stolen money from the government. The generous conclusion would be that the department wasn't fully fraudulent: just an incredibly incrementalist exercise in groupthink that wasn't really moving the dial forward. This was a line of thinking that was completely, completely taboo. I don't need to tell you how the story ends.
>
> This question of scientific and technological stagnation is in some sense the Achilles heel of the universities. It's hard to uncover. Right now the humanities are transparently ridiculous. You might think of the humanities as the Department of Motor Vehicles. And the physics department is sort of like the self-proclaimed rocket scientists at the National Security Agency. The crypsis makes their activities look more intelligent and more advanced. But my belief is that the DMV is probably better run than the NSA. The fact that you don't have a clue what's going on at the NSA gives you a hint as to which of the two is worse. Something like this is going on with the sciences more broadly.
>
> There are two basic debate techniques you can have when you're arguing with someone. You can go after the enemy at the weakest point, which in the college context is the humanities: it's ridiculous, and you're most likely to come away with a sort of tactical victory. But the other strategy is to go after the enemy's strongest point: to say there's no real science going on, that string theorists aren't making the fundamental breakthroughs that we're told, and that physicists have otherwise been twiddling their thumbs for fifty years. And if you can win that point, it's game, set, and match.

For related information on some of the corrosive factors affecting the academic research system, see pp. 49–51, 2274–2275, and the references cited therein [see also Buranyi 2017; Francis 2020; Preston 2021; Sarkowski 2001].

B. Observations of decline in the corporate research system

This book has already quoted Simon Ramo, cofounder of TRW, on how U.S. companies began to view R&D as more of a burden than an opportunity beginning in the 1970s (p. 52). On a similar note, Richard Rosenbloom (1933–2011, a professor at the Harvard Business School) and William Spencer (1931–, president of the SEMATECH semiconductor manufacturers' consortium) commented on the decline in industrial research in a 1993 conference paper [later published in Rosenbloom and Spencer 1996, pp. 1–2, 4–5]:

> Familiar exemplars of organizations devoted to industrial research include DuPont's Experimental Station in Wilmington, IBM's Watson Research Center in Yorktown Heights, AT&T's Bell Laboratories at Murray Hill, and the Xerox Palo Alto Research Center.
>
> The decades following World War II were a golden era for research organizations in American industry. Corporate leaders, persuaded by the dazzling achievements of wartime and such undisputed research successes as nylon and the transistor, funded rapid expansion of research staffs and facilities. DuPont, for example, increased its R&D staff by 150 percent in the first decade after the war and the greatest growth occurred at the Experimental Station, the center of its fundamental research in chemistry. Radio Corporation of America (RCA), a pioneer in electronics, formed the RCA Laboratories Division, with an expansive budget and a campus-like setting in Princeton, New Jersey. Implicit in the rationale for these investments was a simple model of innovation: Scientific research in industry would generate a stream of inventions and discoveries that engineering would then make practical and affordable so that commercial organizations could harvest new revenues and profits.
>
> The stream of industrial innovations that ensued from these investments fulfilled at least the first part of this ambitious corporate vision. Industrial laboratories proved to be wellsprings of important new technologies that then became staples of modern life, such as the integrated circuit, liquid crystals, and a multitude of new synthetic polymers, to name only a few. The interplay of university and corporate laboratories brought the development of lasers, techniques of recombinant DNA, and a host of computer technologies. [...]
>
> Unfortunately, technological fecundity and scientific distinction did not always carry through to the corporate bottom line. Although the new science and technology created in industry contributed substantially to economic growth and productivity, corporate sponsors of the research often failed to capture significant returns. At first, buoyant demand in the U.S. economy in the 1950s and 1960s and the strong international market positions of the leaders in industrial research made it easy for those firms to sustain substantial investments in research even without clear evidence of immediate payoffs. The more competitive business environment of the 1980s, however, led managers to make more careful assessments of the profits gleaned from research. [...]
>
> One after another, these firms are restructuring, redirecting, and resizing their research organizations as part of a corporatewide emphasis on the timely and profitable commercialization of inventions combined with the rapid and continuing improvement of technologies in use. A recent authoritative survey of the American situation by the Na-

> tional Science Board (NSB) has concluded that "In large corporations, effort is shifting away from central [R&D] laboratories toward division-level effort with greater emphasis on risk minimization to meet the needs of today's customers" (National Science Board 1992, iii).
>
> When the directors of Kodak decided to replace Kay Whitmore, the company's chief executive, they let reporters know that one of his most important failings was that he "spent too much on R&D without getting results." According to an article in the *Wall Street Journal*, investors applauded the move, urging Kodak to "become an 'aggressive follower' by capitalizing on rivals' inventions instead of mostly developing its own." Reporters did not record which rivals were expected to replace Kodak as the technological pioneers that the company would imitate. IBM also cut the annual budget of its research division from $650 million to $500 million and redirected its focus toward "Services, Applications, and Solutions" [SAS] and away from investments in basic physical sciences and technology. The company planned to increase the SAS budget from 5 percent to 20 percent of the division's total between 1992 and 1994 with correspondingly sharp reductions in funding for basic sciences.

In the decades since Rosenbloom and Spencer made those observations, corporate research has shifted even further away from innovative research, with top management and investors focused only on daily stock prices and very near-term, very low-risk (non-innovative) products.

More broadly, the changes in corporate culture are illustrated by public statements by the Business Roundtable, a group of U.S. CEOs [Archie Carroll et al. 2012; Pearlstein 2018]. The Business Roundtable's 1981 Statement on Corporate Responsibility reflected the traditional values that had been preached (if not always practiced) by U.S. businesses since the 1930s:

> Corporations have a responsibility, first of all, to make available to the public quality goods and services at fair prices, thereby earning a profit that attracts investment to continue and enhance the enterprise, provide jobs, and build the economy. [...] Responsibility to all these constituents in toto constitutes responsibility to society, making the corporation both an economically and socially viable entity. Business and society have a symbiotic relationship: The long-term viability of the corporation depends upon its responsibility to the society of which it is a part. And the well-being of society depends upon profitable and responsible business enterprises.

In stark contrast, the Business Roundtable's 1997 Statement on Corporate Responsibility revealed a focus on one thing, to the exclusion of all else:

> The principal objective of a business enterprise is to generate economic returns to its owners. If the CEO and the directors are not focused on shareholder value, it may be less likely the corporation will realize that value.

Thus companies such as those represented by the Business Roundtable not only chose to neglect research and other longer-term investments but explicitly eliminated any sense of responsibility to society or even to their own employees. Short-term profits for those individuals running the company or making money from the company became the only goal that mattered.

C. Observations of decline in the government research system

After the 1969 U.S. victory in the moon race, and the end of any serious further international space competition, U.S. government funding for space-related research and development began to decline. However, there were similar declines in other areas of government-funded research.

Beginning in fiscal year 1970, government funding for longer-term research was severely limited by a budget amendment introduced by Senate Majority Leader Mike Mansfield. He also introduced a second, further restrictive amendment in 1973. The U.S. Office of Technology Assessment briefly explained the first Mansfield Amendment [OTA 1991, p. 61]:

> The celebrated Mansfield amendment, passed as part of the fiscal year 1970 Military Authorization Act (Public Law 91-121), prohibited military funding of research that lacked a direct or apparent relationship to specific military function. Through subsequent modification the Mansfield amendment moved the Department of Defense toward the support of more short-term applied research in universities.

Soon after the first Mansfield Amendment in 1970, the chemist Herbert Laitinen published an accurate prediction of the long-term changes it would cause to the U.S. research system [Laitinen 1970]:

> Late in 1969, the Congress of the United States passed an authorization bill for expenditures of the Department of Defense for the fiscal year 1970. An amendment by Sen. Mansfield which passed with virtually no advance public notice has since caused apprehension, confusion, and secondary effects of a magnitude that still eludes estimation.
>
> The amendment, called section 203, states "None of the funds authorized by this Act may be used to carry out any research project or study unless such project or study has a direct and apparent relationship to a specific military function." [...]
>
> Now that the issue of "direct and apparent relationship to a specific military function" has been raised, a similar "Mansfield effect" appears to be emerging in mission-oriented civilian agencies, such as the National Institutes of Health and the Federal Water Pollution Control Agency, to require a closer and more obvious relationship between research and mission. [...] If it were simply a matter of transfer of funds to the one research agency that is not mission-oriented, the National Science Foundation, no serious harm would be done. Unfortunately, the NSF is not receiving additional support. On the contrary, it has been directed, through the Daddario bill, to expand its function to support applied as well as basic research [with its existing budget]. Thus, an already serious squeeze on pure research seems destined to intensify.
>
> Now to complete the circle, the emergence on the job market of a pool of postdoctorates that can no longer be supported on research grants, plus the new group of graduating Ph.D.'s to compete for a dwindling number of research positions in industry, government, and academic departments is being cited as evidence that we have an abundance of Ph.D.'s and that decreased graduate support is therefore justified. Clearly this is short-sighted policy. What is needed is a strong and continuing commitment to basic research in support of all mission-oriented technology, both in relation to research training at pre- and postdoctoral levels and in relation to research output. Anything less will

> waste the talents of a substantial group of skilled research workers and will compromise our technological future.

An old version of the history of DARPA (the Defense Advanced Research Projects Agency) archived on the internet explained the second Mansfield Amendment of 1973 [https://www.bibliotecapleyades.net/sociopolitica/sociopol_DARPA01.htm]:

> The Mansfield Amendment of 1973 expressly limited appropriations for defense research (through ARPA/DARPA) to projects with direct military application.
>
> Some contend that the amendment devastated American science, since ARPA/DARPA was a major funding source for basic science projects of the time; the National Science Foundation never made up the difference as expected. But the resulting "brain drain" is also credited with boosting the development of the fledgling personal computer industry.

While the decline in U.S. government-funded research began around 1970, it became even worse with the end of the Cold War in 1991. Lynn Gref (1941–2013), who spent his career conducting and managing research at Department of Defense (DOD) and NASA laboratories, described the decline of applied research or "Phase Two" research at government laboratories [Gref 2010, pp. 116–117]:

> It is in Phase Two research (device phase) that a decline in research activity of at least a decade duration can be detected. Now let us consider the indicators of a decline in Phase Two research. [...I]ndustry has become the dominant source of funds for R&D. Industry is even more dominant for R&D outside of the medical science arena. This is in itself not necessarily bad. However, it will become evident that industry has lost much of its ability or willingness to perform the Phase Two research that leads to the revolutionary devices of the future.
>
> Second, R&D performed at the Government's laboratories has declined more than 50% since 1970 based on funding received[...] Most of their work falls into Phase Two. After the end of the Cold War, funding for new weapons systems declined dramatically. (The Iraq War has brought an influx of orders for existing weapons systems and benefited much of the remaining defense industry, but it has had the devastating effect of further restricting R&D funding to efforts with an immediate application to the war.) The defense industry went through a major restructuring and consolidation between the end of the Cold War and the beginning of the Iraq War. During this period, industry went after all available funding from the DOD. The large companies turned to sources they previously shunned including Phase Two research. The companies employed massive lobbying efforts to achieve these objectives. Consequently, a goal of the DOD's laboratories became spending approximately 70% of their funding with industry. (The DOD originally established the laboratories to perform research needed by the services. Buying research from industry is a very recent occurrence.) This had two negative effects. First, it further reduced the funds retained by the laboratories to use for their in-house activities including research. The impact was that of a funding cut. Second, the technologists at the laboratories had to use their time to perform contracting functions—writing requests for proposals, evaluating proposals and monitoring the work of contractors—instead of performing their own research. The reduction of internal funding and the change in assignments has dramatically reduced research performed at the DOD laboratories. In addition, studies initiated by Congress have pointed to a

> perceived excess capacity in DOD laboratories and suggested restructuring the laboratories so that they would be Government owned and contractor operated. In this latter case, industry would perform all of DOD's research other than that done by universities. Recalling [...] the rich heritage of innovation of the Naval Research Laboratories and the other DOD service laboratories, the decline in technology development by DOD's laboratories is a tragedy for Phase Two of the development cycle.
>
> The "industrialization of Government research" has not been unique to the DOD. It has affected agencies such as NASA. NASA has terminated "block" funding of technology work at its center laboratories. It has replaced the technology development that its centers previously performed on an assigned basis with various competitions, most of which are open to all comers. With these competitions has come the pressure on NASA to award industry a greater proportion of the R&D dollars. The contraction and consolidation of the military industrial contractors that occurred after the end of the Cold War certainly had a part in this change at NASA as it did with the DOD laboratories. With the need to survive, NASA's research funds became fair game for these contractors. Unfortunately, when the researchers at the NASA centers fail to obtain funding for their efforts, then they must go elsewhere and their research ends. For example, JPL received from NASA approximately $100M on an assigned basis for Phase Two research in FY2000 and today it is less than $50M, mostly obtained on a competitive basis.
>
> Furthermore, competition for Phase Two funding does not foster risk taking and long-term efforts. No matter how one cuts it, the winners of funding are those who can demonstrate the best value for the Government. That is, winners are those that can identify measurable benefits of their research, demonstrate the risks of the proposed work are reasonable and manageable, prove the approach to the research is sound, and argue that success is likely. That just is not the real life situation for Phase Two research [...] where failure occurs more often than success.
>
> Competing for research funding is an environment in which research becomes incremental and unimaginative. In other words, the competitive environment turns the researchers into "surviving" financially. Improving the materials and processes used to build a device is much more likely to meet the requirements of a competition than some "wild new" idea that may take a decade or more to work out with few, if any, applications apparent[...] Similarly, proposing an enhancement to work that has already been funded and is in a proven interest area of the sponsor is more likely to be a successful bid than an "out of the box" or "off the wall" idea. Such a chilling environment for innovation is not conducive to funding research ideas that could really have an impact similar to those of NRL's radar developments of the past.

Summary of observations of decline

According to longtime first-hand observers such as those quoted above, the academic, corporate, and government research sectors of the U.S. innovation system were all very productive during the 1940s–1960s, all began to drift and steadily decline beginning around 1970 or so, experienced a further drop around the end of the Cold War (∼1991), and have declined even more since 2000 due to priority shifts at the highest levels of government, industry, and academia. The end result is the problems discussed in Section 1.1.

11.3.2 Explanations for Decline

The contemporary observers quoted in the previous section ably described the decline in innovation that occurred from around 1970 onward, yet it is necessary to seek a better understanding of the fundamental reasons for that decline. A number of potential explanations have been offered:

A. Exhaustion of the supply of innovators and innovations that had been adopted from the earlier German-speaking world (p. 2271).

B. Abandonment of German-like systemic practices for promoting innovation (p. 2272).

C. The decline and end of Cold War competition that promoted innovation (p. 2272).

D. Darwinian selection of researchers for traits other than innovation (p. 2274).

E. Political divisions that undermine government support for innovation (p. 2276).

F. Loss of consumer demand for innovation (p. 2277).

G. A shift in the types of innovation that consumers demand (p. 2278).

In practice, all of these factors probably played a significant role in the decline, and indeed the various factors likely exacerbated each other.

A. Exhaustion of innovators and innovations adopted from the German-speaking world

As argued in Chapters 2–10 and Section 11.1, a huge number of innovators and innovations were produced by the German-speaking world prior to 1945. By around 1970, most of the thousands of German-speaking creators who had been recruited from that world had retired or died, and the enormous numbers of inventions and discoveries that had originated in that earlier world had already been copied, optimized, and utilized to their fullest potential in the United States and other countries.

B. Abandonment of German-like systemic practices for promoting innovation

As covered in Sections 11.2 and 11.3.1, especially during the 1940s–1960s, the United States (and presumably other countries) implemented many systemic practices that strongly promoted revolutionary scientific innovation, and that were highly similar to systemic practices from the earlier German-speaking world. Just as those practices had cultivated countless creators and creations in the German-speaking world, they also bred homegrown innovators and innovations in the United States. Unfortunately, around 1970, the United States began to abandon some of those systemic practices. That shift made it harder to cultivate as many brand new revolutionary innovators and innovations after that time, and it also made it harder for any innovators and innovations that had been developed in the earlier days of the system to continue to find sufficient financial and political support.

C. Decline and end of Cold War competition that promoted innovation

As argued in Section 11.2.9, just as the earlier German-speaking world was strongly driven throughout its existence by military and industrial competition with the United Kingdom, United States, and other countries, the U.S. system in the 1940s through 1960s was strongly driven first by World War II competition with Germany and then by Cold War competition with the Soviet Union. However, around 1970 (with the U.S. victory in the moon race and the beginning of the Strategic Arms Limitation Talks) that Cold War competition greatly relaxed, and in 1991 it collapsed entirely. Without a strong sense of urgent international competition, the U.S. innovation system fell victim to other priorities and forces.

In the afterword to his book *The Gift*, writing professor Lewis Kenyon described how the end of the Cold War impacted both scientists and artists, with funding decreasing and shifting from longer-term, more philanthropic objectives to very short-term, purely money-making aims [Hyde 2019]:

> Which brings me back to the fall of the Soviet Union, for it was the Cold War that energized much of the public funding devoted to art and science in the decades after World War II. [...]
>
> Of that context one could say, to put it positively, that the Soviet Union turned out to provide a useful counterforce to the harsher realities of capitalism. It goaded the West into provisioning those parts of social life not well served by market forces. To put it negatively, however, if Cold War rhetoric lay at the foundation, then the entire edifice was historically vulnerable. Thus when the Soviet Union fell in 1989 so did the bulk of public patronage in the West. In the U.S., for example, we almost immediately got the attacks on the National Endowment for the Arts and the loss of nearly all funding to individual artists. A similar if less publicized story played out in basic science. In a 1998 interview Leon Lederman, Nobel laureate in physics, said: "We always thought, naïvely, that here we are working in abstract, absolutely useless research and once the cold war ended, we wouldn't have to fight for resources. Instead, we found, we were the cold war. We'd been getting all this money for quark research because our leaders decided that science, even useless science, was a component of the cold war. As soon as it was over, they didn't need science."

> In short, around 1990 the third phase of this history began, an era of market triumphalism in which not only has public support of the arts and sciences begun to dry up but those who stilled their voices during the Cold War, those who have long believed in an unlimited market, have felt free to advance unselfconsciously.
>
> In instance after instance, public institutions have been encouraged to think of themselves as private businesses. The universities have set up "technology transfer offices" and tried to fund themselves by selling knowledge rather than simply disseminating it, as their old mission statements once asked them to do. Grammar schools have learned that they can sell exclusive rights to soft drink vendors intent on creating brand loyalty in the very young. Public radio and television are now cluttered with advertising. Even commercial television has become more so: in the U.S., the networks once limited their ads to nine minutes an hour; they gave that up in the last decade and ads now run eighteen minutes in prime time.
>
> Natural abundance has been similarly commercialized, everywhere subject to the grid of artificial scarcity. Ancient aquifers, by rights belonging to all who live above them, are now pumped and packaged. Drinking water, once an essence of life, has become a resource to be sold in little plastic bottles. Broadcast spectrum, one of nature's richest gifts, has been parceled out to industry and then sold back to the public.
>
> Our cultural abundance suffers the same fate. The ever-expanding reach of copyright has removed more and more art and ideas from the public domain. The Walt Disney Company happily built its film empire out of folk culture ("Snow White," "Pinocchio") but any folk who try to build on Disney can expect a "cease and desist" letter in the next mail. Patents are now used to create property rights in things once thought inalienable–seedlines, human genes, medicines long known to indigenous cultures. A company that makes jam recently got itself a patent on the crustless peanut butter-and-jelly sandwich.
>
> This period of market triumphalism has, in sum, seen a successful move to commercialize a long list of things once thought to have no price, and to enclose common holdings, both natural and cultural, that we used to assume no one was allowed to take private.

Broadening out the discussion beyond just scientific innovation, there appears to have been a sea change in the entire U.S. economy and society around the early 1970s. Economic analyses have shown that from the 1940s until around 1970, the United States experienced strong economic growth, and that growth was shared across all parts of the population. Those same economic analyses have demonstrated that from the 1970s onward, U.S. economic growth was often much weaker than in the preceding decades, and the rewards for what growth did occur were increasingly concentrated in the hands of the wealthiest individuals and companies [Carter Price and Edwards 2020; Saez and Zucman 2016].

It appears that as Cold War competition waned, the wealthiest individuals and their political allies no longer needed the broader population to help produce new innovations, share in their success and generated income, and mount a competition with the Soviet Union. Rather, they seem to have turned toward simply vacuuming up as much of the pre-existing innovations, resources, and wealth as possible, leaving the innovation system and the general populace to suffer a slow but steady decline from the 1970s onward.

D. Darwinian selection of researchers for traits other than innovation

As the United States began to abandon innovation-promoting practices like those from the earlier German-speaking world, from the 1970s onward the modern system came increasingly to value the sheer number of academic papers much more than their quality or significance. Since academic scientists were now rewarded with funding primarily based on their number of published papers rather than the scientific quality, originality, or importance of their work, labs that emphasized quantity over quality received more funding, trained more students, and graduated those students into the system to create their own labs that focused on quantity over quality. In a Darwinian fashion, within a few cycles of "reproduction," scientists who emphasized quantity over quality became vastly more numerous and much more powerful (as peer review committee members for research grant funding, hiring, and tenure decisions) than any remaining scientists who valued the quality, originality, and revolutionary importance of research.

Two scientists, Paul Smaldino and Richard McElreath, described the impact of Darwinian selection for traits other than revolutionary innovation, applied to generation after generation of professors and their students [Smaldino and McElreath 2016]:

> This paper argues that some of the most powerful incentives in contemporary science actively encourage, reward and propagate poor research methods and abuse of statistical procedures. We term this process the natural selection of bad science to indicate that it requires no conscious strategizing nor cheating on the part of researchers. Instead, it arises from the positive selection of methods and habits that lead to publication. How can natural selection operate on research methodology? There are no research 'genes'. But science is a cultural activity, and such activities change through evolutionary processes. Philosophers of science such as Campbell, Popper and Hull have discussed how scientific theories evolve by variation and selection retention. But scientific methods also develop in this way. Laboratory methods can propagate either directly, through the production of graduate students who go on to start their own labs, or indirectly, through prestige-biased adoption by researchers in other labs. Methods which are associated with greater success in academic careers will, other things being equal, tend to spread.
>
> The requirements for natural selection to produce design are easy to satisfy. Darwin outlined the logic of natural selection as requiring three conditions:
>
> (i) There must be variation.
>
> (ii) That variation must have consequences for survival or reproduction.
>
> (iii) Variation must be heritable.
>
> In this case, there are no biological traits being passed from scientific mentors to apprentices. However, research practices do vary. That variation has consequences—habits that lead to publication lead to obtaining highly competitive research positions. And variation in practice is partly heritable, in the sense that apprentices acquire research habits and statistical procedures from mentors and peers. Researchers also acquire research practice from successful role models in their fields, even if they do not personally know them. Therefore, when researchers are rewarded primarily for publishing, then habits which promote publication are naturally selected. Unfortunately, such habits can directly undermine scientific progress. [...]

> The rate at which new papers are added to the scientific literature has steadily increased in recent decades. This is partly due to more opportunities for collaboration, resulting in more multi-author papers. However, the increases in publication rate may also be driven by changing incentives. Recently, Brischoux & Angelier looked at the career statistics of junior researchers hired by the French CNRS in evolutionary biology between 2005 and 2013. They found persistent increases in the average number of publications at the time of hiring: newly hired biologists now have almost twice as many publications as they did 10 years ago (22 in 2013 versus 12.5 in 2005). These numbers reflect intense competition for academic research positions. The world's universities produce many more PhDs than there are permanent academic positions for them to fill, and while this problem has escalated in recent years, it has been present for at least two decades. Such competition is all the more challenging for researchers who graduate from any but the most prestigious universities, who face additional discrimination on the job market. Although there may be jobs available outside of academia— indeed, often better-paying jobs than university professorships—tenure-track faculty positions at major research universities come with considerable prestige, flexibility and creative freedom, and remain desirable. Among those who manage to get hired, there is continued competition for grants, promotions, prestige and placement of graduate students.
>
> Given this competition, there are incentives for scientists to stand out among their peers. Only the top graduate students can become tenure-track professors, and only the top assistant professors will receive tenure and high profile grants. [...]
>
> Incentives drive cultural evolution. In the scientific community, incentives for publication quantity can drive the evolution of poor methodological practices. We have provided some empirical evidence that this occurred, as well as a general model of the process. If we want to improve how our scientific culture functions, we must consider not only the individual behaviours we wish to change, but also the social forces that provide affordances and incentives for those behaviours. We are hardly the first to consider a need to alter the incentives for career success in science. However, we are the first to illustrate the evolutionary logic of how, in the absence of change, the existing incentives will necessarily lead to the degradation of scientific practices.
>
> An incentive structure that rewards publication quantity will, in the absence of countervailing forces, select for methods that produce the greatest number of publishable results. This, in turn, will lead to the natural selection of poor methods and increasingly high false discovery rates. Although we have focused on false discoveries, there are additional negative repercussions of this kind of incentive structure. Scrupulous research on difficult problems may require years of intense work before yielding coherent, publishable results. If shallower work generating more publications is favoured, then researchers interested in pursuing complex questions may find themselves without jobs, perhaps to the detriment of the scientific community more broadly. [...]
>
> Institutional change is difficult to accomplish, because it requires coordination on a large scale, which is often costly to early adopters. Yet such change is needed to ensure the integrity of science.

Other scholars have made very similar arguments about the perverse incentives warping academic research [Bhattacharya and Packalen 2020; Charlton 2009; Chu and Evans 2021; Ritchie 2020].

E. Political divisions that undermine government support for innovation

Severe political divisions in the United States arose by the late 1960s and have only worsened since then, undermining strong government understanding of, support for, and utilization of revolutionary innovation as had existed earlier. The science policy analysts Chris Mooney and Sheril Kirshenbaum described the impact on scientific innovation [Mooney and Kirshenbaum 2010, pp. 28–29]:

> Yet the heyday of science wouldn't last long. The trend of ever-rising federal investment in research reversed itself in the late 1960s; non-military science funding fell through much of the 1970s. The central involvement of the National Science Foundation in shaping high school educational curricula also gradually fell away—as did the prominence of the scientific elite in advising our leaders.
>
> All this occurred for a snarl of reasons that center on the collapse of political consensus in America over the same time period. The scientific community couldn't escape the conflicts of the day any more than any other major social group. The creation of new regulatory agencies, like the Environmental Protection Agency in 1970, repeatedly dragged scientific information into a contested decision-making process. And the growing antiwar and antinuclear movements flailed not only against the "military-industrial complex" but against those parts of the scientific establishment that worked with it or for it, especially on university campuses.
>
> Not only did the new mood of "questioning authority" include the questioning of science, but there was often good reason for skepticism. The environmental and consumer movements, spearheaded by the likes of Rachel Carson and Ralph Nader, brought home the realization that science wasn't always beneficial. Seemingly wonderful technologies—DDT, chlorofluorocarbons—could have nasty, unforeseen consequences. A narrative began to emerge about "corporate science": driven by greed, conducted without adequate safeguards, placing profits over people.
>
> Amid the backlash, the role of scientists in policy making also ebbed, as did the status of the presidential science advisor. Whereas the post had enjoyed a high level of recognition and influence under Eisenhower and Kennedy, the Vietnam War brought that cozy relationship to an end. In 1973, President Richard Nixon fired his science advisers outright over disagreements about the viability of the Supersonic Transport program and other matters.
>
> The emergence of the Religious Right onto the political stage in the 1970s—motivated in part by its adherents' resentment of the nation's intellectual and scientific elites—was also a major factor in curtailing the role of science in public policy. Soon battles between Christian conservatives and the science community over matters like the teaching of evolution and embryo-related research became an inescapable political reality. And so we entered the "culture wars": Secular, scientific, and pro-choice America clashed regularly with a "faith-based" (and very Republican) side of the country. A vast array of political issues could be cast in a pugilistic context that pitted "religion" against "reason." Science ceased to serve as a bulwark for common goals and purposes; instead, its findings came to divide us.

Other books have made similar arguments that increasing political divisions have fostered hostility toward scientists and the loss of innovation or even functionality within the scientific system [e.g., Gruber and Johnson 2019; Mooney 2006; Otto 2016]. By 2020, the consequences of these long-term trends in the United States were all too visible to the entire world.

F. Loss of consumer demand for innovation

Biologist Jan Vijg argued persuasively that the rate of revolutionary scientific innovation has greatly declined in recent decades, then offered his views on the causes of that decline. While the world at present may not be as nearly utopian as Vijg viewed it in 2011, his fundamental point seems sound: In contrast to circumstances that prompted revolutionary innovations in the past, currently there are not enough people with enough power who are sufficiently dissatisfied with the current state of technology to be strongly motivated to change it, and in fact many are strongly motivated to resist change [Vijg 2011, pp. 109–110]:

> The cold war is over and most current states profess support for democracy, the rule of law and a safety net for everyone. Almost all of us seem to have abandoned violence as a way to make progress. Representatives of the earth's states meet regularly and although we tend to think that nothing ever comes out of these meetings, the reality is that there are probably very few citizens who do not profit from the myriad of changes that slowly but surely transform us into a planet-wide commonwealth of states with almost unrealistically good credentials. Good governance, responsible industry leaders and better citizens slowly but irrepressibly take hold of society by creating a network of rules and regulations that make it all but impossible to run roughshod over others. People around the world are becoming healthier, wealthier, better educated, more peaceful, and increasingly connected, and they are living longer.
>
> Precisely because society is so successful, with technology maturing and all structures in place for optimally using it to the benefit of humankind, it has now become very difficult for new, breakthrough inventions to thrive. Investments are more likely in areas that have stabilized and proved their mettle, and regulatory constraints make it often very difficult for new inventions to get a fair chance at being implemented. This is especially true for medicine and biotechnology, two areas where scientific input should all but guarantee rapid progress. However, it also applies to the energy and transportation sectors where we witness a stalling of progress in strategic technologies. In spite of the hype in glossy magazines and the occasional newspaper article, to maintain the current fleet of passenger planes is simply too convenient and the days of Howard Hughes are definitely over. Surprisingly enough, this even applies to information technology where progress has helped us enormously to do the things we were already doing much quicker and in a much more convenient way than in the past. However, it does no longer break new ground and does not radically alter the way we live and work.
>
> In a sense, we have become a victim of our own success. The intricate net we have woven to protect each and every one of us from harm, to allow a maximum of input to everyone in decision making and to patiently listen to all arguments have turned us into the most successful society the world has ever seen. But paradoxically, this very success is now beginning to hold us back from making the further great strides to again transform human society, like the tremendous achievements of the 19^{th} and 20^{th} centuries did before.

G. Shift in the types of innovation that consumers demand

Both Nicholas Carr and Tyler Cowen proposed that the most financially lucrative demand for innovations has shifted from truly revolutionary technologies to mundane consumer products with annual cosmetic updates, "feel-good" products like Facebook and Prozac, and non-technological products for the very wealthy [Carr 2015; Cowen 2011].

Wall Street Journal writer and book author Nicholas Carr argued that the apparent slowdown in revolutionary innovations is largely driven by consumers who are more interested in "technologies of the self" than in more world-changing technologies [Carr 2012, 2015]. Carr's thesis has significant overlap with Jan Vijg's argument (modern society is sufficiently comfortable that innovation is no longer a priority). Carr explained his viewpoint with an essay [Carr 2015] and an accompanying diagram (redrawn in Fig. 11.76):

> Let me float an alternative explanation: There has been no decline in innovation; there has just been a shift in its focus. We're as creative as ever, but we've funneled our creativity into areas that produce smaller-scale, less far-reaching, less visible breakthroughs. And we've done that for entirely rational reasons. We're getting precisely the kind of innovation that we desire—and that we deserve.
>
> My idea—and it's a rough one—is that there's a hierarchy of innovation that runs in parallel with Abraham Maslow's famous hierarchy of needs. Maslow argued that human needs progress through five stages, with each new stage requiring the fulfillment of lower-level, or more basic, needs. So first we need to meet our most primitive Physiological needs, and that frees us to focus on our needs for Safety, and once our needs for Safety are met, we can attend to our needs for Belongingness, and then on to our needs for personal Esteem, and finally to our needs for Self-Actualization. If you look at Maslow's hierarchy as an inflexible structure, with clear boundaries between its levels, it falls apart. Our needs are messy, and the boundaries between them are porous. A caveman probably pursued self-esteem and self-actualization, to some degree, just as we today spend effort seeking to fulfill our physical needs. But if you look at the hierarchy as a map of human focus, or of emphasis, then it makes sense—and indeed seems to be born out by history. In short: The more comfortable you are, the more time you spend thinking about yourself.
>
> If progress is shaped by human needs, then general shifts in needs would also bring shifts in the nature of technological innovation. The tools we invent would move through the hierarchy of needs, from tools that help safeguard our bodies on up to tools that allow us to modify our internal states, from tools of survival to tools of the self. Here's my crack at what the hierarchy of innovation looks like [...]:
>
> The focus, or emphasis, of innovation moves up through five stages, propelled by shifts in the needs we seek to fulfill. In the beginning come Technologies of Survival (think fire), then Technologies of Social Organization (think cathedral), then Technologies of Prosperity (think steam engine), then technologies of leisure (think TV), and finally Technologies of the Self (think Facebook, or Prozac).

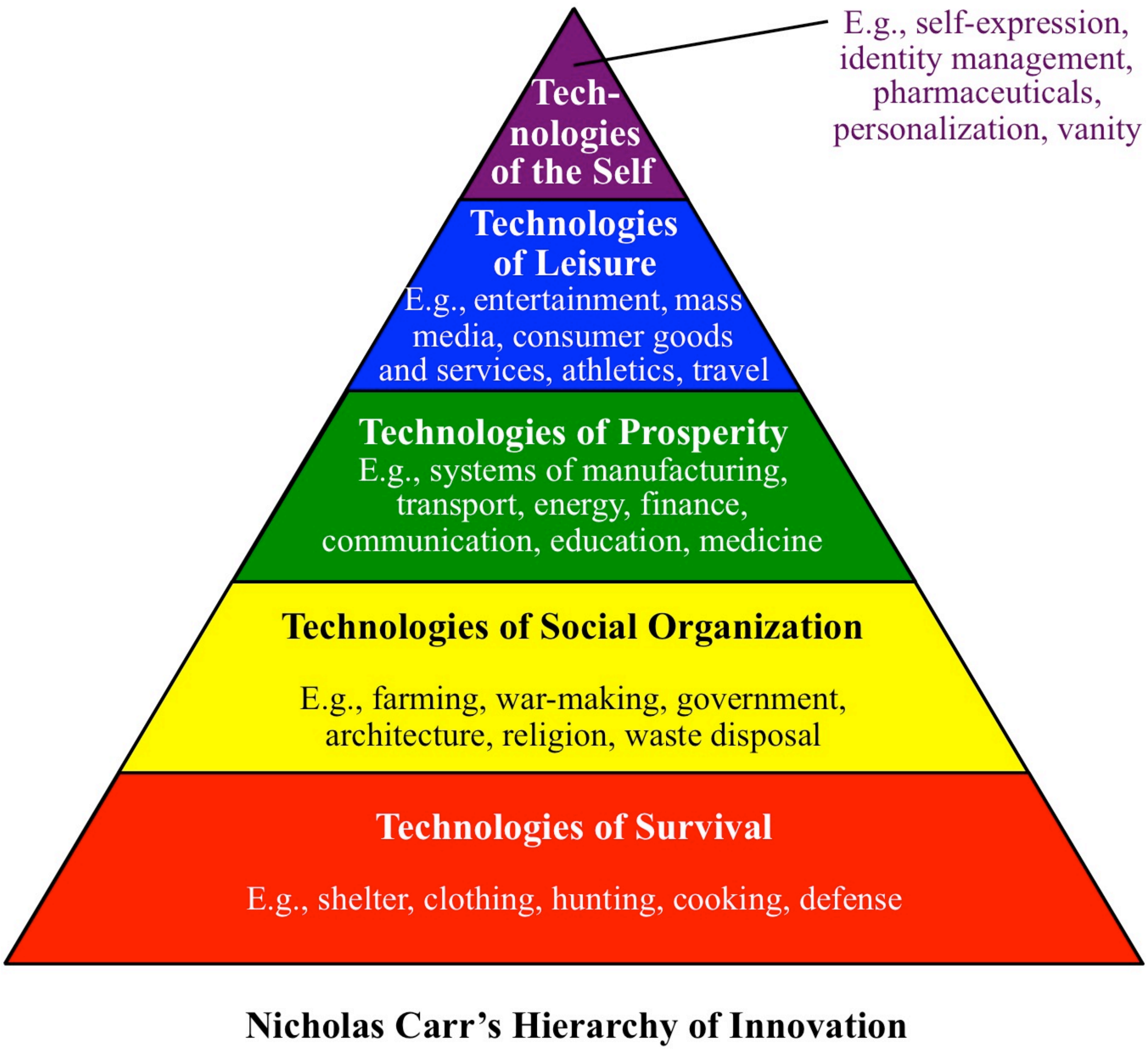


Figure 11.76: Nicholas Carr's proposed "hierarchy of innovation" [redrawn based on Carr 2015].

> As with Maslow's hierarchy, you shouldn't look at my hierarchy as a rigid one. Innovation today continues at all five levels. But the rewards, both monetary and reputational, are greatest at the highest level (Technologies of the Self), which has the effect of shunting investment, attention, and activity in that direction. We're already physically comfortable, so getting a little more physically comfortable doesn't seem particularly pressing. We've become inward looking, and what we crave are more powerful tools for modifying our internal state or projecting that state outward. An entrepreneur has a greater prospect of fame and riches if he creates, say, a popular social-networking tool than if he creates a faster, more efficient system for mass transit. The arc of innovation, to put a dark spin on it, is toward decadence.

> One of the consequences is that, as we move to the top level of the innovation hierarchy, the inventions have less visible, less transformative effects. We're no longer changing the shape of the physical world or even of society, as it manifests itself in the physical world. We're altering internal states, transforming the invisible self. Not surprisingly, when you step back and take a broad view, it looks like stagnation—it looks like nothing is changing very much. That's particularly true when you compare what's happening today with what happened a hundred years ago, when our focus on Technologies of Prosperity was peaking and our focus on Technologies of Leisure was also rapidly increasing, bringing a highly visible transformation of our physical circumstances.

Economist Tyler Cowen noted the decline in innovation and attributed it to several factors [Cowen 2011]. Most prominently, he said that the United States had already consumed all of the low-hanging fruit of technologies that could be readily developed. When viewed from the perspective of the history of science, it would seem unlikely that Cowen's argument is truly correct, that there truly are no more potential new technologies within humanity's current reach. For example, the classical world overlooked Hero's steam engine and its revolutionary potential, the steam era overlooked both gasoline internal combustion engines and the electrical revolution, nineteenth century physics overlooked both relativity and quantum physics, and classical biology overlooked the mechanisms and potential applications of DNA. If the rate of revolutionary innovations has slowed, it seems far more probable that the slowdown is due much more to deficiencies in the current innovation system, rather than to the actual absence of potential new technologies within our grasp.

On the other hand, if a large fraction of our modern technologies originated from the earlier German-speaking research world (as described in this book), then a somewhat more narrow interpretation of Cowen's argument could be quite valid. The United States plucked the low-hanging fruit of inventions and discoveries made in the earlier German-speaking world, took those creations to their fullest potential, and greatly profited from them, but never invested sufficient money, time, and energy to grow large amounts of entirely new fruit for future harvests.

Cowen's other explanations are also enlightening: Innovation shifted first from truly revolutionary technologies to more easily developed, easily marketed consumer products, and then from widely useful (if mundane) products to dubious "innovations" that only benefit a chosen few, sometimes even at the expense of everyone else [Cowen 2011, pp. 7–10, 20–21]:

> In a figurative sense, the American economy has enjoyed lots of low-hanging fruit since at least the seventeenth century, whether it be free land, lots of immigrant labor, or powerful new technologies. Yet during the last forty years, that low-hanging fruit started disappearing, and we started pretending it was still there. We have failed to recognize that we are at a technological plateau and the trees are more bare than we would like to think. That's it. That is what has gone wrong. [...]
>
> Around the globe, the populous countries that have been wealthy for some time share one common feature: Their rates of economic growth have slowed down since about 1970. That's a sign that the pace of technological development has been slowing down. It's not that something specific caused the slowdown, but rather we started to exhaust the benefits of our previous momentum without renewing them. [...]
>
> The period from 1880 to 1940 brought numerous major technological advances into our lives. [...]

> Today, in contrast, apart from the seemingly magical internet, life in broad material terms isn't so different from what it was in 1953. [...] Life is better and we have more stuff, but the pace of change has slowed down compared to what people saw two or three generations ago.
>
> It would make my life a lot better to have a teleportation machine. It makes my life only slightly better to have a larger refrigerator that makes ice in cubed or crushed form. We all understand that difference from a personal point of view, yet somehow we are reluctant to apply it to the economy writ large. But that's the truth behind our crisis today—the low-hanging fruit has been mostly plucked, at least for the time being. [...]
>
> A fundamental way to put the point is this: *A lot of our recent innovations are "private goods" rather than "public goods."* Contemporary innovation often takes the form of expanding positions of economic and political privilege, extracting resources from the government by lobbying, seeking the sometimes extreme protections of intellectual property laws, and producing goods that are exclusive or status related rather than universal, private rather than public; think twenty-five seasons of new, fall season Gucci handbags.
>
> The dubious financial innovations connected to our recent financial crisis are another (perhaps less obvious) example of discoveries that benefit some individuals but are not public goods more generally. A lot of the gains from recent financial innovations are captured by a relatively small number of individuals.

Note that there is considerable overlap among the economics-based arguments of Tyler Cowen, Nicholas Carr, and Jan Vijg: the **supply** of truly revolutionary scientific innovations is much less now because there has been an insufficiently strong and insufficiently widespread **demand** for revolutionary scientific innovations.

Summary of decline

As a final perspective on how much the U.S. innovation system has changed, in 1940 MIT professor Vannevar Bush showed President Franklin Roosevelt a one-page proposal outlining his multi-year, multi-billion-dollar plan for a new federally funded R&D system that would include the Manhattan Project, radar, and all other defense-related research projects. Roosevelt heard and approved the proposal in less than 15 minutes [Zachary 1997a, p. 112].

In contrast, nowadays even a professor's $100,000 proposal to the National Institutes of Health for modest experiments by some graduate students involves writing a detailed grant application that may be over 100 pages long, consumes several person-months to assemble, requires submitting extensive data and references to prove that the proposed experiments will definitely produce the intended results before they are even officially begun, can take over a year to pass through NIH administrative offices and peer review committees, and might stand less than a 10% chance of being funded after all of that. (Moreover, the very low success rate of proposals means that a research group might have to write 10 or more such proposals each year in hopes of getting just one funded, and writing that many proposals every year is a truly massive and enormously expensive diversion of personnel away from doing any of the actual research described in the proposals.)

Chapter 12

Learning from the Creators

Ich habe auf eine geringe Vermuthung eine gefährliche Reise gewagt und erblicke schon die Vorgebürge neuer Länder. Diejenigen, welche die Herzhaftigkeit haben die Untersuchung fortzusetzen, werden sie betreten und das Vergnügen haben, selbige mit ihrem Namen zu bezeichnen.

Upon a small conjecture I have ventured on a dangerous journey and already behold the foothills of new lands. Those who have the courage to continue the quest will enter those lands and have the joy of putting their name on them.

Immanuel Kant. 1755.
Allgemeine Naturgeschichte und Theorie des Himmels, Vorrede
[*Natural History and Theory of the Heavens*, Foreword].

Section 12.1 summarizes the major findings of Chapters 1–11.

Section 12.2 then applies that information to offer suggestions for:

12.2.1. Whole state or national innovation systems that would like to increase their production of revolutionary research.

12.2.2. Individual companies, organizations, or laboratories that would like to pursue more innovative research.

12.2.3. Individuals now trying to pursue careers in innovative research in the existing state of the global system.

12.2.4. Scholars who would like to further study the past, present, and potential future of revolutionary creators and creations.

Finally, Section 12.3 presents an afterword to encapsulate the vision for this book.

12.1 Summary of the Creators, Their Creations, and Their Approaches

As covered in Chapter 1, the motivation for this study follows from a series of logical steps, with many accompanying assumptions and limitations that are freely acknowledged (see Section 1.2.3 for a much longer and more detailed list):

1. Based on data and analyses from authors cited in Section 1.1, compared to earlier times, the modern research system appears to have produced fewer revolutionary innovations per year, or at least fewer revolutionary innovations per year per person in the system, or fewer innovations per year per amount of money spent on the system. (This study does not argue that the modern research system has produced no revolutionary innovations.)

2. Having concluded that the modern innovation rate has declined, this study proceeds on the assumption that it is possible that the modern innovation rate **can** be increased, or in other words that we have not simply encountered physical limits on innovation.

3. Moreover, this study operates on the assumption that the modern innovation rate **should** be increased, or the belief that at least on balance, new innovations will improve people's lives and are morally and socially desirable.

4. Rather than trying to reinvent the wheel, this study focuses on examining already proven ways to promote innovation. It does not consider new, unproven methods to promote innovation, although other scholars certainly should propose and evaluate new methods as well.

5. Among those proven ways to promote innovation, this study specifically considers past innovation systems. (Nevertheless, other scholars should and are evaluating various current innovation systems worldwide, and there is much to learn from those studies.)

6. Out of all past innovation systems, this study focuses on the predominantly German-speaking world of the nineteenth and early twentieth centuries, which admittedly is a topic with very fuzzy spatial, temporal, and intellectual boundaries. Based on the evidence in Chapters 2–9 and the appendices, I believe that world was the most innovative; at the very least it was **one of** the most innovative systems and thus worthy of detailed examination. This study is not intended to make an argument for nationalist or ethnic bragging rights. I highly recommend that readers of this book seek out or even conduct their own studies of scientific innovations from other places and times.

7. This study assumes that we can identify useful methods that promoted innovation in the earlier German-speaking world, yet it is at best a concise overview of a vast field encompassing the actions of thousands of scientists and engineers across many countries during two centuries, as well as investigations into that time period by countless subsequent scholars. I do not mean to imply that innovation systems in the earlier German-speaking world were ever perfect or even unique, or that all of their innovation-promoting factors could or should be applied to the modern world. In no way is this study an argument that the Third Reich had inherently superior scientific research approaches. For reasons of length, this study cannot even begin to address the large number of related ethical questions that are already covered in detail

by many other authors; I highly recommend that all readers seek out those books and study them.[1]

8. The ultimate objective of this study is to make these methods of improving innovation available to the modern world. In order to maximize the potential audience, longevity, and impact of this study, I decided to make the final document freely available on the internet instead of publishing it as a printed book, which might be expensive and difficult to obtain and might rapidly go out of print, as so many of the cited references have.

9. Because the body of information on German-speaking innovators is both so large and so incomplete, this book cannot help but be incomplete and imperfect. I would welcome any suggestions for improvements to future editions. At the very least, hopefully this book will spur discussion, learning, and further work in the important areas that it covers.

Scientists and engineers who were trained in the German-speaking world of the nineteenth and early twentieth centuries produced a wide range of discoveries and inventions that have shaped our modern world, including:

- Biomedical advances from genetics to antibiotics (Chapter 2 and Appendix A)
- Chemical breakthroughs from color film to synthetic rubber (Chapter 3)
- Discoveries about the Earth and our universe from continental drift to stellar distances (Chapter 4)
- Revolutionary physics from relativity to quantum mechanics (Chapter 5)
- Electrical inventions from semiconductors to computers (Chapter 6 and Appendices B–C)
- Mechanical systems from automobiles to submarines (Chapter 7)
- Nuclear reactions and applications from fission to fusion (Chapter 8 and Appendix D)
- Aerospace vehicles from jet planes to moon rockets (Chapter 9 and Appendix E)

Although other authors have studied the history of some of those creations and creators in detail, and Chapters 2–9 and the appendices shed additional light on others, much more work is needed to elucidate the full range and details of the contributions made by the German-speaking research world.

[1] E.g., Bar-Zohar 1967; Beyerchen 1977; Black 2012a, 2012b, 2017; Borkin 1978; Bower 1987; Campbell and Harsch 2013; Cornwell 2003; Crim 2018; Deichmann 1996; Joseph Fisher 2017; Friedrich et al. 2017; Geissler 1998a, 1998b, 1999; Gellermann 1986; Georg 2012; Gimbel 1986, 1990a, 1990b, 1990c; Gröhler 1989; Guillemin 2005; Friedrich Hansen 1993; István Hargittai 2006; Harris Paxman 2002; Haunschmied et al. 2007; Hayes 2001; Heim et al. 2009; Hentschel and Hentschel 1996; Linda Hunt 1991; Jacobsen 2014; Jeffreys 2008; Karlsch and Laufer 2002; Kaszeta 2020; Kater 1989; Keynes 2019; Klee 2001; Kurowski 1982; Lasby 1971; Leff 2019; Le Maner and Sellier 2001; Julian Lewis 2002; Lichtblau 2014; Macrakis 1993; Milton Mayer 2017; Medawar and Pyke 2000; Mick 2000; Nachmansohn 1979; Nash 2013; Michael Neufeld 1995, 2002, 2003, 2007; Plumpe 1990; Posner and Ware 2000; Pringle 2006; Renneberg and Walker 1993; Sasuly 1947; Schambach 2011; Sellier 2003; Simpson 1988; Spitz 2005; Stoltzenberg 1994, 2005; Sutton 1976; Szöllösi-Janze 2001, 2015; Tucker 2006; Wachsmann 2015; Bernd Wagner 2000; Jens-Christian Wagner 2011, 2015; Wallace 2004; Whitman 2018.

As discussed in Chapter 10, one may identify common factors within the German-speaking world that facilitated the success of those creators and creations. These factors promoted greater freedom to pursue longer-term and riskier potential innovations, and they included:

1. Science was socially glorified, from children's activities and amateur science clubs to prestigious jobs and government-lauded scientific heroes.

2. A century-long steady exponential increase in funding gave scientists, employers, and sponsors much more freedom to pursue higher-risk and/or longer-term research.

3. Many Ph.D. students were encouraged to propose their own research topics and to pursue them independently.

4. Scientists received their final degrees nearly a decade earlier in life, and independent research funding up to two decades earlier, than modern scientists do.

5. Scientists who made major contributions to multiple disciplines, and fraternization among scientists from different disciplines, were much more common than in the modern world.

6. Instead of peer review, an autocratic yet farsighted scientific management culture of "enlightened despots" granted stable jobs and funding to the most promising creators and creations.

7. Both scientists and sponsors used a systems analysis approach to focus on the most important problems and the most effective innovations to address those problems.

8. The lack of natural resources spurred the creation of a wide range of innovative alternatives.

9. International rivalry (both economic and military) was a powerful driving force for innovation.

10. German-speaking companies were less afraid of losing their own innovations to each other than of being outstripped by foreign countries, giving them a strong motivation to innovate.

From Chapter 11, the modern world eagerly adopted the creations of the earlier German-speaking world, yet ultimately largely forgot both the creators and the systemic approaches that had made such creations possible. Over the course of waves that occurred before, during, and after the Third Reich, all of the creations, most of the creators, and some of the systemic approaches were transferred from the German-speaking world to the United States and other countries in a German scientific diaspora. Those countries spent many decades fully perfecting and mass-producing the innovations that had been created by the earlier German-speaking world, resulting in our modern world of jet aircraft, electronics, and pharmaceuticals. Most of the creators who had already died or who remained in German-speaking areas were largely forgotten by the non-German-speaking world, which often mistakenly attributed their creations to whichever non-German-speaking individuals or organizations had acquired their technical information. Most of the creators who emigrated out of German-speaking areas led well-funded but quiet lives perfecting their creations and were also ultimately forgotten; only a few, such as Albert Einstein, Edward Teller, and Wernher von Braun, sought or received lasting fame. Especially during the 1940s–1960s, the United States and other countries practiced some of the general approaches that had made the earlier German-speaking world successful, thereby cultivating new innovators and innovations of their own.

By the 1970s, most of the German-speaking creators had retired or died, their creations had been refined to the point of diminishing incremental returns, and global research systems had abandoned most of the German-like practices they had adopted, significantly reducing their efficiency at producing entirely new innovators and innovations. The Cold War as a strong motivating force for innovation had also greatly relaxed around 1970, and most of the truly revolutionary new innovators (or innovations) that were produced by the global research system found it increasingly difficult to obtain proper support as time went by. From the 1990s onward, with the Cold War over and officials both public and private haggling over every research dollar while spending recklessly in other areas, the academic, corporate, and government research sectors each became increasingly dysfunctional in their own ways. As a result, even though the modern world has far more researchers, funding, and political stability than the earlier German-speaking world, it is difficult to identify as many revolutionary innovations that have been wholly developed by that modern system as those examples listed in Chapters 2–9 and Appendices A–E.

In 1946, the U.S. Department of Commerce wrote a press release that compared the German and U.S. approaches to research and explained what the United States could learn from the German model (see p. 5113). Most of those observations are still highly relevant three-quarters of a century later [NARA RG 40, Entry UD-75, Box 3, Folder Press Releases, The Chemical Problem in Germany]:

> The picture in scientific and chemical fields of development has long been very competitive and often retarded by the lack of financial assistance. Many of the industries of the United States while progressive on the production line have been quite willing to accept the benefit of the research and development of others, but not bothering to maintain research units of their own.
>
> Many of the chemical achievements now in use are the result of the research and development accomplished in other countries. While the United States enjoys the privilege of a school system that can and does provide numbers of young scientists, well versed in their particular fields, few are employed by industry at salaries commensurate with their skill. Consequently, the young scientific mind resolves the problem as one of mis-selection [of a career], so therefore, seeks and obtains more remunerative positions outside of their field causing a complete dislocation of their academic achievements.
>
> The German government and German industry had an entirely different attitude toward their scientifically trained men. The research and development work accomplished in the past decade will attest the value of subsidizing the scientists in the form of annuities and awards, not only for completed work but generous support of an idea from its embryonic imaginary state, through the laboratories, pilot plant, to the final production stage.
>
> In an emergency such as this country has just passed through, the United States was very fortunate that it could and did regiment the outstanding scientific brains of the country to undertake the modernization of the materials and warfare. Production lines and basic raw materials plus natural resources played as important a part as did science, yet one without the other would and could have proved quite ineffectual.
>
> The German industry and their subsidized scientists early realized that their natural resources were insufficient and the raw materials that could be imported would not be depended upon, nor were they readily obtainable. The problem was placed before

the German scientist, with the result that synthetic materials were produced, such as the industries in the United States never considered feasible, profitable, probable or possible.

Research and development work in Germany was concentrated in the larger industries of the I. G. Farbenindustrie caliber by grants made to the teaching staffs of universities and scientists of independent laboratories. The larger industries in turn were subsidized or controlled by the government.

Many tens of millions of dollars were expended in the U.S., not lavishly nor extravagantly during the war years, but much of the monies thus expended could have been more advantageously used had the work of research and development been protracted rather than immediately required as a war expedient. [...]

The inherent German love of gadgets, these investigators found, has produced a nation of gadgeteers and inventors. This is fostered by broad thorough elementary education in the mechanical and manual arts and by their system of apprenticeship training and has largely been instrumental in bringing about German development. [...]

The investigators were deeply impressed by the large pool of skilled mechanics upon whom Germany could draw. Their system of training the youth in mechanics, and shop practice, and familiarizing them with all kinds of modern tools had much to do with Germany's ability to wage such a devastating war against so many powerful nations. The same abilities and skills could be used for the increased production of the civilian products needed in peaceful pursuits. [...]

The most striking feature of the work the Germans performed for the development of their war material is undoubtedly the extremely high scientific order of their researches. In many fields they were pioneering and the outstanding results they achieved may, beyond doubt, be attributed to the long range provisions and the scientific approach on which they based their programs and the wealth of refined solutions they investigated in their research laboratories with the well-known German thoroughness.

12.2 Lessons from the Creators

Based on the perspective accumulated in Chapters 1–11, this section will offer suggestions for state or national innovation systems that would like to increase their production of revolutionary research (Section 12.2.1), for individual organizations or laboratories that would like to pursue more innovative research (Section 12.2.2), for individuals now trying to pursue careers in innovative research in the existing state of the global system (Section 12.2.3), and for scholars who would like to further study the past, present, and potential future of revolutionary creators and creations (Section 12.2.4).

12.2.1 Lessons for State, National, and Global Innovation Systems

Just as the nations of the earlier German-speaking world, as well as the United States during the 1940s–1960s, adopted policies that bred, supported, and rewarded revolutionary innovators and innovations, a modern nation or the entire global system could implement some of those proven policies. Many of these methods could even be adopted by an individual state (such as California or Massachusetts) within a nation. Based on the analysis of the earlier systems in Sections 10.2 and 11.2, those policies that a modern state or nation could consider (suitably adapted for modern times) include:

1. Science, science teachers, and science researchers were idolized and well funded in the German world, and also during the 1940s–1960s in the U.S. system, from children's activities and amateur science clubs to prestigious jobs and government-lauded scientific heroes. The social and financial status of science, science teachers, and science researchers should be elevated greatly beyond where they currently are in the modern world:

   (a) Better quality and greater variety of educational science experiment kits for children should be produced and more widely advertised and used.

   (b) Student science competitions (especially ones like science fairs that emulate real scientific research) should be given much greater emphasis, and the winners of those competitions should be publicly praised and rewarded at least as much as student athletes.

   (c) The salaries and working conditions of science and other teachers should be improved in order to attract very talented people to those positions and to recognize and reward the most effective teachers.

   (d) Important new scientific discoveries and inventions should be given much more coverage (comparable to or greater than that of sports stars and popular culture celebrities) in television news programs, movies, online video and audio programs, newspapers, magazines, and popular internet sites.

2. The highly innovative German-speaking world experienced exponential growth of research funding throughout its entire history until 1945, and the very productive period of the U.S. system during the 1940s–1960s also had exponential funding growth. Much greater freedom from funding pressures during those periods promoted much greater freedom to support longer-term, higher-risk, and potentially revolutionary innovators and innovations.

   (a) Although exponential funding growth cannot continue indefinitely, many nations or states could certainly afford to invest much more of their money in advanced research and development than they do currently. For example, U.S. federal funding for R&D as a percent of GDP in 2017 was only around one-third of what it had been in the 1960s, and is expected to continue to decline.

(b) Even without having permanent exponential funding growth, governments could implement policies that would emulate the most important effects of such growth. Specifically, the number of graduating students trained in science research should be very close to the number of available permanent job positions, as it has been during periods of exponential funding growth, not far larger than the number of available permanent job positions as it is now.

(c) Increasing the number of temporary positions such as postdoctoral positions and internships would only put more young scientists into a holding pattern without either solving the fundamental mismatch between the number of scientists and the number of permanent jobs, or allowing those scientists to be independently productive.

(d) If the number of permanent job positions cannot be increased due to national fiscal constraints, the number of graduating students seeking science and engineering research careers should be decreased by motivating some students to seek other majors and other jobs, while still strongly encouraging the most creative students to pursue majors and careers in science and engineering research.

(e) If the amount of available funding and permanent job positions better matched the number of graduating students and career researchers, scientists would be able to spend much more of their time and energy doing productive research, and much less of their time and energy pursuing elusive funding and positions.

(f) If the amount of available funding and permanent job positions were much closer to the number of graduating students and career researchers, it would be much more acceptable to sponsors, institutions, and the scientists themselves for researchers to pursue longer-term work without an immediately demonstrable payoff, as well as more innovative higher-risk work that would be less guaranteed to yield results than very incremental, low-risk work. It would be much easier for the system to gamble that some of the funded researchers and projects would ultimately pay off and some would not, and to deem those stakes acceptable.

(g) Just as the above steps would increase freedom for academic and government researchers to pursue longer-term and higher-risk research, government could take steps to promote more long-term and/or higher-risk research in companies as well. Improved tax, patent, regulatory, or other government incentives could make it much more advantageous for companies to spend more of their money on research, and much more lucrative for the first company that develops any given major innovation, thereby encouraging companies to invest more of their capital in research, and specifically to put a greater fraction of it into longer-term, more innovative R&D.

(h) To conclude this topic, increased funding can be helpful but is not sufficient by itself. Doubling the R&D spending would not do much good if that simply yielded twice as many esoteric and repetitious papers in publicly inaccessible journals from academia, twice as many smart phone apps and erectile dysfunction pills from industry, and twice as much bureaucracy at government laboratories. The most important factor is not just providing more money, but rather providing scientists more freedom from the burden of proposals, from career woes, from the present focus on short-term results, and from the current bias toward very low-risk work.

3. Many German-speaking students were trained from an early age to be very creative and self-reliant researchers and inventors. Once they reached the universities, many (though certainly not all) German-speaking students were actively encouraged to come up with their own original Ph.D. thesis topics and to pursue that research independently, with loose mentorship from their Ph.D. advisors. That seems to have been true to some extent in the early U.S. system as well. In contrast, most modern U.S. students come up through an assembly line of rote science classes, are finally assigned a specific thesis topic and methods by their Ph.D. advisor, and then spend multiple postdoc jobs doing specific assigned work as well. If and when those scientists finally obtain an independent position, they do not have any expertise proposing and conducting truly innovative research.

    (a) Olympic gymnasts and concert pianists train from a very early age for their ultimate goal. It would be ludicrous to expect young people to simply watch Olympic gymnasts or concert pianists from the sidelines for decades, then finally step on stage for the first time in their 40s and be successful Olympic gymnasts or concert pianists themselves. It is equally ludicrous for the modern scientific system to hope to train revolutionary scientific innovators in that same fashion.

    (b) Science students in the modern world should be trained from an early age to be very creative and self-reliant researchers, using methods such as science kits for younger children and science fairs for older children, as already mentioned.

    (c) For university theses, students should be allowed and in fact strongly encouraged to select their own research topic and methods.

    (d) Research advisors should provide as much advice and assistance as is necessary (but only what is necessary) to ensure that their students are pursuing productive research topics using suitable methods.

    (e) Research advisors at universities should not use students as unpaid or low-wage labor to benefit the advisors' own research grants or lists of publications. Rather, advisors should do their own research work themselves, or hire actual paid employees to help them do the work.

4. Scientists in the earlier German-speaking world received their final degrees approximately a decade earlier in life, and independent research funding up to two decades earlier, than modern scientists do. Scientists in the early U.S. research system also received their degrees and funding earlier than modern scientists, although not as early as those in the former German-speaking world.

    (a) The average age at which scientists receive their final degree and are able to work independently should be greatly reduced. Lowering that age back toward the early to mid-twenties now would increase the number of years during which scientists could be productive, and in particular it would greatly increase the number of youthful working years during which those scientists have the greatest creativity, the most energy, and the fewest non-research obligations.

(b) The average age at which scientists receive their Ph.D. should be lowered by decreasing the redundancy between high school and undergraduate courses, streamlining graduate education, and making sure that graduate research is shorter and more focused on a Ph.D. thesis (not work by the graduate student on unrelated projects and papers that primarily benefit the thesis advisor or that simply pad the student's résumé for an overly competitive job market).

(c) The average age at which Ph.D. scientists obtain their first real job position and their own research funding should be lowered by eliminating postdoctoral positions and internships. That change would allow new doctoral graduates to proceed directly to stable, well-paying jobs where they could be maximally creative and productive. Although institutions may claim that postdoctoral positions provide valuable mentoring to young scientists, in practice the postdoctoral positions are much more about providing a pool of highly skilled, low-wage labor to lab supervisors than any essential mentorship or further education.

5. Individuals who made major contributions to multiple disciplines, and routine fraternization among individuals from different disciplines, were rather common in the German-speaking world, and still occurred quite a bit in the early U.S. research system. In this modern era of microspecialization, the older interdisciplinary mindset should be revived and rewarded:

   (a) The modern world should train, support, and reward at least some percentage of multidisciplinary scientists who can make major contributions in multiple fields, apply knowledge and methods from one field to another, and use their broader view to guide fields of research away from less productive areas and toward more productive ones.

   (b) All scientists should be strongly encouraged to make their research comprehensible to people outside their field, and to interact with scientists in other fields in a variety of environments. Increased interactions among individuals from different disciplines would also help cross-pollinate ideas among different fields, and help scientists in different fields obtain greater perspective.

6. In the German-speaking world and the early U.S. research system, "enlightened despots" were able to spot potentially revolutionary innovators and innovations and grant them long-term financial and political support. While there is certainly a place for methodical peer review, entrusting virtually all funding and hiring decisions to peer review risks overlooking those creative new scientists and ideas that are so revolutionary that they cannot easily and immediately get broad consensus from the scientific status quo.

   (a) Rather than allotting all funding (and effectively most jobs) by peer review, the modern research system should set aside some percentage of research funding to be allocated by enlightened despots who are good at identifying potentially revolutionary innovators and innovations.

   (b) Such enlightened despots should have the clear authority to grant financial and political support to any people or projects they deem worthy, and to grant that support for many years without having to demonstrate that there is an immediate payoff, or even that all funded research will eventually pay off.

(c) How enlightened despots with the best discernment would be selected is an unresolved question. In both the German-speaking world and the early U.S. research system, they either arrived at their positions by some combination of luck and force of will, or else they were hand-picked by previously established enlightened despots. Those methods are not perfect but could be tried now, or perhaps a better way to select the best enlightened despots could be found.

(d) Wherever possible, any remaining peer review should be done by reviewers unaware of the researchers' names and affiliations, so that they can more fairly evaluate the actual research in question.

7. In the German-speaking world and in the early U.S. research system, a systems analysis approach was used to great effect in order to identify the most important problems and the most effective innovations to address those problems, and to help focus scientific personnel and funding in those directions. This systems analysis approach was employed by both scientists and sponsors. In contrast, the modern world appears to be too subject to the whims of vast numbers of self-interested individuals whose overriding priority is to maximize outputs other than innovation, such as their number of publications or their stock price. It would be beneficial to re-emphasize a systems analysis approach.

    (a) Systems analysis should be widely taught and practiced in schools and universities.

    (b) By using systems analysis, key decision makers in government, industry, and academia could help focus more resources on the most important problems and potential solutions.

    (c) If individual scientists were taught to practice systems analysis, they could use that method to guide their careers and their research projects in more promising directions, and to ensure that no potentially useful regions of the conceptual "phase space" had been overlooked.

8. The very limited availability of natural resources was a major factor in driving innovation in the German-speaking world. It was much less of a factor in the early U.S. research system, although the United States did adopt many of the synthetic products that had been developed in the earlier German-speaking world.

    (a) Now that the world is much more conscious of its dwindling natural resources and the rising long-term costs of climate change, pollution, and waste, government-funded programs and government regulations for industrial programs should prioritize the development of very innovative methods of reducing the consumption of natural resources and minimizing the creation of waste products.

    (b) Such policies would not only improve the environment in which we and future generations must live, but would also be a strong driver of a wide range of new and very beneficial innovations.

9. International rivalry, largely military but also economic, was the driving force behind the historical German-speaking world and the early U.S. research system. Without seeking a return to militarism and war, a healthy sense of competition among states or nations could be useful:

(a) Peaceful economic rivalry and even regional pride (as in sports competitions) could be employed constructively to motivate states or nations to accelerate their research and development programs.

(b) Existing high-tech innovation centers (small geographical areas in which R&D is concentrated) that support and promote interactions among programs they contain could be strengthened, and rival high-tech centers could be created to compete for the best scientists, projects, research funding, and economic income from resulting inventions and products. [See Gruber and Johnson 2019 for a strong and detailed argument for many regional high-tech innovation centers.]

10. For more than a century, German-speaking companies were much more afraid of being outstripped by foreign countries than of losing their own innovations to each other. Likewise, in the 1940s–1960s, U.S. companies were much more afraid of losing first to the Axis countries and then to the Soviet Union than to each other. In both cases, that mindset toward competition gave the companies a strong motivation to innovate.

    (a) Companies should view very innovative, longer-term R&D as a worthwhile investment in staying ahead of competitors, not a financial liability whose resulting products could be copied by competitors that did not have to spend any money on their own R&D.

    (b) Improved tax, patent, regulatory, or other government incentives could make it much more lucrative for the first company that develops any given major innovation, and/or less lucrative for copycats.

    (c) Suitably structured tax incentives could also provide strong inducements for companies to put much more of their capital and annual income into research and development (and other useful things, including infrastructure and employee salaries/benefits), instead of enormous cash and stock payouts that only benefit a small number of individuals.

12.2.2 Lessons for Individual Organizations and Laboratories

While it might be difficult to persuade an entire nation to reform its scientific system, individual universities, companies, government laboratories, or other organizations could readily adopt certain practices related to those that made the older German-speaking world so successful.

Many of the strategies already listed in Section 12.2.1 could be implemented in a scaled-down, much more local fashion:

1. An organization should do anything within its power to improve the social and financial status of science research. An organization should strongly encourage, support, recognize, and reward innovative research among its own members. It should also promote its scientific innovation and accomplishments to the outside world, and sponsor educational science programs and student competitions in the outside world. The costs of these internal and external promotional programs would be handsomely repaid by both the increased productivity of the organization's own members and the organization's enhanced prestige and desirability as viewed by the outside world.

2. Universities should better match the number of graduating students and career researchers with the amount of funding and permanent job positions, so that scientists do not waste much of their time and energy pursuing elusive funding and positions. With a better balance between people and jobs, and therefore reduced pressure for all job occupants to have maximum short-term productivity, each organization should make room for at least some of its members to spend at least some of their time pursuing longer-term work without an immediately demonstrable payoff, as well as more innovative higher-risk work that would be less guaranteed to yield results than very incremental, low-risk work. While some of those bets would not pay off, others could pay off with revolutionary results that could prove highly lucrative over the long run.

3. In individual organizations from K-12 programs and universities to companies and government laboratories, young scientists should be trained from the very beginning to be creative and self-reliant researchers. Such investments of time, resources, and institutional trust in the younger scientists could ultimately yield very large returns.

4. Individual universities should implement programs in which the average age at which scientists receive their doctoral degrees is in their early to mid-twenties; such programs would be so attractive to students that those universities would have their pick of the best applicants. Organizations should also implement programs to provide jobs and stable funding for extremely young but highly creative scientists. These steps would greatly increase the number of productive working years during which those scientists have the greatest creativity, the most energy, and the fewest non-research obligations. Again, the longer-term payoffs for organizations that take these steps could be tremendous.

5. An organization should train, recruit, and reward at least some percentage of multidisciplinary scientists who can make major contributions in multiple fields, apply knowledge and methods from one field to another, and use their broader view to guide work away from less productive areas and toward more productive ones. All scientists within an organization

should be strongly encouraged to make their research comprehensible to people outside their field, and to interact with scientists in other fields in a variety of environments, in order to cross-pollinate ideas among different fields.

6. An organization should set aside at least some percentage of research hiring and funding decisions to be determined by enlightened despots who are good at identifying potentially revolutionary innovators and innovations. Such enlightened despots should have the clear authority to grant financial and political support to any people or projects they deem worthy, and to grant that support for many years without having to demonstrate that there is an immediate payoff, or even that all funded research will eventually pay off.

7. By using systems analysis, the leadership of an organization could help focus more of the organization's resources on the most important problems and potential solutions. If individual members of the organization were taught to practice systems analysis, they could use that method to guide their careers and their research projects in more promising directions, and to ensure that no potentially useful regions of the conceptual "phase space" had been overlooked.

8. In the face of dwindling natural resources and the rising long-term costs of climate change, pollution, and waste, organizations should prioritize the development of very innovative methods of reducing the consumption of natural resources and minimizing the creation of waste products.

9. Organizational pride and rivalry with other organizations should be used constructively to motivate innovation within an organization, and to promote interactions among the scientists and projects within the organization in order to maximize the potential of each one.

10. Companies should view very innovative, longer-term R&D as a worthwhile investment in staying ahead of competitors, not a financial liability whose resulting products could be copied by competitors that did not fund their own R&D. They should lobby federal and state governments for improved tax, patent, regulatory, or other incentives that would make it much more lucrative for the first company that develops any given major innovation. They should also lobby for structured tax incentives that would reward companies that put more of their capital into research.

In addition to smaller-scale local versions of those strategies, additional steps could be taken by individual labs and organizations:

11. In the German-speaking world, the cost of a university education was very low and not an obstacle, and students were generally able to go straight through their university education without having to spend significant time and energy working other jobs to try to pay for it. With no student loan debt, after graduation those students could immediately use their degrees to earn a good income. A university education in the United States in the 1940s–1960s was also quite affordable. In contrast, nowadays a university education in the United States leaves a student and also the student's family with enormous debts (up to many hundreds of thousands of dollars) that can last for decades or even a lifetime. It is imperative to eliminate this financial obstacle and burden.

(a) Universities with large endowments should use income from those endowments to make their educational programs tuition-free for any students they admit. By doing so, they would get their pick of the best students in the world.

(b) Whatever factors have been driving U.S. tuition costs to astronomical levels (ever-multiplying armies of non-teaching administrators and staff, professors who are paid very highly yet leave most or all of the teaching to adjunct faculty or grad students, overpriced and overly showy buildings and athletic facilities, etc.) were never essential in the past. They can certainly be eliminated in these times when online students all around the world can watch videos of the world's best lecturer on a given topic, read an excellent electronic textbook on any subject, or complete automated assignments and exams on their computers at essentially negligible cost.

12. In the German-speaking world and in the early U.S. research system, many young scientists had already produced revolutionary inventions and discoveries by the time they were in their mid-twenties. Many modern students could do so too if they were given enough time, resources, and support.

    (a) For relatively very little money, individual laboratories or a philanthropic foundation could identify students who have done the most innovative, independent research in high school science fairs such as the International Science and Engineering Fair (ISEF) and Science Talent Search (STS), and offer them summer or part-time positions in college where they would be completely free to develop and pursue their own ideas (with appropriate supervision and assistance as needed).

    (b) Such students should be able to hone and exercise the innovative research talents they have already developed, instead of having to leave those behind to spend years of drudge work slowly working their way up the ladder (undergraduate students following instructions from graduate students following instructions from postdocs following instructions from a tenure-track assistant professor following instructions from the university department and from research sponsors).

    (c) Organizations offering temporary positions to such students should not impose any intellectual property agreements on their new ideas, in order to avoid creating legal and financial entanglements that could strangle the students' ideas in the crib as soon as the students leave their temporary positions.

13. Universities are places where students go to learn; therefore, universities should select and evaluate their professors largely on the basis of their teaching ability, and support and honor those who invest the most energy and talent in their teaching. In the earlier German-speaking world, research was important but never eclipsed, let alone eliminated, the responsibility of professors to be good teachers. If it is too difficult for modern professors to balance teaching and research, some professors' positions could be designated primarily for teaching, and some primarily for research. In that case, universities would need to avoid the pitfalls of giving higher status to research professors than to teaching professors, or of using student tuition to fund non-teaching research professors.

14. Employers, sponsors, and journals should evaluate scientists' research proposals and results on the basis of their true quality, innovation, and significance, not on the basis of the sheer

volume of a scientist's papers or name recognition of people or places involved in the work. In the German-speaking world, a lone and obscure patent clerk without a Ph.D. (Einstein) could submit a highly insightful paper, have it be promptly published and carefully listened to, and change the world as a result. How feasible would that be in the modern system?

(a) Peer reviewers could evaluate papers and research grant proposals more fairly if the reviewers did not know the authors or institutions involved in the research. For that approach to work properly, it might also be necessary to avoid clues in the cited references, resource lists, or other sections that might give the reviewers too much information about the authors or institutions.

(b) Scientists should be evaluated based on the actual scientific quality and importance of their work, as they generally were in the German-speaking world and in the early U.S. research system. Evaluating scientists primarily on the basis of the sheer quantity of their publications or where they appeared is a concept that arose in the modern system and that does not give priority to the types of work, scientists, or research projects that will actually have the greatest impact.

15. Scientists should strive to make their work more comprehensible and relevant to scientists in other fields, to government, and to the general public. Whereas scientists now seemingly seek to invent more and more unnecessarily specialized language and isolated subfields, scientists of all fields once rubbed shoulders in the coffeehouses and symposia of the German-speaking world.

16. Corporate leaders, managers, and workers should be rewarded on the basis of their contributions to the long-term potential and success of the company, not on the basis of tomorrow's stock price or next year's product. In the German-speaking world and in the United States of the 1940s–1960s, companies deliberately recruited, supported, rewarded, and profited from leaders and scientists with successful long-term visions for revolutionary products.

17. In the German-speaking world, government laboratories such as the Kaiser Wilhelm Institutes and the military labs were strong centers of innovation that could very effectively focus on revolutionary research because they were free of both the teaching obligations of universities and the product manufacturing obligations of companies. In the United States of the 1940s–1960s, government-run laboratories such as Los Alamos, NASA centers, and U.S. Air Force, Navy, and Army research labs enjoyed similar advantages and supported revolutionary innovators and innovations. Yet in the modern United States, many government-run and government-funded laboratories now struggle through 70+ years of accumulated red tape to continue working on technologies that have not been revolutionary for 70+ years.

(a) Any remaining truly essential functions that government laboratories perform regarding those now extremely mature technologies should be transferred to much cheaper, simpler contractors. Current government laboratories should be drastically restructured or otherwise replaced with new government laboratories to eliminate their red tape and to refocus them on new potentially revolutionary technologies.

(b) Modern government laboratories should make the most of their potential to combine the best qualities of academia and industry and to avoid the worst qualities of each, just as such laboratories did in the German-speaking world and in the early U.S. research system. In principle, government laboratories can avoid the teaching and constant paper-publishing obligations of academia while emulating its focus on longer-term research, and also avoid the obligations of industry to produce lucrative products in the short term while retaining industry's focus on applications instead of pure basic research.

18. Whereas many modern organizations view their employees as interchangeable and inexpensive components to be replaced frequently and at will, older German organizations viewed their employees as a valuable long-term resource to be cultivated (p. 1997). Modern organizations should adopt that same view, carefully hiring the best job applicants; paying and treating them very well; giving them the training, resources, time, freedom, and support they need to be as successful as possible; and recognizing and rewarding their accomplishments. Having the best employees with the best resources will help an organization be as innovative and productive as possible in the long term, and will also help it continue to hire and support new employees to maintain that tradition.

12.2.3 Lessons for Individual Scientists and Engineers

While individual scientists and engineers are very unlikely to be able to exert control over the whole research system or even part of it, they can control their own careers. Based on this study comparing the earlier innovation systems with the present system, options and suggestions for individuals are given below and summarized graphically in Fig. 12.1.

1. Everyone should be very cognizant that the modern innovation system is divided into academic, corporate, and government research sectors, and that in general each is currently suffering from deep-seated problems outlined in Sections 1.1 and 11.3. If someone is interested in science but would like to avoid those problems by pursuing a career not in scientific research and development, there are a large number of potentially fulfilling and potentially lucrative careers that involve science but not R&D. To give just a few examples, one might consider:

   (a) Becoming a medical doctor, nurse, veterinarian, or other healthcare worker.

   (b) Practicing law in science-related areas such as writing patent applications or negotiating technology licensing agreements.

   (c) Pursuing a business or finance career in science-related areas, for example by evaluating scientific ideas for venture capital firms, or by earning business or finance degrees to work in corresponding positions in science-related companies.

   (d) Teaching science or math subjects at K-12 grade levels or at a community college.

   (e) Producing and/or selling scientific or medical tools, equipment, or supplies, or even educational scientific kits and toys.

   (f) Writing or offering science advice for science fiction films, television shows, novels, comics, etc.

2. Because the problems in the modern innovation system are so pronounced, only someone who feels strongly personally compelled to pursue a career in scientific R&D should do so. After having studied the problems in the academic, corporate, and government research sectors, if someone finds one of those sectors preferable to the other two and is willing to endure its known difficulties for the duration of a career, that can be a clear and well-informed choice:

   (a) Some individuals will be most willing to live with the problems in academic research.

   (b) Some individuals will be most willing to live with the problems in corporate research.

   (c) Some individuals will be most willing to live with the problems in government research.

   (d) If someone feels personally compelled to pursue an innovative scientific career and yet is not satisfied with the current state of the academic, corporate, and government research sectors, the available options involve harder choices and murkier information.

3. One possibility for intrepid young innovators is to seek areas where R&D funding for new projects might be more readily available than is the case in the mainstream system:

    (a) Some corner of the existing research system may still be conducive to revolutionary innovation, especially if it is nurtured and protected by an enlightened despot like those of earlier times—perhaps a particularly farsighted corporate CEO/owner/investor/senior manager, philanthropist, university administrator, or defense or intelligence sponsor.

    (b) Some field that is so incredibly old, so new, such a novel combination of existing fields, or so offbeat that it is not filled to overflowing with peer-reviewed competitors may afford better opportunities.

    (c) There might be better funding prospects for new innovators and innovations in those few countries that still have steadily increasing investments in R&D.

4. Another possibility, though only for the very courageous individual, would be to try to improve some specific part of one of the existing research sectors (academic, corporate, or government). Several guidelines should be kept in mind:

    (a) Before proceeding down this path, one should very carefully select which specific part of which research sector to try to improve, and equally carefully plan exactly how that improvement could be realistically accomplished.

    (b) One should expect fierce resistance from the existing system at every step of the way.

    (c) One should recognize from the outset that there is a high probability any effort at reform or improvement will fail, no matter how well intentioned, carefully planned, and diligently executed it might be.

    (d) Anyone advocating for improvement should seek supportive allies at all levels from high government positions to physical plant maintenance. That is sound advice for any pursuit, but especially critical if a reformer is to have any hope of success.

5. If someone feels personally compelled to pursue innovative R&D and is not satisfied with (or cannot access) any of the options outlined above, the remaining possibility is to try to pursue a research career outside of the official sectors. Several keys are important to make this sort of career path possible:

    (a) In the absence of financial support from the academic, corporate, or government research sectors, it is necessary to seek and obtain alternative sources of financial support for independent scientific work. The nature of those alternative sources will depend upon an individual's specific circumstances, interests, and opportunities, but could range anywhere from taking a normal job that pays well but allows enough outside time for research (e.g., Swiss patent clerk), to marrying into wealth, to accepting internet donations or crowdfunding.

(b) It is critical to identify and focus on projects that can be accomplished with limited labor (often only that of the individual, or even just some fraction of the individual's time) and very limited equipment, supplies, and other resources. Those considerations will likely limit any work to theoretical analyses or at best very small-scale experimental research.

(c) Two or more individuals interested in the same or similar areas might pool their time and resources in order to accomplish more and to provide mutual encouragement. Among other possibilities, one might establish or join a "maker space," amateur science club, scientific co-op, or other organization.

(d) No matter how high the quality of an unaffiliated individual's work might be, that person will likely have great difficulty getting proper consideration from scientific journals, government patent offices, or corporate technology licensing offices. Therefore, without necessarily giving up on those establishment methods for output, one should seriously consider alternative methods of output for any significant scientific results, including freely releasing results on the internet without any possibility of monetary gain in hopes of maximizing the ultimate impact of those results.

6. Based on the examples of successful creators from the earlier research systems, modern individuals should follow these practices both for finding/creating a suitable job (which requires innovative problem solving in its own right) and for conducting innovative research:

   (a) No matter how limited your time, resources, and options may be, practice innovation right now and every day after that, rather than hoping to start later on down the road. Brainstorm for new ideas for innovative research projects, make a list of the ideas, and add to that list every time you think of a new idea, day or night. Constantly consider various ways in which those ideas could be analyzed theoretically, computationally, or experimentally, or how they could be developed in part or in whole into models or prototypes. Seek outside input to correct or supplement your ideas, but do not simply copy what others say or do. To be as successful as possible at scientific innovation, you must practice it from as early an age as possible, and as much as possible (just like any other skill).

   (b) Constantly seek out resources and opportunities to test or develop any of the innovative ideas from your list, and keep your eyes open for opportunities that may arise spontaneously.

   (c) Employ a top-down systems analysis approach [Zwicky 1969] to identify first the most important problems to work on, and then the range of possible solutions for those problems, and finally out of those possibilities the best solutions for the best problems that one could pursue, all subject to the constraints of your own particular talents, resources, and opportunities.

   (d) Study multiple fields, and multiple areas within a field. Having multidisciplinary expertise can enable you to make contributions in different fields (as opportunities arise), achieve new results by applying knowledge and methods from one field to another, and use your broader view to guide your work away from less productive areas and toward more productive ones.

(e) Actively seek out people who are as close to being enlightened despots as you can find—individual people who (i) are most inclined to support the sort of innovative research you would like to do and (ii) are best able to offer you financial support, political support, and/or useful advice.

(f) Present your research in such a way that it will be comprehensible to scientists outside that particular field and also to non-scientists. Along the way, actively maximize your interactions with scientists in other fields in a variety of environments, in order to cross-pollinate ideas.

(g) Wherever and however possible, help inspire, train, support, and reward aspiring scientists who are younger than you. Although you may have few resources, a younger aspiring scientist will probably have even fewer than you do. You could be the closest thing to an enlightened despot that they will find.

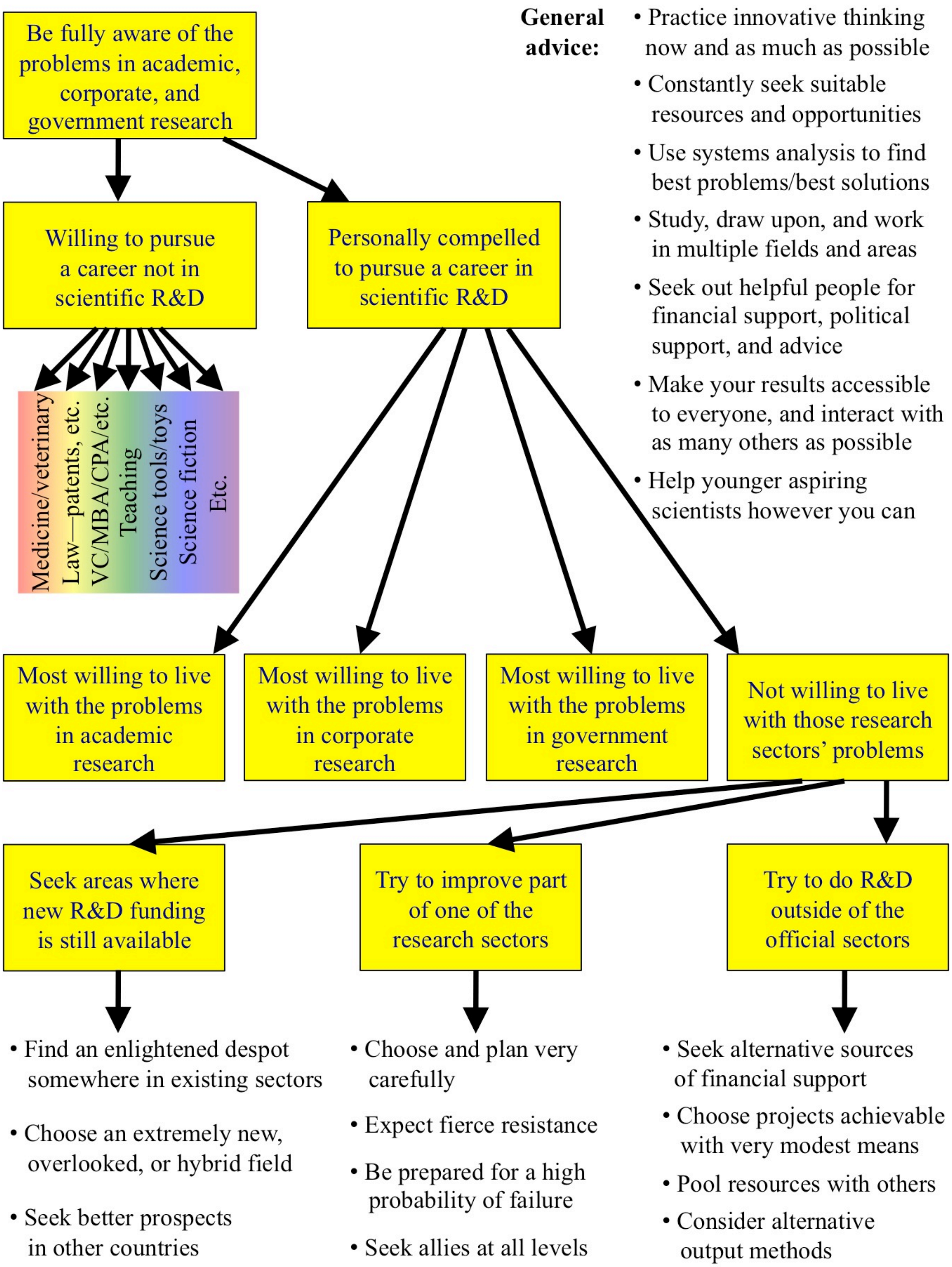


Figure 12.1: Options for individual scientists and engineers.

12.2.4 Lessons for Scholars of Past, Present, & Potential Future Innovation Systems

Due to limitations of time, resources, and length, this study could only give an overview of some of the issues involved in revolutionary scientific innovation in the historical German-speaking world and in the United States. Issues that were briefly introduced in this study deserve to be investigated and written up in far more detail. Many related areas could not be addressed at all in this study, yet warrant thorough exploration in their own right. For convenience, all of these issues for further study may be categorized on the basis of whether they primarily focus on past, present, or potential future innovation systems.

Some questions that should be further investigated by scholars of past innovation systems include:

1. What factors helped or hindered revolutionary scientific innovation in the German-speaking world:

   (a) Prior to 1800?

   (b) From 1800 to 1945? Is there other evidence to support or refute the factors proposed in Chapter 10? Is there evidence for major factors that were not considered in Chapter 10? (See p. 2042 for some possibilities.)

   (c) After 1945 (on both sides of the Iron Curtain)?

   How could knowledge about those historical factors be applied to improve modern innovation systems?

2. What factors helped or hindered the U.S. innovation system:

   (a) Prior to the 1940s?

   (b) During the 1940s–1960s? Is there other evidence to support or refute the factors proposed in Chapter 11? Is there evidence for major factors that were not considered in Chapter 11? (See p. 2042 for some possibilities.)

   (c) After the 1960s? Is there other evidence to support or refute the factors proposed in Chapter 11? Is there evidence for major factors that were not considered in Chapter 11?

   How could knowledge about those historical factors be applied to improve modern innovation systems?

3. What factors helped or hindered the historical innovation systems in:

   (a) United Kingdom?

   (b) France?

   (c) Russia/Soviet Union?

   (d) Scandinavian countries?

   (e) Italy?

   (f) Japan?

   (g) Other countries?

   How could knowledge about those historical factors be applied to improve modern innovation systems?

4. What were the major innovators, leaders, details, timeline, and maximum extent of the historical German-speaking world's contributions in:

   (a) Molecular and cellular biology, including DNA, RNA, proteins, immunology, cancer, antibiotics, vaccines, fermentation, biotechnology, offensive and defensive biological warfare, etc.?

   (b) Chemical weapons more advanced than tabun, sarin, and soman?

   (c) Microelectronics, including diodes, transistors, laser diodes, other semiconductor devices, printed circuits, integrated circuits, computers, robotics, guidance systems, encryption systems, photocopiers, etc.?

   (d) Directed energy technologies, including lasers, masers, ion beams, electron beams, neutron or other neutral particle beams, electromagnetic pulse, X-ray and gamma-ray beams, ultraviolet beams, infrared beams, microwave beams, acoustic beams, electric and/or magnetic railguns, etc.?

   (e) Nuclear technologies, including fission reactors, fission weapons, fusion reactors, fusion weapons, nuclear aircraft propulsion, nuclear rocket propulsion, nuclear submarine propulsion, transuranic isotope production and characterization, etc.?

   (f) Advanced aerospace technologies, including intercontinental jet aircraft, multistage rockets, intercontinental ballistic missiles, submarine-launched missiles, manned spacecraft, space planes and space shuttles, reentry systems, large liquid propellant rocket engines, solid propellant rockets, electric rocket propulsion technologies, and space stations?

   (g) Other areas in biology and medicine?

   (h) Other areas in chemistry and materials science?

(i) Other areas in earth and space science?

(j) Other areas in physics and applied mathematics?

(k) Other areas in electrical and electromagnetic engineering?

(l) Other areas in mechanical engineering?

(m) Other areas in nuclear science and technology?

(n) Other areas in aerospace engineering?

Because Allied documentation (foreign scientist case files; Alsos, BIOS, CIOS, FIAT, JIOA, and NavTecMisEu reports; etc.) on German and Austrian research is so extensive yet only accessible as paper documents in a few national archives, it would be extremely helpful if the German and Austrian governments would fund scholars to photograph or digitize those documents and make them available on the internet. Such a step would greatly enhance the general understanding of all of the above areas.

5. How did family traditions, immigration status, and cultural backgrounds affect the production of creators?

   (a) What aspects of Jewish family life in the early German-speaking and U.S. systems, East Asian or South Asian family life in the modern U.S. system, or other family backgrounds resulted in a far larger percentage of creators having those backgrounds than was true for the entire population in those countries?

   (b) What aspects of being an immigrant, or the descendant of people who immigrated in a recent previous generation (for example, parents or grandparents), resulted in a far larger percentage of creators having that background than was true for the entire population in those countries?

   (c) What aspects of the general culture in various countries made it less likely that children of families that had been in those countries for many generations would become successful scientific innovators? What cultural aspects encouraged children to be less intellectually driven, or if intellectually driven less inclined toward a career in scientific research, or if scientists less creative or less successful?

6. For the most successful scientific enlightened despots in the German-speaking world, early U.S. system, or other research systems:

   (a) How did the system select the best despots and measure their success during their careers?

   (b) What criteria and methods did the best despots use to select the most promising new innovators and innovations?

(c) What managerial, political, and financial methods did the despots use to ensure proper support for their own positions and for the scientists that they backed?

(d) How did the system best support the despots and the scientists that they backed?

7. What were the major creators, creations, innovation methods, and transfer methods involved in transferring innovations from the German-speaking world to:

    (a) Other countries before the Third Reich?

    (b) Other countries during the Third Reich?

    (c) The United States after the Third Reich?

    (d) The Soviet Union after the Third Reich?

    (e) The United Kingdom after the Third Reich?

    (f) France after the Third Reich?

    (g) Other countries after the Third Reich?

Some questions that should be further investigated by scholars of present innovation systems include:

1. What factors help or hinder the current innovation systems in:
   (a) The United States?
   (b) China?
   (c) Japan?
   (d) Germany?
   (e) South Korea?
   (f) India?
   (g) France?
   (h) United Kingdom?
   (i) Russia?
   (j) Singapore?
   (k) Other countries?

   How could knowledge about those factors be applied to improve the innovation systems in other countries?

2. What fractions of modern corporate R&D funding are spent on:
   (a) Products for which some version and/or competitor is already on the market?
   (b) Products that reach the market within one, two, three, four, five, or more years?
   (c) Products that never reach the market?

   How do those figures compare to statistics from earlier times or from other countries? What do the results say about the current level of innovation, creative risk, and long-term planning in the modern corporate R&D system?

3. On average, how much time does a modern principal investigator at a government-funded and/or government-run laboratory spend on:
   (a) Actual research—designing and carrying out experimental or theoretical research?
   (b) Work that is not actual research—writing grant applications, writing up progress reports and papers, seeking bureaucratic approvals, attending meetings, etc.?

How do those results compare with statistics from earlier times or from other countries?

4. On average, how much time does a modern university professor spend on:
   (a) Actual teaching?
   (b) Actual research—designing and carrying out experimental or theoretical research?
   (c) Work that is not actual research or teaching—writing grant applications, meeting with sponsors or donors, writing up progress reports and papers, serving on peer review committees, attending other meetings, etc.?

   How do those results compare with statistics from earlier times or from other countries? What do the results say about the quality of education and research in the modern academic system?

5. What is the average age at which a modern principal investigator is truly free (in a position of long-term employment; provided with sufficient funding, equipment, labor, and time; etc.) to propose and pursue their own entirely original scientific research projects? How do those results compare with statistics from earlier times or from other countries?

6. Why has the average cost of university education (at least in the United States, and possibly in other countries) risen much faster than the inflation rate for several decades? What fractions of those increases went toward administrators, buildings, university endowments, direct improvements in teaching, direct improvements in research, direct improvements in student life, etc.?

7. Why has the average cost of K-12 and university textbooks (at least in the United States, and possibly in other countries) risen much faster than the inflation rate for several decades? If publishers can profitably sell much lower-priced "international editions" of those same books outside of the United States, why can or do they not profitably sell editions of those books within the United States for the same lower prices? Why are textbooks so much more expensive than other types of books, even other types of books that require the same level of detail and editing as textbooks?

8. What fraction of the scientific work published each year is freely available online without registrations, memberships, subscriptions, pay-per-article firewalls, conference costs, having to find or purchase a copy of a book or journal, etc.?

Some questions that should be further investigated by scholars of potential future innovation systems include:

1. In addition to lessons that can be learned from past or present innovation systems, what entirely new strategies can be devised for improving innovation systems? How could those strategies be tested at a smaller scale to measure and optimize their effectiveness and to minimize any negative consequences before implementing them at a large scale?

2. Given the capabilities of the internet and the desirability to minimize costs while maximizing the accessibility and quality of education, what is the best system for university-level education and degrees?

3. What are the most effective ways to inspire young students to want to become scientific innovators?

4. What are the best strategies for finding the most innovative students and giving them the skills, resources, support, and freedom to create revolutionary innovations?

5. Are there better alternatives for research funding decisions than peer review? If some fraction of research funding and hiring decisions were entrusted to scientific enlightened despots, what would be the best way to select despots with the greatest discernment and skill? Even letting successful despots select new despots could lead to a decline in quality, like the gradual decline of early Christian popes or the abrupt end of the "Five Good Emperors" of the Roman Empire.

6. Are there better alternatives for publication than the current system of peer review in (mostly) highly specialized journals? What are the best ways to disseminate researchers' results while (a) enforcing standards for scientific quality, (b) making the results as widely and freely accessible as possible, and (c) reducing the glut of virtually unread and insignificant papers?

12.3 Afterword

I believe that the ability to create revolutionary scientific innovations is a noble and all-too-rare skill that has transformed the world (mostly for the better) over the past millennia, and that has the potential to further improve the world in the future. While a certain number of revolutionary scientific innovators can arise spontaneously in almost any environment and may sometimes find just the right opportunities to realize their creations, a far larger number of revolutionary innovators and innovations can be produced if there is a system that actively inspires and trains new revolutionary innovators, and then diligently supports and rewards them for developing revolutionary innovations. By researching, writing, and presenting this book, I have endeavored to offer what I hope is a new and useful perspective on the past, the present, and the possible future of systems for promoting revolutionary scientific innovation.

In science and engineering, it is helpful to represent complex signals or data as the sum of several different simple signals of steadily decreasing size and importance, with the simple individual signals sometimes interacting with each other in nonlinear and less easily predictable ways. Likewise, I believe it can be useful to view the complexities of history as the sum of many different simple forces and movements, from larger and more dominant ones to smaller and less significant ones; sometimes those simple individual historical forces interact with each other in nonlinear and less predictable ways.

The history of revolutionary scientific innovation covers the world, spans thousands of years, and includes countless individual larger and smaller forces as well as their nonlinear interactions. I have not even attempted to tackle that complete picture and that complete set of forces. Rather, I have endeavored to illuminate one of those individual forces, the predominantly German-speaking scientific world of the nineteenth and early twentieth centuries, which served as an engine for producing enormous numbers of revolutionary scientific innovators, who in turn produced huge numbers of revolutionary scientific innovations. I believe that most historians, scientists, and leaders have not had a proper understanding of the accomplishments, the methods, and the importance of that earlier German-speaking innovation engine.

Based upon data such as that summarized in this book, I would like to propose a theory, and to encourage others to consider it, modify it, prove it, disprove it, or offer alternatives to it:

> The German-speaking world of the nineteenth and early twentieth centuries was the strongest (though certainly not the only) engine for producing revolutionary scientific innovators during its time, and quite possibly even the strongest (but not only) such engine in all of history. That engine was carefully constructed and nurtured throughout the nineteenth and early twentieth centuries, but then was seriously damaged in 1933 and almost entirely dismantled in 1945.[2] Thus it ceased to produce many new revolutionary scientific innovators around

[2]The Third Reich drove out, fired, imprisoned, and/or killed a large fraction of the scientific innovators. Most of the remaining ones were mistreated and misused, even if some of their creations did receive lavish funding. The Third Reich also caused huge numbers of its students (many of whom would have become future scientists) and some of its existing scientists to die fighting in the war, made the schools and universities highly ideological and dysfunctional, and made scientists focus their energies solely on developing military projects without also refilling the research pipeline by training the next generation of innovators and making new discoveries in fundamental science. Even if the Third Reich had won the war, the German-speaking scientific world that had been so carefully cultivated by earlier generations would have been destroyed. As it was, the Third Reich lost, and most of the remaining scientists

1933–1945. (Rebuilding the German-speaking research world after 1945 took decades, and one could debate whether the rebuilt German-speaking research world more closely resembles the earlier German-speaking world or the rest of the postwar scientific world.)

Newly educated and empowered revolutionary scientific innovators tend to have rather specific visions of the revolutionary scientific innovations that they would like to create and perfect. Succeeding waves of innovators that were produced by the German-speaking world throughout the nineteenth and early twentieth centuries created and perfected succeeding waves of microbiology discoveries, applied chemistry methods, earth science discoveries, physics theories, electromagnetic devices, mechanical inventions, and early aircraft. The final wave of revolutionary innovators produced by the German-speaking engine before its 1933–1945 decline and demise immediately fixed their sights on antibiotics and biotechnology, synthetic drug molecules and polymers, high-energy physics and cosmology, microelectronics and computers, sophisticated automobiles and submarines, nuclear reactors and nuclear weapons, and jets and rockets. Beginning during the period 1933–1945 and continuing for the remaining decades of their careers, that final wave of German-speaking scientific innovators made those visions a reality, the fabric of the modern world in which we now live.

I would also like to suggest two corollaries to my theory for people to debate, and I believe that they too are supported by data such as that presented in this book:

1. If the German-speaking engine of the nineteenth and early twentieth centuries had never existed, most of the revolutionary innovators it produced would never have existed, and they would never have been able to create their revolutionary innovations. In that case, the state of science and engineering in the modern world might have been many years or even decades less advanced than it currently is. (Naturally, some revolutionary German-speaking innovators would have found a way to develop and to succeed even in the absence of a nurturing system, and the rest of the world would have continued to produce some revolutionary innovators and innovations, although I believe at a slower rate.)

2. The world's primary engine for producing revolutionary scientific innovators was one of the least recognized casualties of World War II, yet perhaps the one with the longest lasting and most widespread consequences. If the German-speaking engine had not been damaged and dismantled in 1933–1945, but rather had continued to function or even to grow, the state of science and engineering in the modern world might be decades more advanced than it currently is. What revolutionary scientific innovations would have been conceived and developed by the wave of new revolutionary innovators that the fully functional German-speaking engine might have produced by 1960? By 1980? By 2000? Today? What revolutionary medicines and materials might we have developed by now? What power sources and vehicles might we have had by now? How far might human settlements have ventured into the oceans and into space by now? (Of course, even after the end of the German-speaking engine in 1945, the world continued to produce some new revolutionary innovators and innovations, yet I would suggest not at the same rate as what the German-speaking engine had produced or what it might have continued to produce.)

and all of their innovations were removed and divided among the Allied countries, which generally used them up for short-term gain instead of leveraging them as a long-term investment to help create and support large numbers of new revolutionary innovators.

Nevertheless, the ultimate purpose of this book is not to get lost pondering the possibilities of the past, but rather to contemplate potential strategies for the future. If the world previously constructed an effective engine for creating huge numbers of revolutionary scientific innovators and innovations, it can assemble another such engine, or maybe even a better engine, now. We need not debate whether it is possible to create such an engine of revolutionary innovation. We need not wonder how we might build such an engine. We just need to fully remember the Forgotten Creators, and to learn all that we can from them.

Appendices

Es läßt sich wohl behaupten, daß die Geschichte der Wissenschaften die Wissenschaft selbst sei. Man kann dasjenige, was man besitzt, nicht rein erkennen, bis man das, was andere vor uns besessen, zu erkennen weiß.

It can be argued that the history of science is science itself. One cannot recognize clearly what one has found until one knows what others found before us.

Johann Wolfgang von Goethe [Schwenk 2000, p. 7].

1. In order not to obscure the book's arguments by simply referring readers to numerous documents that may be difficult to obtain, relevant excerpts from a large number of key sources are presented in the appendices.

2. To make the contents computer-searchable for readers and internet search engines, most documents have been retyped (with annotations as appropriate) instead of being reproduced as photographs.

3. Where I have retyped documents, I have tried to preserve the formatting of the original documents (underlining, etc.) as much as possible.

4. To avoid variant spellings that would not come up in a computer text search, I have silently corrected some obvious typographical errors in some of the quoted source documents. U.S. and U.K. documents that were typed during and shortly after World War II were often careless in their spellings of the German names of people and places.

5. In order to avoid increasing the length of this already enormous book by a factor of several fold, I have abridged portions of the documents that seemed less relevant, as denoted by [...] in the quoted text.

6. Where I wanted to add emphasis to passages in quoted documents to draw the attention of readers, I have displayed those passages in red. Even passages not in red are relevant, though, which is why I have taken the time to type them up and include them too.

7. To add my own commentary regarding quoted documents yet clearly distinguish my commentary from the text of the source documents, [my commentary appears in blue text inside square brackets].

8. Key sources not in English are presented in both their original language and a parallel English translation.

9. Citations direct interested readers to the original sources of these documents in case readers would like to verify their authenticity and read them in full.

10. Each source quote has been placed in the most relevant section, but it may be germane to other sections as well, as indicated by cross-references.

Appendix A

Advanced Creations in Biology and Medicine

Was war also das Leben? Es war Wärme, das Wärmeprodukt formerhaltender Bestandlosigkeit, ein Fieber der Materie, von welchem der Prozeß unaufhörlicher Zersetzung und Wiederherstellung unhaltbar verwickelt, unhaltbar kunstreich aufgebauter Eiweissmolekel begleitet war.

What then was life? It was warmth, the warmth generated by a form-preserving instability, a fever of matter, which accompanied the process of ceaseless decay and repair of protein molecules that were too impossibly complicated, too impossibly ingenious in structure.

Thomas Mann. 1924. *Der Zauberberg* [*The Magic Mountain*]. Chapter 5.
English translation adapted from H. T. Lowe-Porter.

This appendix presents portions of archival documents from during and immediately after World War II. These documents suggest that Germany:

A.1. Had the largest and most advanced biotechnology programs in the world at that time.

A.2. Was developing neural interfaces to control prosthetic limbs and weapons systems.

A.3. Possessed a significant offensive program in biological warfare.

A.4. Discovered advanced V-series nerve agents during the war.

Much more archival research is needed to elucidate the complete history and accomplishments of these programs.

A.1 Biotechnology

[A commonly held view among historians of science is that biotechnology was a postwar U.S./U.K. invention and that the German-speaking world was very late and far behind in pursuing biotechnology. For example, historian of science Luitgard Marschall summarized this view of biotechnology in Germany [Szöllösi-Janze 2001, pp. 112–114]:

> Owing to their theoretical foundation in organic chemistry, the research and production methods of chemical synthesis were regarded already at the beginning of the twentieth century as extremely science-based and therefore as modern and innovative. Biotechnology, in contrast, was for a long time considered to be an empirical and backward production technique, just because of its lack of theory and science-based methods [...]
>
> [B]etween 1933 and 1945 biotechnological processes were used only to compensate the deficits of chemical syntheses. Biotechnology was thus relegated to special processing niches. However, this relegation of biotechnological processes in favour of chemical ones had already started prior to 1933 and, after 1945, it culminated in further retardation. This of course indicates a continuous process. Nevertheless, the development in the Third Reich demonstrated particular features which had a lasting influence on the further course of biotechnology. [...]
>
> The metaphor of technological trajectories provides a viable explanatory model for the development of industrial biotechnology in Germany. As is well known, the German chemical industry decided early on to follow the path of chemical synthesis [...] This decision proved to be extraordinarily successful and contributed to its gaining a leading position in synthetic organic chemistry. It had some opportunity costs, however: up to now the fact has been ignored that the early commitment to chemical synthesis and its intensive expansion was detrimental to the development of biotechnology. For a long period in the twentieth century biotechnology played the part of a 'loser technology'. Its academic and industrial development was neglected in Germany until the 1970s in favour of chemical synthesis.

As shown in this section and in Chapter 2, there is a large amount of evidence that biotechnology and molecular biology (including knowledge, tools, methods, and applications) were developed by the German-speaking world in the nineteenth and early twentieth centuries, then transferred to the United States, United Kingdom, and other countries:

1. German-speaking scientists invented and perfected instruments suitable for biotechnology:

   (a) Carl Zeiss (German, 1816–1888), Ernst Abbe (German, 1840–1905), and Otto Schott (German, 1851–1935) perfected diffraction-limited optical microscopes during the 1870s–1880s (p. 1279).

   (b) In 1902, Richard Zsigmondy (Austrian, 1865–1929) and Henry Siedentopf (German, 1872-1940) invented the ultramicroscope for determining particle sizes in colloids; see p. 1280.

   (c) August Köhler (German, 1866–1948) and Moritz von Rohr (German, 1868–1940) invented the ultraviolet microscope in 1904, as shown on p. 1281.

(d) August Köhler and Henry Siedentopf invented the fluorescence microscope in 1908 (p. 1282). Fluorescence microscopes are now a widespread tool in biology laboratories because different cellular components can be labeled with different colors of fluorescent tags.

(e) Karl Bratuschek (German?, 1865–1913) at the Zeiss company was apparently moving toward the development of phase contrast microscopy before his death [Wimmer 2017]. Frits Zernike (Dutch, 1888–1966) invented phase contrast microscopes in 1933, and they were mass produced by Zeiss (pp. 1283, 2486–2496).

(f) In 1926, Hans Busch (German, 1884–1973) created the first electrostatic and magnetic lenses for electrons. From 1931 onward, four different groups, all in the greater Berlin area, built and demonstrated electron microscopes: Technische Hochschule Berlin, Siemens & Halske, Allgemeine Elektrizität Gesellschaft (AEG), and Manfred von Ardenne (German, 1907–1997). See pp. 1298–1304.

(g) Fritz Pregl (Austrian, 1869–1930) developed micro-pipetting and micro-analysis tools and methods in the 1910s (pp. 479, 2332–2336).

(h) Scientists from the German-speaking world invented and used centrifuges for a large range of applications from 1864 through World War II (pp. 2406–2411).

(i) German-speaking scientists harnessed focused sound waves for a wide variety of applications, ranging from the first ultrasound imaging devices to ultrasonic sonicators to disrupt chemical solutions and molecules. Documents in Section C.4 demonstrate that those technologies were developed and successfully demonstrated in Germany and Austria during the 1930s and early 1940s, and then directly transferred to other countries in 1945, leading to modern acoustic and ultrasound devices.

(j) Robert Havemann (German, 1910–1982) invented spectrophotometers no later than 1936 (pp. 2390–2400). He also conducted important research on colloids (p. 725).

(k) P. H. Keck (German?, 19??–19??) invented luminometers no later than 1943 (pp. 2458–2459).

(l) In 1940 or earlier, Andreas Lembke (German, 1911–2002), Hellmuth Bayha (German?, 19??–19??), Karl Krammer (German?, 19??–19??), Eugen Sauter (German?, 19??–19??), and other scientists developed and successfully implemented methods of using intense ultraviolet light to sterilize liquids and other materials (pp. 2379–2385).

2. German-speaking scientists discovered most of the major types of bacteria and developed antiseptics and antibiotics to prevent or treat bacterial infections:

   (a) With newly improved microscopes (Section 6.9), it became much easier to see organisms as small as bacteria. However, a remaining problem was that most bacteria are essentially clear, and surrounded by essentially clear liquid or other sample material. Therefore, scientists in the German-speaking world developed methods that stained bacteria different colors than the surrounding sample material, making it much easier to visualize their shapes and identify them under the microscope. Scientists who developed important early microscope staining techniques for bacteria included Karl Weigert (German, 1845–1904), Paul Ehrlich (German, 1854–1915), and Robert Koch (German, 1843–1910), as shown on p. 167.

(b) In 1872, Ferdinand Cohn (German, 1828–1898, p. 168) created the modern classification system for bacterial shapes (spheres or cocci, rods or bacilli, spirals or spirochetes, etc.).

(c) Based on the earlier stains, Hans Christian Gram (Danish but worked and made his discovery in Germany, 1853–1938, p. 167) developed the "Gram staining" method in Berlin in 1884 while working with Carl Friedländer (German, 1847–1887, p. 175). Gram staining is still widely used to distinguish between bacteria with two different types of cell walls, "Gram-positive" bacteria that turn purple with this technique and "Gram-negative" bacteria that turn red. The ability to distinguish between Gram-positive and Gram-negative bacteria, and among bacteria with different shapes, was and remains a powerful method to identify bacteria under the microscope (p. 164).

(d) Robert Koch (German, 1843–1910) and many other German-speaking scientists discovered most of the common pathogenic types of bacteria (pp. 165–177).

(e) In 1847 (approximately two decades before Joseph Lister), Ignaz Semmelweis (Austrian, 1818–1865) developed and demonstrated antiseptics to prevent bacterial infections (pp. 165–166).

(f) Paul Ehrlich (German, 1854–1915) discovered Salvarsan, the first antibiotic, in 1909 and successfully used it to treat syphilis (p. 188).

(g) Gerhard Domagk (German, 1895–1964) discovered and demonstrated sulfa antibiotics, the first broad-spectrum antibiotics, in 1932. The large sulfa family of antibiotics is still widely used today (p. 189).

(h) Ernst Chain (German, 1906–1979) purified penicillin in 1940 (p. 190), taking penicillin from an effect that could only be demonstrated in Petri dishes to an effective antibiotic that could be mass-produced and administered to people.

(i) Richard Kuhn (Austrian, 1900–1967) produced and tested synthetic antibiotics such as "3065" during World War II, using massively parallel chemical synthesis and testing to carry out very modern methods of structure-activity relationship (SAR) optimization of the drug molecules (pp. 191, 2337, 2364, 2401, 2418–2423).

3. German-speaking scientists developed methods of culturing and utilizing prokaryotic (bacteria) and eukaryotic (yeast, animal, and plant) cells:

(a) Working together with Robert Koch, Julius Petri (German, 1852–1921) invented Petri dishes in 1881. In that same year, spouses Fanny Hesse (born of German parents in the United States, lived in Germany, 1850–1934) and Walther Hesse (German, 1846–1911) developed agar nutrient gel to fill those dishes [Brock 1999; Schlegel 2004]. The agar provides a solid surface that does not decay to a messy liquid as microorganisms grow on it. Agar-filled Petri dishes are now virtually ubiquitous in biology laboratories for culturing microorganisms.

(b) By 1890, Carl Wehmer (1858–1935) was using yeast fermentation to produce citric acid, fumaric acid, and other substances [Benninga 1990]. See pp. 2327–2331.

(c) Otto Röhm (German, 1876–1939) and his company Röhm and Haas developed industrial-scale culture of microorganisms to produce and purify enzymes (proteases, starch hydrolases, pectinases, lipases, etc.) for many different commercial applications during the period from 1906 through World War II (pp. 2460–2464).

(d) Franz Schardinger (Austrian, 1853–1920) used bacterial fermentation to produce acetone (1903–1904). See p. 181 for some of his publications demonstrating his methods and results.

(e) In 1910, Chaim Azriel Weizmann (Belarus, educated and worked in Germany and Switzerland, 1874–1952) began internationally popularizing Schardinger's methods of using bacterial fermentation to produce acetone (p. 184). (Sometimes international credit was given to Weizmann for popularizing these methods, but not to Schardinger for first inventing, demonstrating, and publishing these methods.)

(f) In the early twentieth century, bioreactors for the continuous liquid culture of microorganisms were developed by scientists at Benkiser, Boehringer, I.G. Farben, Phrix, Röhm and Haas, and other German companies and laboratories (pp. 2338–2351, 2413–2416, 2424, 2460–2464).

(g) In the 1940s, the use of bioreactors for the continuous liquid culture of microorganisms was internationally popularized by German-speaking refugees such as Ernst Chain (German, 1906–1979, working in the United Kingdom) and Leo Szilard (Hungarian, 1898–1964, working in the United States, p. 184), and also by Allied investigators who wrote numerous reports on the German biotechnology industry (pp. 2413–2416, 2424).

(h) German-speaking scientists developed methods of isolating cells from larger organisms and using "tissue culture" methods to keep those cells alive and even get them to reproduce under laboratory conditions (p. 87). Wilhelm Roux (German, 1850–1924) conducted the first animal cell tissue culture experiments in 1885, removing medullary plate cells from a chicken embryo and keeping them alive in culture for 13 days. Paul Grawitz (German, 1850–1932) experimented with tissue culture of additional animal cell types in the 1890s. Gottlieb Haberlandt (Austrian, 1854–1945) developed plant cell tissue culture and also discovered totipotency, the ability of some "stem" cells to give rise to any type of specialized cell in an organism, in 1902.

4. German-speaking scientists made key discoveries regarding viruses:

(a) Peter Plett (German states, 1766–1823) developed and successfully demonstrated a cowpox-based vaccine for smallpox virus beginning in the late 1780s, and first reported his results in 1790. Edward Jenner (English, 1749–1823) rediscovered the same thing several years later, and published his first results in 1798. Yet Jenner became famous as the discoverer of smallpox vaccine, and Plett has been virtually forgotten [Plett 2006]. See p. 195.

(b) German-speaking scientists discovered and characterized tobacco mosaic virus from 1886 onward (pp. 196–197).

(c) From 1897 onward, German-speaking scientists discovered and characterized foot-and-mouth disease virus, produced therapeutic antibodies for it, created vaccines for it, demonstrated a tissue culture model for it, and developed immunoassays for it (pp. 198–200).

(d) German-speaking scientists discovered and characterized poliovirus from 1908 onward (pp. 201–202).

(e) German-speaking scientists pioneered the study of bacteriophages, viruses that infect bacteria, and made numerous other contributions to virology (pp. 201–203).

5. German-speaking scientists discovered and analyzed nucleic acids (DNA and RNA):

(a) Gregor Mendel (Austrian, 1822–1884) discovered the rules of genetics using plants he grew at his monastery (1864 or earlier), and meticulously documented his discoveries and explanations in a lengthy book. See p. 97.

(b) In 1869, Johannes Friedrich Miescher (Swiss, 1844–1895) extracted and purified DNA (which he called nuclein) from human white blood cells and suggested that DNA is involved in heredity (p. 98).

(c) Walther Flemming (German, 1843–1905) made detailed observations of chromosomes during mitotic cell division from 1873 onward (p. 99).

(d) Beginning in the 1870s, Albrecht Kossel (German, 1853–1927) showed that DNA and RNA contain five different bases (adenine, cytosine, guanine, thymine, and uracil), demonstrated that those bases are connected via linkages of sugars and phosphates, and isolated and studied proteins that bind to nucleic acids in the nucleus (histones and other accessory proteins). See p. 100.

(e) No later than 1907, Wilhelm Weinberg (German, 1862–1937) discovered the equilibrium distribution of alleles (different versions of a gene) within a population of a species (p. 101).

(f) In 1933 or earlier, Ernst Caspari (German, 1909–1988), Alfred Kühn (German, 1885–1968), Adolf Butenandt (German, 1903–1995), and other researchers in Germany analyzed mutations in insects and discovered that individual genes encode individual proteins (pp. 102–103).

(g) In a revolutionary 1935 paper, Max Delbrück (German, 1906–1981), Nikolai Timoféeff-Ressovsky (Russian but worked in Germany 1925–1945, lived 1900–1981), and Karl Günter Zimmer (German, 1911–1988) at the Kaiser Wilhelm Society in Berlin described and demonstrated the structure of chromosomal DNA, methods and consequences of inducing point mutations in DNA, and forced genetic recombination of different pieces of DNA (p. 104).

(h) In or before 1940 (under wartime conditions and 13 years before the discovery by Rosalind Franklin, Francis Crick, and James Watson), Hans Friedrich-Freksa (German, 1906–1973) proposed that the structure of DNA is double-stranded with electrostatic attraction between complementary sequences on the two strands (p. 105).

(i) By 1940–1942, and also despite the severe wartime hindrances, Gerhard Schramm (German, 1910–1969) identified the genome of the tobacco mosaic virus as RNA, showed that its protein subunits are identical, and mutated the RNA to create mutant proteins (p. 106).

(j) Many other German-speaking scientists also made significant contributions to knowledge about DNA and RNA (pp. 107–113).

6. German-speaking scientists pioneered the study, diagnosis, prevention, and treatment of cancer:

(a) During the period 1889–1891, Erik Johan Widmark (Swedish but closely coupled to the German-speaking research world, 1850–1909) and Friedrich Hammer (German, 1860–1943) demonstrated via a series of experiments that ultraviolet light causes suntans and sunburns, and that those effects could be reduced by coating the skin with a protective layer of certain natural plant extracts (p. 126).

(b) Leopold Freund (Austrian, 1868–1943) and Eduard Schiff (Austrian, 1849–1913) developed and employed radiation therapy to kill tumors from 1896 onward (pp. 1519–1520). Freund wrote the first medical textbook on radiation therapy in 1902 and published it in 1903 [Leopold Freund 1903]. Translations of the book in English and other languages were published in 1904, so Freund truly founded and shaped the field of radiation therapy worldwide.

(c) Theodor Boveri (German, 1862–1915) realized in 1902 that cancer can be caused by pro-mitotic (cell-division-inducing) mutations from radiation, chemicals, or viruses (pp. 114–118).

(d) In 1922, Leopold Freund and Josef Maria Eder (Austrian, 1855–1944) invented the first chemical sunscreen, which was marketed as Antilux (p. 127).

(e) Fritz Lickint (German, 1898–1960) began medical studies of smokers vs. nonsmokers in the 1920s, published evidence that smoking causes cancer in 1929, and published a >1200 page medical book on the detailed pathology caused by smoking in 1939 (p. 119). His discoveries led to public health campaigns against smoking, first in Germany and much later worldwide [Haustein 2004].

(f) German-speaking scientists identified specific carcinogens from the 1870s through World War II and developed methods to control and prevent exposure (pp. 114–125, 2387–2386).

(g) By the early 1940s, German-speaking scientists developed therapeutic antibodies against cancer-related antigens (pp. 2366–2371). Such therapeutic antibodies are currently one of the most modern and most effective methods of treating cancers in patients.

(h) German-speaking scientists also made many other significant contributions to knowledge about cancer (pp. 120–125).

7. German-speaking scientists characterized and harnessed proteins and enzymes:

(a) Wilhelm Kühne (German, 1837–1900) was one of the first scientists to study proteins in detail (p. 129). He discovered trypsin, a digestive enzyme or protease that degrades other proteins, studied proteins in muscle and rhodopsin in human photoreceptor cells, and in fact coined the word “enzyme” (p. 139).

(b) Franz Hofmeister (Austrian, 1850–1922) established many methods of protein chemistry that are still used today (Fig. 2.43). He discovered the peptide bonds in proteins, the effect of various salts on proteins, differing protein solubilities, methods of protein purification, and methods of protein crystallization [Abernethy 1967].

(c) Beginning in the 1870s, Albrecht Kossel (German, 1853–1927) showed that proteins are composed of amino acids, and isolated and characterized the individual amino acids (p. 141).

(d) German-speaking scientists invented immunoassays (229). Max von Gruber (Austrian, 1853–1927) discovered the agglutination reaction, in which antibodies and pathogens clump together, in 1896. Rudolf Kraus (Austrian, 1868–1932) used the agglutination reaction to create an antibody assay for specific bacterial precipitins in 1897. August von Wasserman (German, 1866–1925) used similar methods to create a complement fixation test for syphilis bacteria in 1906.

(e) In 1912, Leonor Michaelis (German, 1875–1949) and Maud Menten (Canadian, worked in Germany, 1879–1960) developed experimental and theoretical methods to analyze the chemical reaction rates of enzymes (p. 143).

(f) Otto Röhm (German, 1876–1939) pioneered the industrial production, purification, and use of enzymes (proteases, starch hydrolases, pectinases, lipases, etc.) for applications such as leather production (1906), washing detergents (1914), pharmaceuticals (1920), and juice processing (1934). See pp. 2365, 2457, 2460–2464.

(g) Starting in the 1910s, Max Bergmann (German, 1886–1944) created methods of determining the amino acid sequences of natural proteins and of artificially synthesizing proteins with specific amino acid sequences (p. 131).

(h) German-speaking scientists played leading roles in discovering and understanding the enzymes involved in mitochondria, cellular respiration, and related metabolic reactions (pp. 157–160).

(i) In the 1930s and early 1940s, German-speaking scientists developed several egg protein substitutes that consisted of protein extracted, purified, and processed on an industrial scale from cultured yeast, animal blood plasma (Plenora), fish (Eiweiss), and milk (Milei). See pp. 2338–2351, 2402–2405, 2412–2413.

(j) Max Perutz (Austrian, 1914–2002) developed and demonstrated methods of determining detailed three-dimensional protein structures such as hemoglobin (p. 145).

(k) German-speaking scientists also made many other contributions to knowledge about proteins and enzymes (pp. 136–138).

8. In addition to all of the above production, German-speaking scientists produced and purified a wide range of other biomolecules for many different applications:

(a) In the 1930s and early 1940s, many German-speaking scientists developed artificial methods to produce lipids or fats for foods, soaps, fuels, and other products. Glycerin, sterols, fatty acids, and triglycerides were produced from chemical synthesis on an industrial scale and sold for food products and other applications [BIOS 86; BIOS 805; FIAT 213; FIAT 407]. See p. 524.

(b) Fats were produced and purified from various strains of cultured algae and fungi using biotechnology methods [BIOS 236; BIOS 691; FIAT 371]. In addition to the food applications, this appears to have been the origin of algal and other microbial biofuel technologies. See pp. 2338–2351, 2373–2376, 2442–2456.

(c) Artificially produced fats were used to make a variety of food products, including cooking oil, cooking fat (shortening), margarine, creamer, salad oil, chocolate [Clarke 1946], synthetic human milk (infant formula) [FIAT 107], etc.

(d) Both the natural science and the practical applications of steroid hormones were developed almost entirely by creators from the greater German-speaking world.[1] See pp. 360–369. The discoveries regarding these hormones had revolutionary, immediate, and long-lasting implications, making possible the creation of pregnancy tests (1927), oral contraceptives (1930), menopause treatments, anabolic steroids, anti-inflammatory steroid drugs, blood pressure medications, therapeutics for high cholesterol, etc.

(e) German-speaking scientists made virtually all of the key discoveries regarding the role of insulin in controlling and preventing diabetes.[2] See pp. 375–376.

(f) During World War II, German-speaking scientists developed freeze-dried human blood for transfusions (pp. 2366–2370).

(g) Also during the war, German-speaking scientists invented and widely used periston synthetic blood plasma (pp. 342–343, 2352–2363, 2430–2441). They created capain synthetic blood plasma too (p. 344).

(h) German-speaking scientists made most of the major discoveries regarding vitamins and their production.[3] See pp. 351–352.

(i) German-speaking scientists developed most of the major preservatives that are still widely used in foods, pharmaceuticals, and biotechnology reagents, such as: (1) Ascorbic acid (vitamin C), which was identified in 1930 by Albert Szent-Györgyi (Hungarian, 1893–1986) and mass-produced via chemical synthesis in 1933 by Tadeusz Reichstein (Polish, educated and worked in Switzerland, 1897–1996). (2) Benzoic acid, which was first analyzed in 1832 by Friedrich Wöhler (German, 1800–1882) and Justus von Liebig (German, 1803–1873). (3) Citric acid, which was first produced from fermentation in fungi in 1890 by Carl Wehmer (German, 1858–1935). (4) Sorbic acid, which was discovered in 1859 by August Wilhelm von Hofmann (German, 1818–1892). (5) Ethylenediaminetetraacetic acid (EDTA), which was synthesized and demonstrated in 1935 by Ferdinand Münz (Austrian, 1888–1969). See pp. 528–529.

(j) German-speaking chemists developed artificial methods of producing caffeine, including from direct chemical synthesis [FIAT 885] and from the conversion of uric acid harvested from snake urine [BIOS 449]. See pp. 520, 2366–2367.

(k) A wide variety of other biomolecules were also produced (for example, see p. 2378).

Thus the available evidence shows that most aspects of biotechnology and molecular biology were developed in the German-speaking world, and that the German-speaking world was the leader in those areas through World War II.

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[1] Butenandt 1931; Dominguez-Lacasa 2005; Gausemeier 2005; Jahn 2004; Junker 2004; Karlson 1990; Koesling and Schülke 2010; Kohler 2008; Magner 2002; Marks 2010; Possehl 1989; Raviña and Kubinyi 2011; Schieder and Trunk 2004; Schneider 1972; von Schwerin 2013; Sneader 2005; Stoff 2012; Taschwer 2016; Weatherall 1991.

[2] Bliss 2007, pp. 25–31; Meienhofer 1963; Mellinghoff 1971, 1972; von Schwerin et al. 2013, pp. 151–155; Sneader 2005, pp. 164–166.

[3] Jahn 2004; Junker 2004; Kohler 2008; Magner 2002; von Schwerin 2013; Sneader 2005; Stoff 2012; Weatherall 1991.

The evidence also shows that knowledge, methods, and materials for biotechnology and molecular biology were transferred to other countries:

- Before the Third Reich, in the form of published and patented information, German-speaking companies (e.g., Röhm and Haas) that transferred technologies to other countries, some scientists (e.g., Carl and Gerty Cori, Chaim Weizmann) who moved to other countries, and scientists from other countries who received part of their education in the German-speaking world.

- During the Third Reich, in the form of published and patented information and also many key scientists (Charlotte Auerbach, Max Bergmann, Ernst Chain, Erwin Chargaff, Max Delbrück, George Gamow, Richard Goldschmidt, Hans Krebs, Max Perutz, Albert Szent-Györgyi, Leo Szilard, etc.) who fled to other countries.

- After the Third Reich, in the form of huge numbers of scientists who moved to other countries, Allied seizures of German and Austrian plants and documents, and Allied reports (BIOS, CIOS, FIAT, etc.) on German and Austrian technologies.

Due to length constraints, this section and Chapter 2 can only briefly mention a limited number of examples. Hopefully other authors will more fully investigate and report the history and contributions of German-speaking scientists to the development of biotechnology and molecular biology.]

H. Benninga. 1990. *A History of Lactic Acid Making: A Chapter in the History of Biotechnology.* Dordrecht: Kluwer.

In 1893 a short communication from the hands of Carl Wehmer appeared about citric acid fermentation in the Bulletin de la Société Chimique de France[...] In the same year he applied for patents in Great Britain (British Patent 5620, granted in 1893) and in Germany (German Patent 72,957, granted in 1894); the "Fabriques de Produits Chimiques de Thann et de Mulhouse" was registered as the owner of both patents.

In the communication to the "Bulletin" Wehmer reported that he had already begun the experiments in 1890, and now was able to produce citric acid on a 10 kg scale. [...]

The first metabolic product obtained by Wehmer was oxalic acid. This acid is present in many plants and in molds as well, which sometimes produce it in appreciable quantities.

The next metabolic acid of importance he discovered was citric acid. Two species of fungi which he denominated *Citromyces*—but today are included in the genus *Penicillium*—were able to produce interesting quantities of citric acid when grown on 10% sugar solutions. Wehmer immediately recognized the practical importance of his findings and applied for patents.

[Wehmer also pioneered the use of cultured fungal cells to produce fumaric acid and possibly other substances as well. See pp. 2328–2331.]

N° 146. — Note sur la fermentation citrique ;
par M. Charles WEHMER.

Les fermentations acides provoquées par les champignons filamenteux ne sont connues que pour des cas isolés, et quoique le phénomène le mieux étudié de cette catégorie, la formation oxalique, puisse être de quelque intérêt, j'estime que la fermentation citrique en a davantage. En effet, d'après mes expériences et en observant les conditions les plus favorables, il se trouve que l'acide citrique est un produit de sécrétion de quelques moisissures. Ce phénomène est une fermentation dans le genre de celle provoquée par certaines bactéries qui sécrètent les acides acétique et lactique. L'acide citrique, répandu dans le règne végétal, n'a pas encore été observé comme produit de fermentation, et le nombre des acides organiques obtenus de cette façon est restreint. Les observations que j'ai recueillies dans cet ordre d'idées sont en substance les suivantes :

Si l'on abandonne des solutions sucrées, de composition déterminée, à l'action de certains champignons, ceux-ci transforment aussitôt une partie plus ou moins grande de l'hydrate de carbone en un acide qui, chimiquement, est identique à celui que renferme le jus de citron ; on l'obtient aisément sous forme cristalline. La production de cet acide citrique de fermentation n'est pas différente, dans ses traits les plus saillants, de celles par lesquelles on obtient les acides d'un autre genre ; mais les conditions jouent dans le cas particulier un rôle essentiel.

J'ai déterminé, pour le travail qui nous occupe, deux espèces de champignons, et il se trouve que nous sommes en présence d'organismes qui ont échappé à l'observation des savants, en partie, par la raison évidente de la petite dimension de leurs organes reproducteurs et, plus encore, à leur ressemblance macroscopique frappante avec les espèces ordinaires connues.

Ces moisissures apparaissent sur le terrain qui leur convient, sous forme de tissus verts, très compacts, dont on ne distingue de différence avec les espèces du penicillium que grâce au concours du microscope, différence caractérisée, d'ailleurs, par leurs caractères physiologiques. Les différences morphologiques des deux espèces similaires sont difficiles à trouver.

Je propose d'appeler ce genre nouveau de moisissures *citromycètes*, et je désigne ces deux espèces pour les distinguer par C. pfefferianus et C. glaber ; la première en l'honneur de M. le

Figure A.1: Carl Wehmer pioneered the use of cultured fungal cells to produce citric acid and other substances [*Bulletin de la Société Chimique de France* 9:728–730 (1893)].

professeur Pfeffer, à Leipzig; la dernière par suite de l'aspect uni de la surface des tissus qu'elle présente.

Les spores de ces espèces sont très répandues dans l'air, de sorte que leur sélection par cultures dans différents endroits [à Hanovre et à Thann (Alsace)] me réussit fort bien. Je les ai eues aussi sous la main à Leipzig, quoique n'en connaissant pas la nature; c'est là, soit dit en passant, en 1890, que je fis les premières observations concernant l'acide citrique, à l'Institut botanique.

Les liquides sucrés, les fruits, etc. fournissent un bon support pour ces moisissures; on doit les rencontrer encore à la surface de substances de nature semblable, quoique je n'en puisse donner la preuve.

J'en ai étudié de très près la morphologie, l'histoire de leur développement, la physiologie; ces observations se trouvent décrites ailleurs (1). Je ne relèverai ici que quelques points caractéristiques qui concernent l'acidification et la croissance par rapport au liquide nourricier, à la température et à l'oxygène.

Les solutions sucrées sont pour tous deux le terrain le plus propice, la matière première la plus favorable. L'énergie de croissance est telle, à la température convenable, qu'on ne connaît que peu d'organismes de ce genre comparables à eux. Il en est de même de la fermentation. Le manque d'oxygène exclut la germination et le développement des conidies, son atténuation arrête la croissance, le besoin d'oxygène de ces champignons est très marqué. Des traces d'acides minéraux agissent aussi défavorablement sur leur développement; il n'en est pas de même de l'acide citrique libre qui est sans action dans des solutions atteignant de 5 jusqu'à 8 0/0 et que l'on rencontre très fréquemment dans les cultures. La durée de germination des conidies, conservées dans un endroit sec, dépasse un an; les variations brusques de température détruisent en peu de temps les jeunes tissus.

Le procédé de dédoublement acide est influencé de différentes manières, il est intéressant à plusieurs points de vue, et peut être régularisé dans son abondance, à volonté. Il n'existe pas de rapport entre la fermentation et la croissance, car l'une peut se passer de l'autre. Des tours de mains de nature particulière, la présence de certains sels (chlorures), la saturation surtout de l'acide formé ne sont pas sans influence et accélèrent en général l'échange.

(1) Beiträge zur Kunstriess einheimischer Pilze truci neve Hyphomyuten als Erreger einer Citromusaüre Gährung; Mit 2 Tafeln Hannover 1893, Verlag der Hahnech1 Buckhanlung.

Figure A.2: Carl Wehmer pioneered the use of cultured fungal cells to produce citric acid and other substances [*Bulletin de la Société Chimique de France* 9:728–730 (1893)].

720 MÉMOIRES PRÉSENTÉS A LA SOCIÉTÉ CHIMIQUE.

La périodicité provoquée par les relations déterminées que nous venons d'énumérer dans le cours de ce qui vient d'être dit, embrasse aussi les fonctions acides qui, suivant les circonstances, peuvent être de longue ou de courte durée.

Elles durent d'ailleurs aussi longtemps que les phénomènes vitaux sont en jeu dans l'intérieur du tissu. L'intensité est telle, si les proportions sont bien choisies, que 50 0/0 du sucre sont transformés en acide citrique. Un essai sur une certaine échelle comportant 11 kilogrammes de sucre produisit 6 kilogrammes d'acide. Il ne se forme pas dans ces conditions d'autres produits organiques secondaires.

La séparation d'une quantité d'acide citrique aussi importante n'exerce pas d'influence sur la croissance de l'organisme Ce fait mérite d'être rapproché d'une observation analogue que j'ai faite à l'occasion de la fermentation oxalique (1).

Dans ce cas, l'acide carbonique se produit-il aux dépens de la molécule citrique ? C'est une hypothèse probable, que je ne discuterai cependant pas ici, car la disparition finale de l'acide citrique pourrait être expliquée d'une autre façon. Je reviendrai ailleurs sur cette question, qui a son importance en ce qui concerne l'explication du phénomène de la respiration; elle offre peut-être plus d'intérêt que la simple discussion d'autres hypothèses.

La composition chimique de notre acide (chaîne à carbone anormale) rend la théorie de semblables phénomènes intéressante, mais ce n'est pas le lieu d'en parler, pas plus que de l'importance industrielle possible que peut avoir le procédé de fabrication de l'acide citrique, dont les résultats ne sont pas encore établis (2).

Figure A.3: Carl Wehmer pioneered the use of cultured fungal cells to produce citric acid and other substances [*Bulletin de la Société Chimique de France* 9:728–730 (1893)].

SCHWEIZERISCHE EIDGENOSSENSCHAFT

EIDGEN. AMT FÜR GEISTIGES EIGENTUM

PATENTSCHRIFT

Veröffentlicht am 1. Oktober 1921

Nr. 90955 (Gesuch eingereicht: 22. Juni 1920, 20 Uhr.) Klasse 36 o

HAUPTPATENT

Prof. Dr. Carl WEHMER, Hannover (Deutschland).

Verfahren zur Darstellung von Fumarsäure durch Gärung von Zucker.

Die Erfindung betrifft ein Verfahren zur Darstellung von Fumarsäure durch Gärung aus Zucker.

Der Patentinhaber hat gefunden, daß man Zucker, z. B. Maltose, Dextrose und insbesondere Rohrzucker, durch Gärung mittelst des Aspergillus fumaricus bis zu 80 % in Fumarsäure überführen kann. Gleich wie bei anderen Säuregärungen wird die entstehende freie Säure durch zugesetzte Kreide oder andere Neutralisationsmittel abgestumpft. Am Schlusse wird die Fumarsäure durch eine stärkere Säure in Freiheit gesetzt. Der als Aspergillus fumaricus bezeichnete Pilz ist die Laboratoriumsrasse einer von Soja-Bohnen aus Ost-Asien stammenden Schimmelform, die in bekannter Weise gezüchtet wird. Mit Hilfe dieses Pilzes gelingt es zum Beispiel, Rohrzuckerlösungen mit hoher Ausbeute auf Fumarsäure zu vergären, so daß im Mittel 123 % des Zuckers an rohem Calciumfumarat (Maximum bis ca. 160 %) erhalten wurden. Man verfährt also zweckmäßig in der Weise, daß die durch Aufkochen steril gemachten Zuckerlösungen beliebiger Konzentration in geeigneten Gefäßen nach Zugabe eines Neutralisationsmittels, wie Kreide oder dergleichen, mit einer Reinkultur geimpft werden. Bei Verwendung von reinem Zucker sind die üblichen Pilznährstoffe zuzusetzen. Die Pilzentwicklung verläuft unter sonst günstigen Verhältnissen in wenigen Tagen. Die entstehende freie Fumarsäure löst die zugesetzte Kreide unter Gasentwicklung allmählich auf; an ihrer Stelle erscheinen alsdann derbe Krusten von kristallisiertem fumarsaurem Kalk. Nach Trennung von der Flüssigkeit wird aus ihnen durch Schwefelsäure freie kristallisierte Fumarsäure abgeschieden. Die erhältliche Fumarsäure ist in ihren Eigenschaften mit der käuflichen Säure übereinstimmend, sie sublimiert oberhalb 200° unzersetzt in feinen Nädelchen. Der Schmelzpunkt liegt beim Schmelzen in geschlossenen Röhrchen bei ca. 278°.

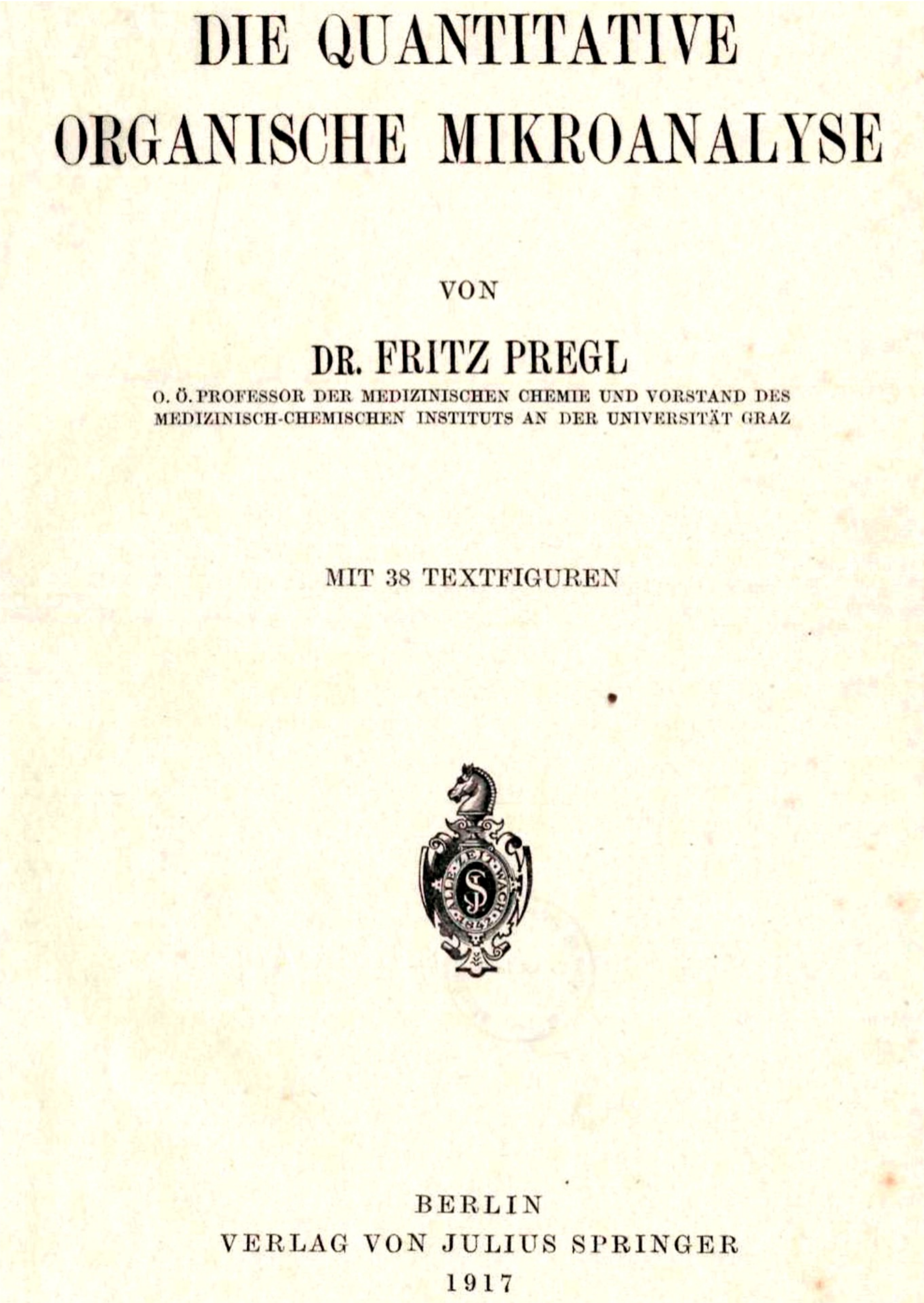
Beispiel:

Eine Lösung von 100 Teilen Zucker in 1 Liter Wasser wird nach Zusatz von 25 gr Kreide und den üblichen Pilznährstoffen mit einer Kultur des Fumarsäurepilzes geimpft. In 2—3 Wochen langer Gärung bei 20° scheiden sich rund 120 gr Calciumfumarat ab, aus dem durch Schwefelsäure die Fumarsäure freigemacht und durch Lösen in Alkohol und Filtrieren der Lösung vom Gips getrennt wird. Man kann auch das Kalksalz zunächst in das Bleisalz überführen und dieses durch Schwefelwasserstoff zerlegen.

PATENTANSPRUCH:

Verfahren zur Darstellung von Fumarsäure durch Gärung aus Zucker, dadurch gekennzeichnet, daß man eine Zuckerlösung mittelst Aspergillus fumaricus vergärt, die dabei entstehende freie Fumarsäure durch zugesetzte Neutralisationsmittel bindet und hierauf durch eine stärkere Säure in Freiheit setzt.

Figure A.4: Carl Wehmer pioneered the use of cultured fungal cells to produce fumaric acid and other substances [Swiss patent CH 90,955].



DIE QUANTITATIVE
ORGANISCHE MIKROANALYSE

VON

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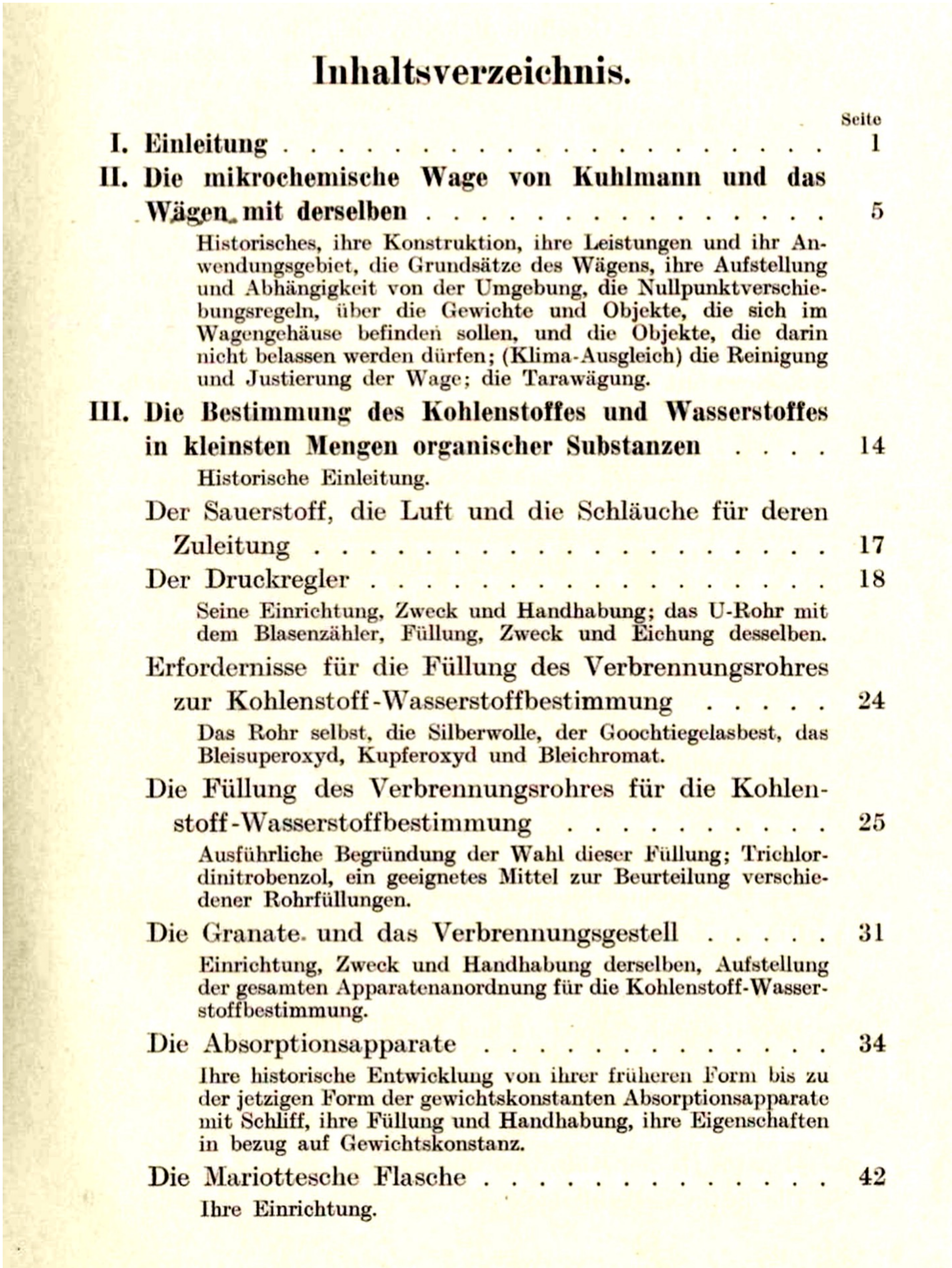
MEDIZINISCH-CHEMISCHEN INSTITUTS AN DER UNIVERSITÄT GRAZ

MIT 38 TEXTFIGUREN

BERLIN
VERLAG VON JULIUS SPRINGER
1917

Figure A.5: In the 1910s, Fritz Pregl developed micro-pipetting and micro-analysis tools and methods that are now used in virtually all biology and chemistry laboratories [Pregl 1917].



Inhaltsverzeichnis.

Figure A.6: In the 1910s, Fritz Pregl developed micro-pipetting and micro-analysis tools and methods that are now used in virtually all biology and chemistry laboratories [Pregl 1917].

VIII Inhaltsverzeichnis.

Figure A.7: In the 1910s, Fritz Pregl developed micro-pipetting and micro-analysis tools and methods that are now used in virtually all biology and chemistry laboratories [Pregl 1917].

Die Bestimmung des Molekulargewichtes in kleinen Mengen organ. Substanz.

konzentrischer Lage gegeneinander zu erhalten, während der größte, der äußere Cy_1, auf dem vorerwähnten großen Metallteller seinen Platz findet. Die Anordnung dieser drei Zylinder ist ohne weiteres aus den beistehenden Zeichnungen ersichtlich. Ihre Dimensionen sind: Der äußere hat eine Höhe von 140 mm und einen Durchmesser von 84 mm, der zweite eine Höhe von 120 mm und einen Durchmesser von 48 mm, der dritte, der innerste, ist ein oben abgeschnittener Rundbrenner-Lampenzylinder von 110 mm Höhe und einem Durchmesser an der Basis von 36 mm und im zylindrischen Teil von 26 mm. Über seiner verjüngten Stelle ist ein kreisrundes Kupfer- oder Messingdrahtnetz *Dr* angebracht, um den hier aufsteigenden Luftstrom in seinem ganzen Querschnitt gleichmäßig zu erwärmen. Über diesen ist an seinem oberen Ende ein vierter einfacher Zylinder Cy_4 von 26 mm Höhe und einem Durchmesser von 36 mm mittels dreier dazwischengelegter Asbestpappestreifen darüberge-

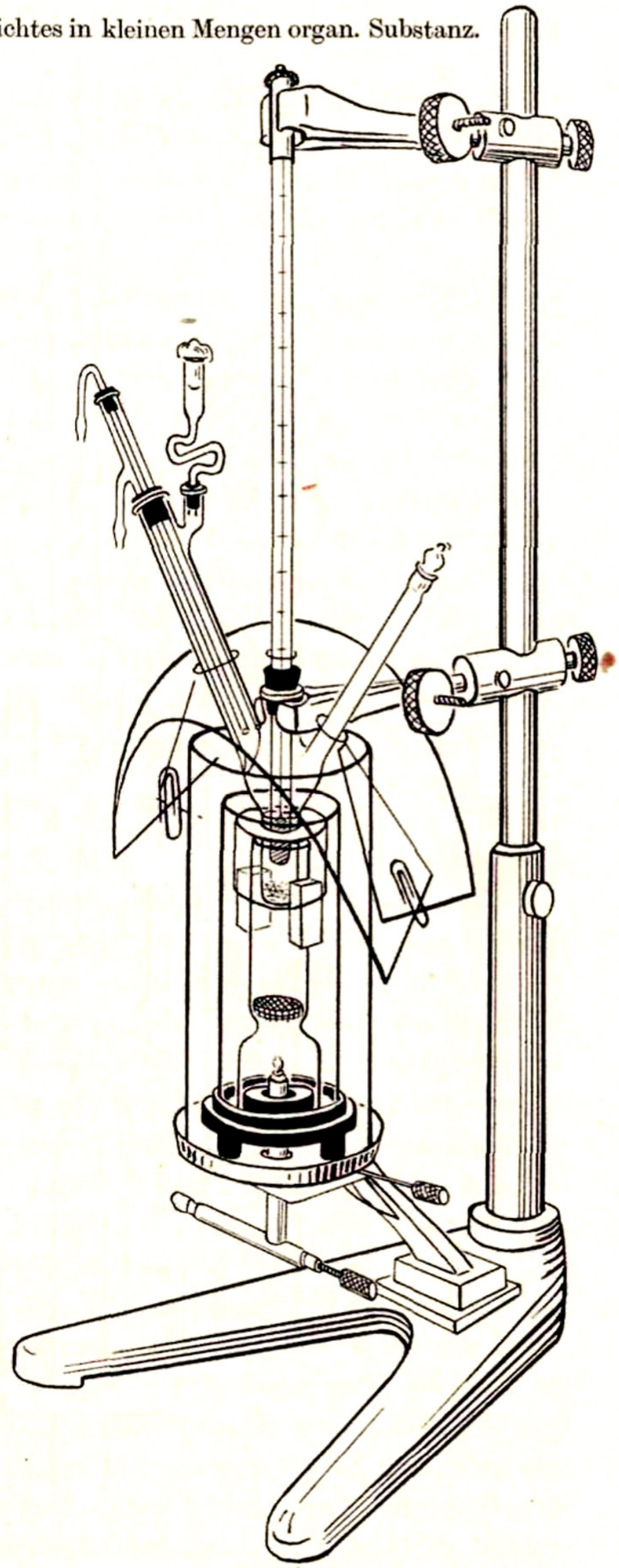
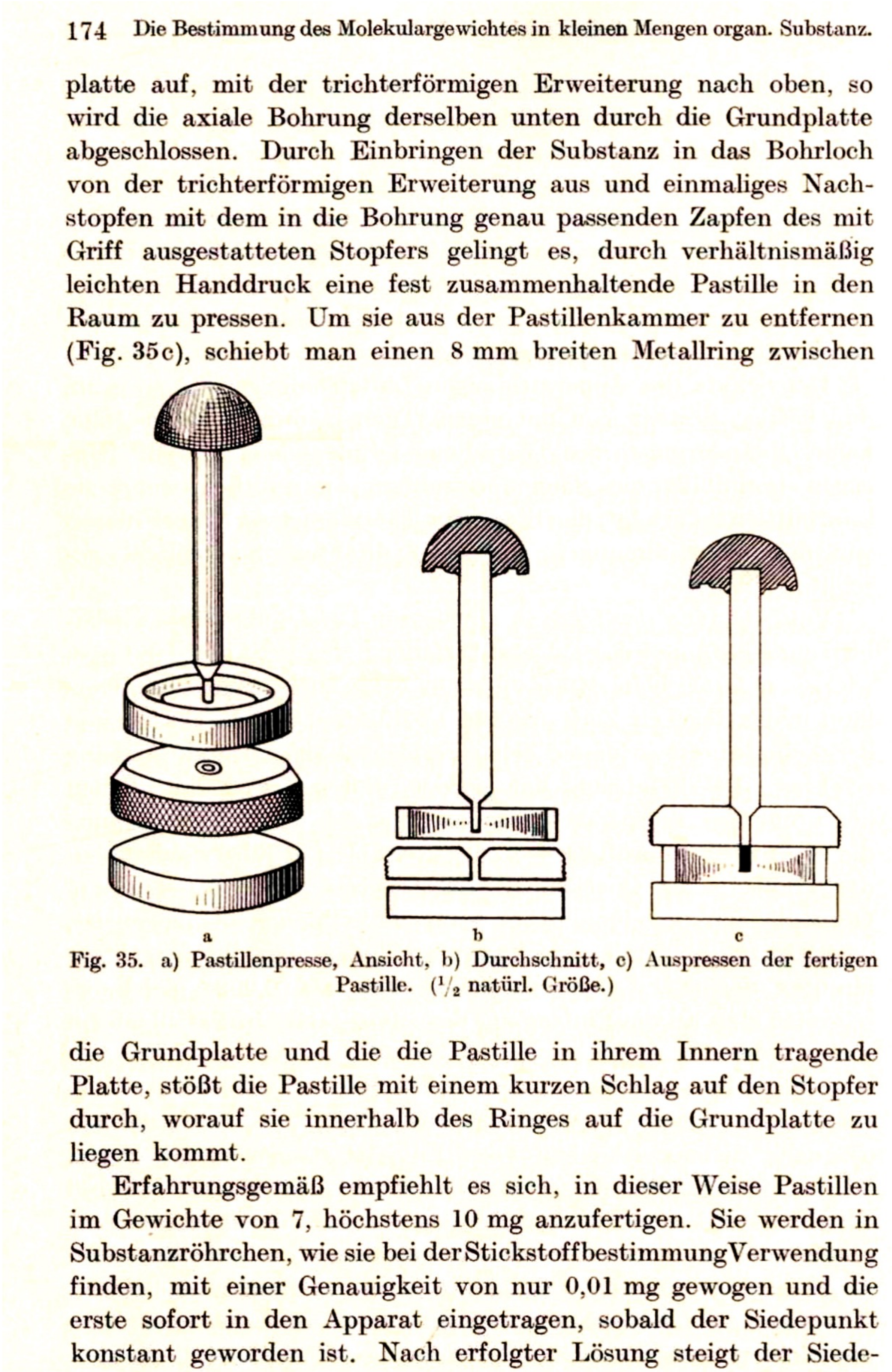


Fig. 33. Apparat zur Bestimmung des Molekulargewichtes aus der Siedepunktserhöhung an kleinen Substanzmengen. (1/4 natürl. Größe.)

Figure A.8: In the 1910s, Fritz Pregl developed micro-pipetting and micro-analysis tools and methods that are now used in virtually all biology and chemistry laboratories [Pregl 1917].



174 Die Bestimmung des Molekulargewichtes in kleinen Mengen organ. Substanz.

platte auf, mit der trichterförmigen Erweiterung nach oben, so wird die axiale Bohrung derselben unten durch die Grundplatte abgeschlossen. Durch Einbringen der Substanz in das Bohrloch von der trichterförmigen Erweiterung aus und einmaliges Nachstopfen mit dem in die Bohrung genau passenden Zapfen des mit Griff ausgestatteten Stopfers gelingt es, durch verhältnismäßig leichten Handdruck eine fest zusammenhaltende Pastille in den Raum zu pressen. Um sie aus der Pastillenkammer zu entfernen (Fig. 35c), schiebt man einen 8 mm breiten Metallring zwischen

a b c

Fig. 35. a) Pastillenpresse, Ansicht, b) Durchschnitt, c) Auspressen der fertigen Pastille. ($^1/_2$ natürl. Größe.)

die Grundplatte und die die Pastille in ihrem Innern tragende Platte, stößt die Pastille mit einem kurzen Schlag auf den Stopfer durch, worauf sie innerhalb des Ringes auf die Grundplatte zu liegen kommt.

Erfahrungsgemäß empfiehlt es sich, in dieser Weise Pastillen im Gewichte von 7, höchstens 10 mg anzufertigen. Sie werden in Substanzröhrchen, wie sie bei der Stickstoffbestimmung Verwendung finden, mit einer Genauigkeit von nur 0,01 mg gewogen und die erste sofort in den Apparat eingetragen, sobald der Siedepunkt konstant geworden ist. Nach erfolgter Lösung steigt der Siede-

Figure A.9: In the 1910s, Fritz Pregl developed micro-pipetting and micro-analysis tools and methods that are now used in virtually all biology and chemistry laboratories [Pregl 1917].

BIOS 219. *Work on Synthesis and Production of Drugs 3065 (2:2^1-Dihydroxy-5:5^1-Dibrome Benzil) and 3214 (2:2^1-Dihydroxy-3:3^1-5:5^1-Tetrachlor Benzil).*

The M.L.D. of 3065 is one gram per kilogram which is almost the same as sulphapyridine.

[Richard Kuhn] stated that 3065 is the first compound found to be effective against Rickettsia virus and Influenza virus strain A. These experiments have been carried out at Marburg. In a typical experiment on mice infected with Influenza virus strain A, all the treated animals survived whereas all the control group were dead within 6–7 days.

A number of cases of Gonorrhea had responded to treatment with 3065 after being unsuccessfully treated with the sulphonamides.

The main clinical trials on 3065 have been on amputations, thoracoplastic work, and ruptured appendices. Summaries of some of these clinical trials are given in Appendix II.

Prof. Kuhn stated that the drug was first prepared at the end of 1943, and asked about cost he was of the opinion that it would be more expensive than the sulpha drugs.

After the discussion on the drug work inspection was made of the laboratories and the following three items of general interest noted.

1. Prof. Zimmerman, who was working at the I.G. Farben in Ludwigshafen, developed during the war an automatic micro-analysis apparatus which is capable of carrying out 16 micro-analyses per day. Details of this apparatus have not been published and Prof. Kuhn was of the opinion that it would be rather difficult to obtain the essential details of construction.

2. The attack on potatoes by the Colorado Beetle has been a severe problem during the war. The work carried out under the supervision of Kuhn has revealed that an alkaloid can be extracted from the leaves of resistant types of potatoes, bred at an agricultural station near Heidelberg, but there has been no evidence that this substance occurs in plants that are attacked.

3. Kapsenberg Caps. The caps have been developed and used as an alternative to cotton wool plugs in bacteriological tubes and according to Kuhn have entirely supplanted the use of cotton wool at the K.W.I. The caps are made from aluminium and the attached sketch gives some idea of their construction.

   [...] According to Ambros he was simply making 3065 as a personal favor for Kuhn since they are close friends. [...]

   In vitro experiments with 3065 and Burroughs-Wellcome penicillin which had been captured from the British Army showed that 3065 was 300 times more effective against staphylococcus aureus. Ambros pointed out, however, that they did not know the history of [the] penicillin so that it may have undergone some deterioration before they got it. Also the difference in solubility between the two compounds made comparison difficult. A clinical test carried out on a leg amputation wound has shown that 3065 was five to six times more effective than Marfinil.

   Naturally he was not able to give any figures on cost since the material had only been made in the laboratory, but he seemed to think that it would be produced for something like 10–20 Marks per kilogram.

BIOS 236. ***Developments in Pure and Applied Microbiology (American, British and French Zones) During World War II.***

SECTION "A"

DEVELOPMENTS IN PURE AND APPLIED MICROBIOLOGY IN GERMANY (AMERICAN, FRENCH & BRITISH ZONES) DURING WORLD WAR II

[...T]he study of industrial microbiology is really in its infancy, and developments are to a large extent dependent on the outcome of fundamental investigations in research laboratories. A considerable part of the work of the [BIOS] team was therefore concerned with the review of relevant investigations in agricultural experiment stations, universities and other research institutions. [...]

Prof. [F.] Rindel's interests cover a wide field. His earlier work was in the field of pure organic chemistry, and he had within recent years revised Richter's textbook on Organic Chemistry. From a study of the chemistry of various microbiological products, his interests had extended to many nutritional problems. A list of his publications during the war period is given below (5 to 10), but his contacts with microbiological research extended beyond the subjects of these papers.

On the subject of food yeast and other protein preparations of microbiological origin he gave the following information and opinions:

(a) Lactose-fermenting strains of yeast had been isolated which yielded 52 Kg of protein per 100 Kg lactose. These were of no use for bakery purposes, but other lactose-fermenting yeasts had been isolated which would give good gas-production when whey is incorporated in bread dough.

(b) Yeast protein is lacking in cysteine and when fed alone to rats, causes liver damage. The authority for this statement was given as Dr. Fink, who had been associated with the development of the fermentation of wood sugar by Torulopsis utilis and was now stated to be with the Irex Company at Fulbach. Later a similar view was expressed by Prof Lembke of Kiel (see report on protein production by micro-organisms issued separately).

(c) Food yeast grown on waste sulphite liquor from wood pulp had frequently been found to contain lead to the extent of 70 to 80 parts per million (determined by dithizone).

(d) Organisms other than Torulopsis utilis had been used to produce protein for food purposes, e.g. Oidium lactis at a factory at Lenzing, Austria (reference to our visit to this factory is included in our separate report), and Aspergillus sp. at a factory at Traunstein, between Salzburg and Munch. (It was not possible to devote time to locating this factory). Prof Reindel was dubious about using such protein preparations as food until it had been established that they are free from anti-biotic substances. [...]

From the industrial standpoint, the work of most significance appeared to be that on fat production by micro-organisms. An undeveloped observation was that yeasts of the genus Nectaromyces give high fat yields (10 to 15 g per 100 g. sugar utilized) when cultivated by the aeration procedure used for Torulopsis utilis and other yeasts used for food purposes or bread fermentation.

Prof Rippel had recently completed an advanced textbook on the physiology and morphology of micro-organisms which was to have been published by J. Springer of Berlin. [...]

Prof Dr. S. Strugger, however, had been transferred to this institute from the Botanical Institute of the University of Jena, where his work had been financed by the firm Carl Zeiss. He is a cytologist and one of the editors of the journal "Protoplasma". During the war he had been developing the technique of fluorescence microscopy, using Zeiss apparatus with quartz lenses [...], and had also studied methods of vital staining of bacterial cells and spermatozoa using acridine-orange[...] The technique was demonstrated to us and appear to be rapid and reliable for application to the control of certain industrial fermentations. [...]

SECTION "B"

PRODUCTION OF PROTEIN BY MICROBIOLOGICAL METHODS

[...] During the war the German food economy was particularly short of proteins and fat. An intensive effort was therefore made to overcome part of this deficiency through the production of micro-organisms which could be grown on carbohydrates present in whey or the waste liquors from pulp mills. In addition plants were erected to hydrolyse wood cellulose to sugars for this purpose and the necessary nitrogen was supplied in the form of inorganic ammonium salts. This report summarises the processes used in three industrial plants for the production of proteins and does not claim to be comprehensive. The first section deals with production of wood sugars by the Bergius process using concentrated hydrochloric acid. Following this is an account of the Scholler process in which dilute sulphuric acid is used to saccharify wood. On the medium obtained Torula utilis was grown to produce proteins. The third section describes a process used in a wood pulp plant whereby Oidium lactis was grown on waste sulphite liquor for the same purpose. The use of this product as human food had not met with approval and, although on industrial scale, the process was really still experimental.

The final report deals with some of the laboratory research leading up to the cultivation of moulds for their nutritive qualities. [...]

A short interview with Dr. [Andreas] Lembke in the Sanatorium indicated that he had carried on considerable research work on the question of cultivating mould for the production of protein. He stated that during the first World War, his predecessor, Professor Henneberg had begun the cultivation of yeasts for use in protein supplement while working in the Garungewerbe Institute of Berlin. He had also discovered that urea could be fed to cows with beneficial results as a source of nitrogen. After Prof. Henneberg's death in 1936 his work was continued by Prof. Lembke in Kiel.

Prof. Lembke's interest in this work centred around the nature of the amino acids produced by yeasts and moulds. He cultivated many different strains of moulds but found that only a few races were rich in cysteine, methionine and glutathione. Since most yeasts being grown for protein production were very low in cysteine he was anxious to select other organisms which were rich in this particular amino acid. He claims to have had success in obtaining cultures of several moulds which met these requirements.

Strains of Fusarium, Candida, Oidium, Endomyces and Rhizopus were cultured and both wet and dry powdered preparations were made for use in feeding experiments. Some of these products were smoked like bacon or sausages and he said they were quite edible. Being a doctor of medicine as well as a microbiologist, he conducted nutritional studies and claimed that feeding up to 60 grams per day for over 6 months had been beneficial. He stated that the general health of the group of people fed on these proteins was better than the controls.

In feeding experiments he said that it was very important that the moulds should be heated or autolysed before eating them, otherwise they caused diarrhoea.

Of the different moulds used in this work Prof. Lembke thought Fusarium was probably the most satisfactory. He said the East Munich Dairy Station was growing Fusarium on whey. It was also quite satisfactory when grown on waste sulphite liquor. [...]

SECTION "C"

PRODUCTION OF FATS BY MICROBIOLOGICAL METHODS

The process showed some novel feature with regard to the cultivation of a mould [Oidium lactis] for high fat production and with regard to the combination of different types of waste material used.

SECTION "D"

ORGANIC ACID MANUFACTURE BY MICROBIOLOGICAL METHODS IN GERMANY

[...] This firm was equipped for preparing lactic, gluconic and citric acids by microbiological methods, but was not producing these at the time of the inspection, owing to shortage of fuel. The plant had in each case been installed prior to the war, that for citric acid immediately prior to the war. [...]

The firm Boehringer was established in Wurtemberg over a century ago and was concerned originally with the manufacture of tartaric acid and tartrates from wine byproducts. A branch was established in Oberingelheim in 1885 to manufacture lactic acid by a fermentating process and the firm claims to be a pioneer in this field. Subsequently other fermentation processes were introduced, and a large section of the firm is now concerned with the manufacture of pharmaceutical preparations by chemical methods. This last aspect of the firm's activities was outside the scope of our investigations.

REPORT IV

Laboratory Investigations on Proteins from Micro-Organisms

Laboratory Visited

Bacteriologisches Institut der Preussischen Versuchs Forschungsanstalt für Milchwirtschaft

Location

Kiel.

Date of Visit

3 Oct 45

Personnel Interviewed

Professor Andre Lembke, Director

The Bacteriological Institute in Kiel was found to have suffered extensive bomb damage. The Directors office had been destroyed and it was impossible to determine from the staff still working in the Institute whether or not any of the records had been salvaged. Apparently routine water, food and milk analysis were still being carried on but there was no research work in progress. It was learned, however, that the Director was in a Sanatorium at Tonsheide, near the town of Innien.

A short interview with Dr. Lembke in the Sanatorium indicated that he had carried on considerable research work on the question of cultivating mould for the production of protein. He stated that during the first World War, his predecessor, Professor Henneberg had begun the cultivation of yeasts for use in protein supplement while working in the Garungewerbe Institute in Berlin. He had also discovered that urea could be fed to cows with beneficial results as a source of nitrogen. After Prof. Henneberg's death in 1936 his work was continued by Prof. Lembke in Kiel.

Prof. Lembke's interest in this work centred around the nature of the amino acids produced by yeasts and moulds. He cultivated many different strains of moulds but found that only a few races were rich in cysteine, methionine and glutathione. Since most yeasts being grown for protein production were very low in cysteine he was anxious to select other organisms which were

Figure A.10: Biotechnology methods for producing and purifying edible protein from cultured yeast [BIOS 236].

rich in this particular amino acid. He claims to have had success in obtaining cultures of several moulds which met these requirements.

Strains of Fusarium Candida, Oidium, Endomyces and Rhizopus were cultured and both wet and dry powdered preparations were made for use in feeding experiments. Some of these products were smoked like bacon or sausages and he said they were quite edible. Being a doctor of medicine as well as a microbiologist, he conducted nutritional studies and claimed that feeding up to 60 grams per day for over 6 months had been beneficial. He stated that the general health of the group of people fed on these proteins was better than the controls.

In feeding experiments he said that it was very important that the moulds should be heated or autolysed before eating them, otherwise they caused diarrhoea.

Of the different moulds used in this work Prof. Lembke thought Fusarium was probably the most satisfactory. He said the East Munich Dairy Station was growing Fusarium on whey. It was also quite satisfactory when grown on waste sulphite liquor. Rhizopus produced a product with a different content of salts and fats and had a rather pronounced odour but this could be overcome by heating it strongly.

Since Prof. Lembke might be able to salvaged records and cultured if he was allowed to return to the Institute in Kiel, for a visit we arranged with J.Parlane, Regional Food Office, 312 P Det Mil Gov., Hamburg, B.A.O.R. to keep in touch with him and endeavour to get a more detailed account of this research work. We also requested that, if at all possible, cultures of these high cysteine races of moulds should be procured.

Figure A.11: Biotechnology methods for producing and purifying edible protein from cultured yeast [BIOS 236].

SECTION "C"

C22/2056

PRODUCTION OF FATS BY MICROBIOLOGICAL METHODS

Reported by

D.H.F.CLAYSON - BIOS (British Ministry of Food)
G.A.LEDINGHAM - BIOS (Canadian Dept of Reconstruction)

with acknowledgements to A.K.BALLS (U.S.A. Dept of Agriculture who was also present)

Production of Fat from Oidium Lactis

Plant Visited

Biologisch Chemisch Gesellschaft m.b.H. C22/2056

Location

Bad Tölz

Date of Visit

11 and 15 Sep 45

Object of Visit

To obtain information on the laboratory and pilot plant scale production of fat from OIDIUM LACTIS

Summary

The process showed some novel features with regard to the cultivation of a mould for high fat production and with regard to the combination of different types of waste material.used.

Personnel Interviewed

Geheimrat Jungel - Director
Dr. H. Jungel - Director
Herr Stoeb - Unqualified Chemical Engineer

General

From information received from Prof. Fromel and Prof. Schropp at Weinstephan Agricultural College,

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Figure A.12: Biotechnology methods for producing and purifying lipids from cultured yeast [BIOS 236].

Freising, it was learned that fundamental work on fat production by moulds had been carried out by the late Prof. Niklas and that Dr. Stark, who happened to be at Wienstephan at the time, could give more information. Dr. Stark stated that he had only been associated with the work for a short time, and that it had been carried out mainly by a laboratory assistant named Stoeb. This man was traced at Bad Tolz and is referred to later in this report.

There is also a Dr. K.Koch of Munich who wrote an article on the conversion of carbohydrates to fats by micro-organism (Fette u.Seifen 1943, 50(10/477) but this name was not mentioned and the article in question was not seen until our return to England. Later in our tour it was found that Prof. Dr. A. Rippel of Göttingen had also been concerned with some preliminary work on this question; this is referred to in a separate report on developments in pure and applied microbiology in Germany.

The location of the Biologisch Chemische Gesellschaft was traced, after some difficulty, by a remark by the superintendent of the German police in Bad Tolz that a Geheimrat Jungel had sponsored a public lecture on food yeast during the war.

Geheimrat Jungel and his son Dr. Hans Jungel were first visited at their country home at Bohmerhof, near Bad Tolz. Apparently they had contacts with the Bergius wood sugar plant of the Suddeutsche Holzverzucherung Werke A.G. at Regensburg through their interests in the Heyden Corporation. Dr. Jungel had been in American before the outbreak of war. He had recently been released from the German army and had formed a company of his own, the "Biologische Chemische Gesellschaft m.b.H., with headquarters at Bad Tölz. A small laboratory containing equipment for biological and chemical experimental work and some larger equipment for pilot plant operations had been installed in an adjoining building. Jungel had procured the services of an engineer, Herr Stoeb, the man mentioned above, who had formerly worked in the capacity of laboratory assistant on fat and protein production in the Technical High School in Munich with Prof. Niklas.

On September 15th, at the laboratory in Bad Tölz processes were described for the utilization of whey from cheese factories and straw or oat hulls, separately or in conjunction, for the cultivation of fat-producing moulds. This work was obviously still in the experimental stage but the methods used, especially for the utilization of

Figure A.13: Biotechnology methods for producing and purifying lipids from cultured yeast [BIOS 236].

straw, are worth while noting.

(a) Whey as a Fermentation Medium

Cheese whey is treated with sulphuric acid to precipitate the lactalbumin. This precipitate is then dried as a feeding material but the yield is only 0.5%. After removal of the proteins a small amount of ammonium phosphate is added and Oidium lactis is grown on the medium. Fat production takes place best in a mat of mycelium freely exposed to air, hence the organism was grown on canvas sheets, the backs of which were sprayed with the nutrient medium. The procedure is discussed more fully later in this report.

(b) Straw Hydrolyzates as Fermentation Media

Several different processes appear to have been experimented with in order to obtain a suitable fermentation medium from straw or oats hulls. The aim of this work appeared to be to develop a process whereby fermentable sugars could be extracted, and a high-protein cellulosic residue prepared for feeding livestock. Either straw or oat hulls could be used, though the latter were preferred since they required less processing. Oat hulls contain more pentosans extractable with 1.5% H_2SO_4 in 5 to 6 hours, without pressure cooking, than straw. It was claimed that, from 100 kilos of oat hulls, it was possible to obtain 40 to 45 kilos of sugars in a 7% solution. The process outlined for straw however, was really a modification of the Bergius process, using 70 to 72% H_2SO_4. When we were at the laboratory the process was not in operation, and the description given below is that of their experience from previous operations.

Stage 1

Wood sawdust or straw is treated with an equal weight of H_2SO_4 at concentrations between 50 and 72% at 20°C for 30 hours. This treatment is sufficient to hydrolyze practically all the polysaccharides present and leave a lignin precipitate.

Stage 2

The liquors from stage 1 are diluted with water to a 5% acid concentration (and presumably filtered to remove the lignin fraction.) This acid sugar solution is applied to fresh straw which is cooked at 125°C (1 atmosphere pressure) for 90 minutes. Only part of

Figure A.14: Biotechnology methods for producing and purifying lipids from cultured yeast [BIOS 236].

the straw polysaccharides are saccharified by this process but the solution is further enriched by these readily soluble fractions.

Stage 3

The solution from stage 2 is then partially neutralized with NaOH and is diluted with water until it contains 6 to 7% sugars. The slightly acid solution is heated and treated with rock phosphate, thereby introducing soluble phosphate to the medium. After filtration to remove $CaSO_4$, nutrient salts in the form of a small amount of $MgSO_4$ and ammonium salts (introducing nitrogen equivalent to 2% of the sugar) are added. The growth of the mould was said to be favoured by the presence of lactate, and acetate ions. It appeared that they contemplated introducing these in the form of whey fermented by Lactobacillus pentoaceticus or by growing this organism symbiotically with Oidium. The final pH of the medium was 4.5 to 5.0.

Stage 4 - Fermentation

The organism used was a specially selected strain of Oidium lactis (Oosphora lactis). It was grown for test purposes on strips of canvas hung in a wooden chamber. The temperature was thermostatically controlled at 25°C. The solution was sprayed on one side of the canvas sheets and allowed to flow down to a tank from which it was re-circulated. Spore inoculum was sprayed on the opposite side of the canvas and a thick mat of mycelium developed. After 5 days growth it was scraped off and treated with methyl alcohol to remove water and liberate the fat. The fat was subsequently extracted with trichlorethylene, after first boiling off the methanol. The same process was used for cultivating the mould on whey.

For larger scale production amodified apparatus was being developed in which the canvas sheets were replaced by a continuous canvas band, fastened at the sides to roller chains which passed over 6 pairs of sprockets, thus giving tortuous path and exposing a large canvas surface. The fermentation medium was distributed, with continuous re-circulation, from a shallow perforated tray at one point on the inside of the canvas band. The fungus developed on the outside where it could be readily scraped off by a stationary knife.

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Figure A.15: Biotechnology methods for producing and purifying lipids from cultured yeast [BIOS 236].

Stage 5 - Utilization of Residues

The residues from dilute acid hydrolysis of straw (Stage 2) are treated with 1.3% sodium hydroxide, as in the preparation of straw pulp, to remove some lignin and render the pulp more digestible. The protein content of this cellulosic material was then enhanced by one or more of the following treatments:-

(a) Addition of the lactalbumin fraction from whey.

(b) Addition of the residues from the extracted Oidium mycelial mats

(c) Addition of 15 kilos of sugar beets and other nutrients to 100 kilos of residue, followed by inoculation with Aspergillus oryzae. This treatment (c) was claimed to give a product containing 15% of digestible proteins, as determined by feeding experiments conducted elsehwere. The alkaline extract from the straw residue was neutralized by mixing it with the liquors after re-circulation over the Oidium mat, thus precipitating lignin (which was filtered off and dried). The filtrates, containing lactate and acetate is then used in preparation of fresh culture media for growth of Oidium or, alternatively, for treatment of the cellulosic residues before inoculation with Aspergillus oryzae.

Conclustions

The following yield figures, calculated from the pilot plant operations described above, were given by Dr. Jungel:-

100 tons of crude straw (82% dry substance) would yield

31 tons of utilizable sugar, from which one would obtain
15 tons of fat-containing mycelial dry substance.
From this
5 tons of fat could be extracted, leaving a residue of
10 tons of protein-rich fat-free mycelial dry substance.
The same
100 tons of crude straw would also yield
44 tons of dry cellulosic residues, and
7 tons of salts and nitrogen compounds, which together
would yield
35 tons of utilizable feeding stuff, containing
24 tons of digestible cellulose; the same
100 tons of crude straw would also yield
8 tons of utilizable lignin

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Figure A.16: Biotechnology methods for producing and purifying lipids from cultured yeast [BIOS 236].

These theoretical yields refer to the treatment of straw alone, whereas the schemes outlined cover combinations of straw, wood and whey. No figures were available to give estimate of yields from such combinations. It is evident that by combining the processes it would be possible to economize in the use of chemicals but one weak point of the scheme is that it is unlikely that all these waste materials would be available at the same time and in the same district at any one time. For instance, in the neighbourhood of Bad Tölz there is much dairy farming and wood is available from the Bavarian Alps, but there was no evidence of any straw surplus, as cereals were being grown only to a limited extent.

Samples of the fat produced had been submitted to Dr. Bleyer of the Munich Technical High School for analysis. He had reported that they contained about 41% of Oleic acid 2% of linoleic and linolenic acids, and 2% of oxyacids. Dr.Jungel could not procure the report and did not know whether these acids were found to be in the free or combined form. Dr. Bleyer had apparently not expressed any view on the possible uses of the fat. Samples, one prepared in March 1945 from straw and the other in April, 1945, from whey were brought to England for more detailed analysis and submitted to Dr.Lampitt, of Lyons Laboratories, London W.14 whose report is appended.

This work may be considered as a development along the lines indicated by Haeseler and Fink (Zeitschr.f. Spiritusind 63, 89, 94, 96), who reported yields of 12.5 to 14.3 g fat per 100 g lactose when using whey, and also that similar yields could be obtained using other sugars in combination with whey. The yield at the Bad Tölz plant calculated in this way would be 16.1g fat per 100g sugar. A culture of the selected strain of Oidium lactis used has been obtained.

Oidium lactis has also been used in Germany during the war for production of microbial protein by processes similar to that used for Torulopsis utilis. We have reported separately on such a process at Lenzing in Austria, and McGovern of the U.S. Forest Products Lab. Madison, Wis, and also A.C.Neil and W.B.Campbell of the Canadian Dept of Reconstruction, have reported on a similar plant operated by the Westfalische Zellstoff A.G. at Arnsberg. Dr. McGovern obtained a culture from that used at Arnsberg, which he has passed to Mr. Bunker of Barclay Perkins, Park Street, London, S.E.1.

Figure A.17: Biotechnology methods for producing and purifying lipids from cultured yeast [BIOS 236].

Appendix

Examination of Fat Samples

Routine Analysis	March Sample ex Straw	April Sample ex Whey
Acidity (as oleic acid)	1.70%	0.71%
Iodine number	51.7	60.2
Saponification value	208.5	195.5
Loss at 100°C	2.21%	0.10%
Reichert Value	10.60	4.98
Polenske Value	1.30	0.84
Kirschner Value	8.72	3.93

Except for the loss at 100°C, the above determinations (and those reported below) were made on the filtered fats, which contained a small amount of non-fatty matter and, in the use of the "straw" sample a small amount of moisture.

Special Determinations

Glycerine (total)	11.03%	7.75%
Unsaponifiable matter (by aluminium oxide adsorption method)	1.15%	3.00%
Percentage removed by adsorption on aluminium oxide (normally only free acids are removed)	3.3%	1.25%

Antioxidant Determinations

The induction period of Premier Jus was determined before and after the addition of 1% of the samples. The results obtained were :-

Premier Jus	3 hours
" " 1% sample ex straw	2¼ hours
" " 1% " " whey	2 "

Comments

The samples were yellow in colour and their flavour ruled out the possibility of their use for edible purposes in the condition in which they were submitted. They were slightly rancid, but at least part of their objectionable flavour was probably derived from the solvent used in

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Figure A.18: Biotechnology methods for producing and purifying lipids from cultured yeast [BIOS 236].

their preparation, viz trichlorethylene. It is possible that the fats would have had a satisfactory flavour at the time of their manufacture if they had been deodorised. A peculiar feature of the analytical results is that the presence of about 35% of butterfat was indicated in the "straw" sample and about 15% in the "whey" sample. This would be the conclusion normally drawn from the results, but it is of course possible to argue that such a conclusion is not justified in the present instance. It is curious that the Reichert-Polenske-Kirschner figures should be exactly correct for butter fat (in the proportions indicated above) in a product which presumably does not contain butterfat.

A second abnormality in the analytical figures is the lower percentage of glycerine in the "whey" sample. This result does not correspond with the Saponification Value, which is normal, and no explanation can be offered, unless esters of a water-insoluble alcohol are present.

In view of their biochemical origin, it was thought that the fats might contain substances having antioxidant properties, but the tests showed them to be slightly pro-oxidant. This is of no importance since the fats were undoubtedly oxidized themselves.

Figure A.19: Biotechnology methods for producing and purifying lipids from cultured yeast [BIOS 236].

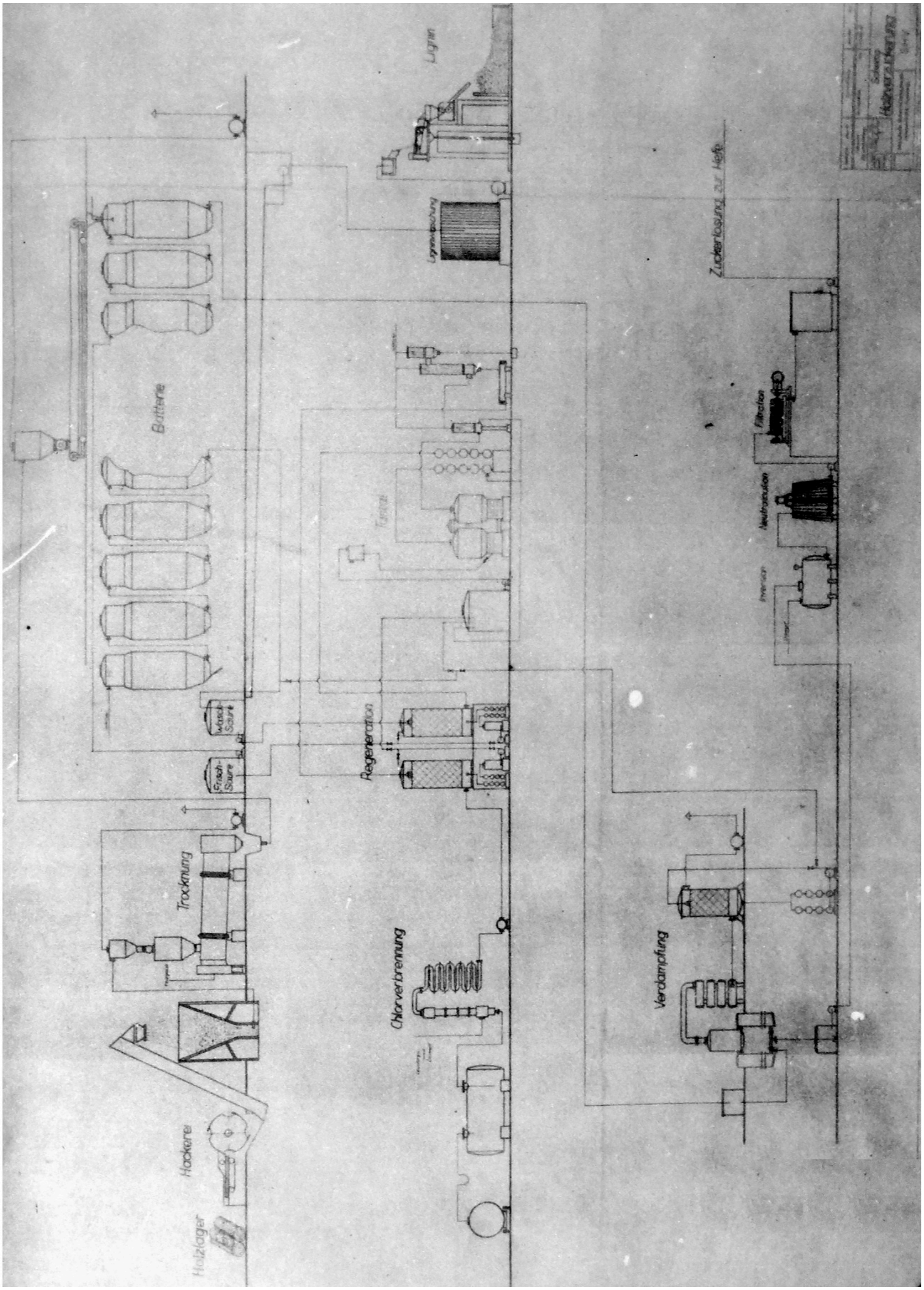

Figure A.20: Schematic overview of bioreactors and processing pipeline [BIOS 236].

BIOS 266+Appendix. ***New Technical Applications of Acetylene.***

[This report was based on interrogations of Walter Reppe, and outlined the large-scale production of periston synthetic blood plasma and many other products from acetylene.

Please see tables from this report on pp. 2353–2355.]

BIOS 354. ***Polvinyl Pyrrolidones. Translation of a Report by Dr. Fikentscher and Dr. Herrle, Ludwigshafen, with an Addendum on Periston (Synthetic Blood Serum).***

[Please see part of this report on pp. 2356–2363.]

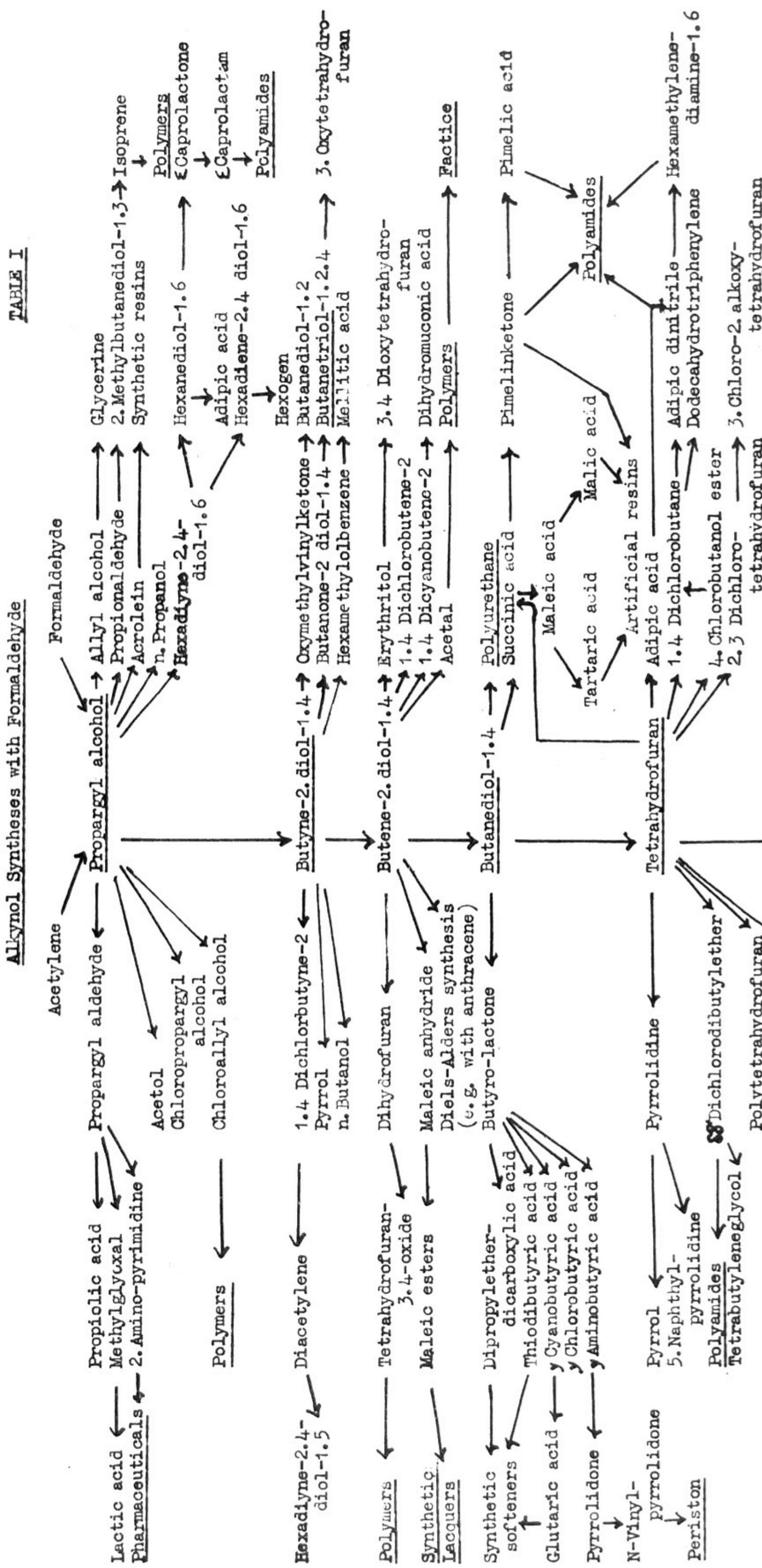

Figure A.21: Large-scale production of periston synthetic blood plasma and many other products from acetylene [BIOS 266 Appendix].

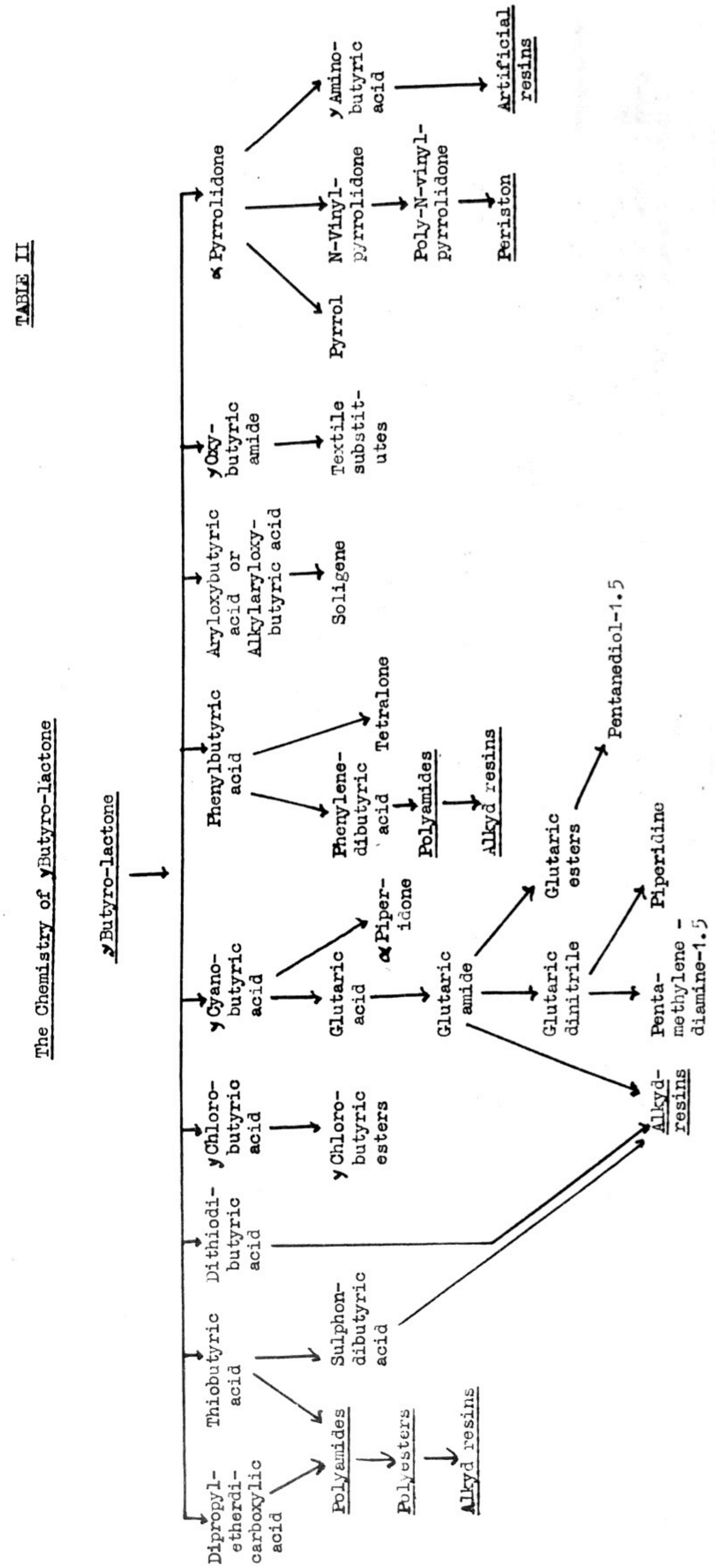

Figure A.22: Large-scale production of periston synthetic blood plasma and many other products from acetylene [BIOS 266 Appendix].

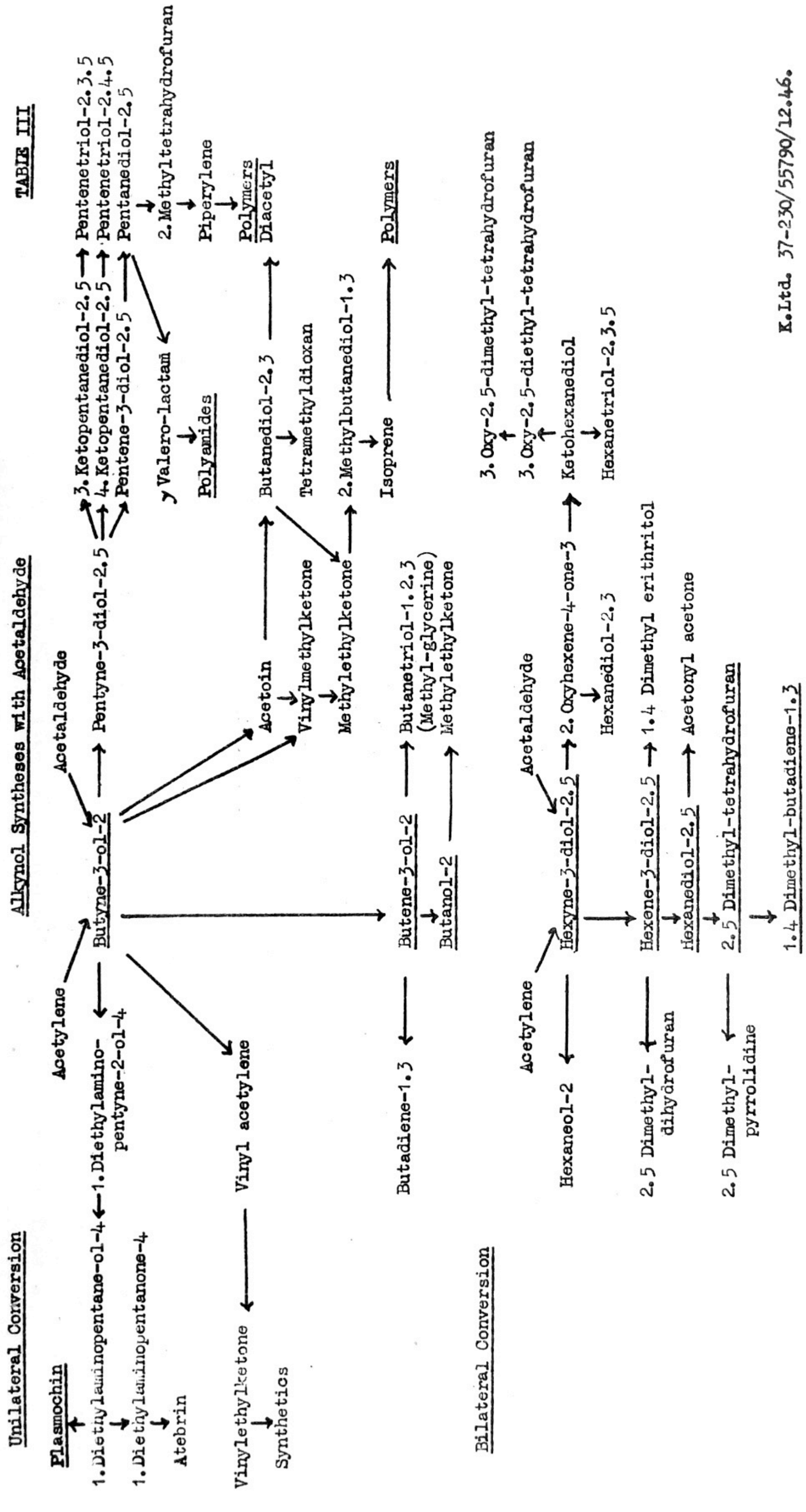

Figure A.23: Large-scale production of periston synthetic blood plasma and many other products from acetylene [BIOS 266 Appendix].

P E R I S T O N

(Name ges. geschuetzt)

Blutfluessigkeitsersatz
(Hergestellt in unserem Werk Elberfeld)

"BAYER"
I.G.Farbenindustrie Aktiengesellschaft
LEVERKUSEN

Die Folgen schweren Blutverlustes aeussern sich zunaechst in einem Erlahmen des Kreislaufes. Dieser Kreislaufkollaps ist bei akuten Blutungen bis zum Verlust etwa $1/3$-$1/2$ der zirkulierenden Blutmenge lediglich die Folge des Fuellungsverlustes des Gefaesssystems, also ein rein haemodynamisches Geschehen. Erst bei noch staerkeren akuten Blutungen macht sich zusaetzlich auch der Verlust an Erythrozyten bzw. Haemoglobin, dem Sauerstoffuebertraeger, geltend. Es kommt zur Gewebserstickung, der das Vasomotoren- und Atemzentrum zuerst erliegen.

Jede Substitutionstherapie nach Blutungen muss folglich zunaechst den Kreislauf aufzufuellen versuchen. Hierbei erscheint die intravenoese Verabfolgung ausreichender Mengen solcher Fluessigkeiten am aussichtsreichsten, die reaktionslos vertragen und womoeglich tagelang im Gefaesssystem festgehalten werden, bis die physiologischen Regulationen die normale Blutmenge nach Blutungen wieder ergaenzt haben.

Bisher wurde nach starken Blutverlusten in erster Linie versucht, den Kreislauf durch Infusion physiologischer Salzloesungen zu stuetzen. Derartige Loesungen werden zwar gut vertragen, sie wirken zunaechst auch ausreichend. Ihre Wirkung ist aber viel zu fluechtig, denn nach laengstens 2 Stunden haben diese Salzloesungen die Gefaesswaende durchwandert, und der Kreislauf ist wieder an Fluessigkeit verarmt. Um Salzloesungen ueber viele Stunden, evtl. Tage im Kreislauf zu halten, muessen sie ausser den physiologischen Salzen noch ein Kolloid enthalten, welches Wasser bindet. Zur Vermeidung von Ueberempfindlichkeits-Reaktionen darf dieses keinen Allergencharakter besitzen. Das Kolloidmolekuel muss mit seiner Wasserhuelle so gross sein, dass es selbst die geschaedigte Gefaessmembran nich zu durchwandern vermag (Bayliss).

Nach diesen Gesichtspunkten wurde im Pharmakologischen Institut der "Bayer"-Forschungsstaetten unseres Werkes Elberfeld nach einem geeigneten Kolloid gesucht. Unter zahlreichen hochmolekularen Stoffen, die in dieser Richtung tierexperimentell geprueft wurden, erwies sich das von Reppe und seinen Mitarbeitern in unserem Werk Ludwigshafen entwickelte Polymerisationsprodukt Polyvinylpyrrolidon als optimal. Eine hieraus hergestellte, den physikalischen Eigenschaften des Blutes angepasste Loesung bildet den Blutfluessigkeitsersatz.

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Figure A.24: A report on periston synthetic blood plasma [BIOS 354].

"PERISTON"

Seine Verweildauer in der Blutbahn entspricht den oben erwaehnten Anforderungen, so dass auch die haemodynamische Funktion der Kreislaufauffuellung mit Periston von ausreichender Dauer ist.

Es fehlen ihm aber die spezifischen chemischen und biologischen Funktionen des transfundierten Blutes (Sauerstoffuebertragung, Knochenmarksreizung, Gerinnungsfoerderung, Umstimmung, Abwehrfunktionen).

Nach schwersten, akut lebensbedrohenden Blutverlusten (etwa $1/3$-$1/2$ der Gesamtmenge) wird daher immer die Bluttransfusion das Verfahren der Wahl bleiben, denn in derart kritischen Faellen muessen unbedingt saemtliche Funktionen des verlorengegangenen Blutes ersetzt werden. Wenn die Bluttransfusion sich aus aeusseren Gruenden verzoegert, kann Periston jedoch die Rolle eines behelfsmaessigen Ersatzes bis zu ihrer Ermoeglichung spielen.

Da auch beim Schock (= vegetativer Kollaps) vornehmlich durch Gefaessatonie und bei Bluteindickung durch Plasmauebertritt ins Gewebe oder infolge vermehrter Fluessigkeitsabgabe durch Durchfaelle und Erbrechen ein Missverhaeltnis zwischen Fassungsvermoegen des Kreislaufapparates und seiner Fuellung besteht, zeigt Periston in analoger Weise auch hierbei, gegebenenfalls in Ergaenzung spezifiischer Massnahmen, hervorragende therapeutische Leistungen.

Chemisches

Das Periston enthaelt eine 3,5%ige Loesung von Polyvinylpyrrolidon, kurz "Kollidon" genannt. Diese Loesung ist versetzt mit 0,9% NaCl, 0,042% KCl, 0,025% $CaCl_2$, 0,0005% $MgCl_2$, 0,0024% $NaHCO_3$ und ca. 10 Vol. % freier CO_2, wodurch die sonst neutrale Loesung schwach sauer wird (pH 6,0). Die Loesung ist blutisotonisch ($\Delta = -0{,}55^\circ$ bis $-0{,}57^\circ$). Die Viskositaet, bezogen auf Wasser = 1, betraegt durchschnittlich 3,0. Die Loesung ist nach Hitzesterilisierung gebrauchsfertig, unbegrenzt haltbar und tropenfest.

Das Kollidon besitzt im Mittel eine Molekulargroesse von 25 000 und entwickelt im Hepp'schen Onkometer in 3,5%iger Konzentration einen maximalen Kolloiddruck von etwa 400 mm Wasser.

Pharmakologisches

(a) Vertraeglichkeit

Periston wird subkutan, intramuskulaer, intravenoes und intralumbal ohne jede Reizwirkung vertragen. Bei intravenoeser Injektion treten an Maus, Kaninchen, Katze und Affen keinerlei spezifische toxische Symptome auf. Eine toedliche Grenzdosis konnte erst mit einer 25%igen Kollidonloesung erreicht werden. Die D.l.m. betraegt 8 g Kollidon/kg Maus bei langsamer intravenoeser Injektion. Die Tiere

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Figure A.25: A report on periston synthetic blood plasma [BIOS 354].

gehen unspezifisch an einer Ueberlastung des Kreislaufes infolge der hyperviskoesen (Viskositaet = 15-20 auf Wasser als 1 bezogen) und hyperonkotischen Eigenschaften (ueber 2000 mm Wasser) dieser Loesung ein.

Da Periston weder zur Antigenbildung noch zur Entwicklung von Komplementkoerpern anregt, kann es in beliebigen Zeitabstaenden reaktionslos verabfolgt werden.

Periston hemmt aber die Abwehrkraefte nicht. An Hand des Bakterícidietestes gegenueber Staphylokokken und haemolytischen Streptokokken konnte gezeigt werden, dass der Titer 1 Stunde nach einer Periston-Infusion zwar infolge der Verduennung des Plasmas herabgesetzt war, schon nach 24 Stunden war aber der Ausgangstiter wieder erreicht, haeufig sogar ueberschritten. Dieser Titer wurde dann gehalten.

In Gewoehnungsversuchen an Kaninchen und Katzen wurden die Tiere waehrend mehrerer Wochen zweimal woechentlich entblutet und das verlorene Blut durch Periston ersetzt. Insgesamt wurde bis ueber ein Drittel der normalen Blutmenge entzogen. Es ergab sich, dass hinsichtlich der toxikologischen Wirkungen kein Unterschied besteht, ob das Blut durch physiologische Salzloesungen oder durch Periston ersetzt wird.

(b) Pharmakodynamik

Im Blutdruckversuch wird nach kraeftigem Aderlass der Blutdruck durch Injektion der entsprechenden Menge Periston wieder endgueltig hergestellt. Noch eindrucksvoller sind die "Austauschversuche", in denen immer wieder Blut abgelassen und durch dieselbe Menge Periston ersetzt wurde. Sie zeigten folgendes Gesamtergebnis:

Anzahl der Versuchstiere	Tierart	Blutfluessigkeitsersatz	Im Einzelversuch moegl. max. Menge ausgetauschter Fluessigkeit in % Koerpergewicht	Durchschnittlich ausgetauschte Menge in % Koerpergewicht	Rotes Blutbild, tiefster Wert kurz vor dem Tode	
					Hb%	Erythr. Mill.
8	Katze	Tyrode	3,65	3,19	31	-
9	Katze	Periston 2,5%ig	6,4	5,4	14,5	1,5
7	Hund	Periston 3,5%ig	14,0	7,8	8	0,89

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Figure A.26: A report on periston synthetic blood plasma [BIOS 354].

Nach Austausch des schubweise entnommenen Blutes durch eine optimale physiologische Salzloesung (Tyrode) ging die widerstandsfaehigste Katze schon bei einer Haemoglobinkonzentration von 31,0% ein. Unter denselben Versuchsbedingungen, jedoch nach schubweisem Austausch des entnommenen Blutes gegen Periston ging eine Katze erst bei einer Haemoglobinkonzentration von 14,5% ein, ein Hund sogar erst bei 8%.

Die Ursache, weshalb nach Periston soviel groessere Blutverluste ueberlebt werden als nach Injektion einer Salzloesung, liegt an dem Wasserbindungsvermoegen des fuer die Haargefaesse impermeablen Kollidons. Durch eine einzige Infusion von Periston kann die Blutfluessigkeitsmenge und damit auch das Schlag- und Minutenvolumen fuer 1-2 Tage wieder normalisiert werden. Da Periston gleichzeitig wieder den physiologischen Kolloiddruck und die normale Viskositaet herstellt, stabilisiert sich der gesamte Wasserhaushalt des Organismus. Damit ist die Voraussetzung fuer den Einsatz und die Aufrechterhaltung der physiologischen Regulationen gegeben.

In gleicher Weise wie an der entbluteten Katze stabilisiert Periston auch den Kreislauf nach Histaminschock.

Periston hemmt trotz seines Wasserbindungsvermoegens weder die Diurese noch die Leberfunktionen.

Kuenstlich entblutete Tiere, die uebermaessig grosse Periston-Dosen erhalten hatten, vertrugen dieselben ohne sichtbare Nebenwirkungen. Im Harn liessen sich nur in den ersten 3 Tagen p.i. wenige % unveraenderten Kollidons nachweisen. Nach 14 Tagen war das Kolloid im Blut noch deutlich nachweisbar, nach 3 Wochen konnte man eben noch Spuren feststellen. Ueber den Abbau und die Form, in der es ausgeschieden wird, laesst sich bisher noch nichts aussagen.

Die ueber einige Tage anhaltende Wirkung kann als optimal bezeichnet werden. Periston steht in dieser Hinsicht zwischen den reinen Salzloesungen und der Gummiloesung. Die Salzloesungen einerseits haben infolge Diffusion den Kreislauf nach spaetestens 2 Stunden bereits verlassen. Die Gummiloesung andererseits wird gespeichert. Daher war noch $4\frac{1}{2}$ Jahre nach ihrer Verabfolgung im Serum des Patienten die Gummireaktion positiv. Ausserdem fuehrt Gummi zu histologisch nachweisbaren Leberschaedigungen.

Die Blutgerinnung wird durch Periston nicht beeinflusst. Auffallenderweise uebernimmt Kollidon als einziges Kolloid nichttierischer Herkunft die Vehikelfunktionen des Plasmas. Weitere pharmakologische Daten siehe Hecht und Weese, Muench.Med.Wschr.1943,Nr.1,S.11.

Klinisches und Indikationen

Aus dem in der Einleitung beschriebenen Wesen des Periston als Blutfluessigkeitsersatz zur Kreislaufauffuellung ergeben sich als Indikationsgebiete:

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Figure A.27: A report on periston synthetic blood plasma [BIOS 354].

1. akute Blutverluste
2. Schock
3. Bluteindickung

1. AKUTE BLUTVERLUSTE (Verletzungen, Operationen, Blutungen der Geburtshilfe und Gynaekologie usw.), die eine schnelle Stuetzung des Kreislaufes erfordern:

(a) Schwerste akut-lebensbedrohende Blutungen:

Wenn die hier unersetzliche Bluttransfusion nich sofort vorgenommen werden kann, ist nach Blutstillung eine Kreislaufauffuellung mit Periston vorzunehmen. Dieses Vorgehen hat sich zur Ueberbrueckung der Zeit bis zur Bluttransfusion in zahlreichen Faellen lebensrettend bewaehrt. Ebenso erfolgreich waren Periston-Infusionen als anschliessende Ergaenzung der Bluttransfusion bei Patienten, welche die erforderlichen Blutmengen nicht vertrugen.

(b) Schwere bis mittlere Blutungen bei Verletzungen nach erster Versorgung oder Operation:

Die nachhaltige Stuetzung des Kreislaufes durch Auffuellung mit Periston reicht aus bis zum spontanen Einsatz der physiologischen Regulationen. Periston kann hier die Bluttransfusion vollwertig ersetzen, sofern noch keine Dauerschaedi gung vorliegt.

Eine Indikation zur Periston-Anwendung liegt nicht vor bei Sickerblutungen (blutende Magenulcera usw.) und anderen chronischen Anaemien. Hier besteht kein Mangel der Kreislaufuellung. Eine Auffuellung mit indifferenter Fluessigkeit kann keinen Nutzen bringen, hier kann nur die Bluttransfusion wirksam sein.

Man beachte, dass durch die Periston-Infusion der Blutdruck ansteigt und hierdurch bei nicht endgueltiger Blutstillung die Gefahr der Nachblutungen besteht. Man gebe daher Periston nur nach endgueltiger Blutstillung bzw. wo diese nicht moeglich ist, unter Zusatz eines Haemostypticums (Manetol).

2. SCHOCK (= vegetativer Kollaps) infolge mechanischer Insulte (Trauma, Operation) oder Narkose:

Hier liegt ein Missverhaeltnis zwischen Fassungsvermoegen und Fuellung der Strombahn vor. Die Erhoehung der zirkulierenden Blutmenge mit Periston als einer indifferenten, stunden- bis tagelang in der Strombahn verweilenden Loesung reicht erfahrungsgemaess aus, um den ganzen vegetativen Apparat wieder zu normalisieren, ohne dass das Risiko der Nebenwirkungen von koerpereigenen Fluessigkeiten mit

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Figure A.28: A report on periston synthetic blood plasma [BIOS 354].

in Kauf genommen werden muss. In der Hirnchirurgie duerfte Periston die Bluttransfusion weitgehend verdraengen. Hirnoedem wird durch Periston nicht unguenstig beeinflusst.

3. BLUTEINDICKUNG infolge vermehrter Fluessigkeitsabgabe durch Durchfaelle und Erbrechen oder infolge Plasmauebertritt ins Gewebe (protoplasmatischer Kollaps):

Ausgedehnte guenstige Erfolge wurden erzielt mit der Periston-Behandlung der Exsiccosen der Paediatrie, ferner auch der Kreislaufschaeden im Verlauf von Brechdurchfaellen Erwachsener (Ruhr, Cholera).

Nachdem sich Periston bei Verbrennungen bereits hervorragend bewaehrte, stellen die analogen Kreislaufschaeden durch Plasmauebertritt ins Gewebe infolge Kapillarwandschaedigung bei Infektionskrankheiten, wie z.B. Sepsis, Diphtherie, Pneumonie, Fleckfieber und andere, Indikationen zur Periston-Anwendung dar.

Auch bei Kreislaufschaeden bei Erfrierungen, die denen bei Verbrennungen entsprechen, wurden guenstige Erfahrungen gemacht. Ist bei exsiccotischen Zustaenden neben der Kreislaufauffuellung eine Befeuchtung der Gewebe erforderlich, so empfehlen sich subkutan oder rektal verabfolgte kolloidfreie Salz- und Zuckerloesungen.

Anwendung und Dosierung

Obwohl Periston von jedem Gewebe vertragen wird, ist es seinem Wesen entsprechend nur intravenoes anzuwenden. Bei anderweitiger Verabreichungsart kann der beabsichtigte Erfolg nicht eintreten.

(a) Erwachsene. Die durchschnittliche Dosis beim Erwachsenen betraegt 500 ccm. Je nach Lage des Falles koennen kleinere oder groessere Mengen angezeigt sein.

(b) Kinder. Bei Exsiccosen (Toxikosen) hat sich die Dosis von 25 ccm Periston je kg Koerpergewicht, evtl. zweimal taeglich, als zweckmaessig erwiesen.

Die Infusion des auf Koerpertemperatur erwaermten Periston soll langsam in 10-15 Minuten intravenoes erfolgen. Gegebenenfalls kann es auch als Tropfinfusion verabreicht werden.

Die Infusion kann nach Bedarf wiederholt werden. Periston ist kein Allergen, Vorsichtsmassnahmen in dieser Hinsicht eruebrigen sich.

Gleichzeitig erwuenschte injizierbare wasserloesliche Medikamente lassen sich zusammen mit Periston, das bei der Reaktionstraegheit des Polyvinylpyrrolidons keine chemischen Umsetzungen verursacht, in folgender Weise anwenden:

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Figure A.29: A report on periston synthetic blood plasma [BIOS 354].

1. Mittel, die schnell oder in konzentrierter Form wirken sollen, wie z.B. zentral angreifende Analeptica, Haemostyptica, Traubenzuckerloesung, werden in den Schlauch kanuelenwaerts injiziert.

2. Mittel, die in verduennter Form besser vertragen werden, wie z.B. Serum, vor allem Gasbrandserum, Strophanthin, Kreislauftonica der Ephedrin-Reihe, werden vor Anschluss des Infusionsschlauches in die Ampulle oder im Verlauf der Periston-Infusion in das der Periston-Ampulle angeschlossene Ende des Schlauches ampullenwaerts gespritzt.

3. Wasserloesliche Vitamin-Praeparate (Betaxin, Cantan, Citrin) koennen ebenfalls gemischt mit Periston angewandt werden.

<u>Anwendungstechnik</u>

1. Ampulle in warmem Wasser auf 37-40° erwaermen.

2. Den geraden Ampullen-Ansatz am Ende oeffnen und den sterilisierten Gummischlauch fuer die Infusion (zwickmaessig mit zwischengeschalteter Tropfkugel) anbringen.

3. Schlauch abklemmen und dann den hakenfoermigen Ansatz an der Spritze oeffnen.

4. Etwa 20 ccm Periston abfliessen lassen, um die beim Verbinden von Schlauch mit Ampullen von der Innenseite des Schlauches evtl. abgestossenen Gummiteilchen auszuschwemmen und Injektionsnadel an den Gummischlauch anschliessen.

5. Infusionsdauer etwa 10-15 Minuten, wobei die Ampulle mittels des hakenfoermigen Ansatzes aufgehaengt werden kann.

<u>Original-Packung</u>

Schachteln mit je 1 Spezial-Ampulle zu 500 bzw. 250 ccm Periston. Schachtel mit 5 Spezial-Ampullen zu 100 ccm Periston (fuer die Kinderpraxis).

<u>Literatur</u>

Hecht und Weese: "Periston ein neuer Blutfluessigkeitsersatz." Muench.Med.Wschr.1943,Nr.1,S.11.

Klees: "Erfahrungen mit Periston, einem neuen Blutfluessigkeitsersatz." Muench.Med.Wschr.1943,Nr.2,S.29.

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Figure A.30: A report on periston synthetic blood plasma [BIOS 354].

Joppich: "Zur Behandlung des Wasserverlustes bei der Darmstoerung des Saeuglings."
Mschr.f.Kinderhlkd.1943,Bd.92,S.28.

Toennis: Richtlinien fuer die Behandlung der Schussverletzungen des Gehirns und die Beurteilung ihrer Folgezustaende.
(Verl.Lehmann 1942)

Figure A.31: A report on periston synthetic blood plasma [BIOS 354].

BIOS 395. ***German Fluorescent Lamp Industry and Phosphor Chemical Manufacture.*** **pp. 1–2**

Dr. Leonhard Birkofor was assistant to Prof. Richard Kuhn described as Director of the Institute for Chemistry and Administrative Head of the Kaiser Wilhelm Institute.

[...] Dr. Leonhard Birkofor was interviewed during the period the investigating team was awaiting Dr. Leibnitz. He volunteered the information that the work of Dr. Kuhn and himself was directed largely to biological and biochemical research. He stated that they had developed a substituted benzil compound of the following constitution:-

i.e., symmetrical 1.1. dihydroxy 4.4 dibrom benzil, which he stated had bacteriocidal properties similar to those of penicillin. The compound MP 213^{o}C consisted of yellow needles and a 5 gm. sample was obtained.

Dr. Birkofor stated that so far 500 gms. had been distributed and tests in various hospitals had shown positive reactions against streptococcus, staphylococcus, gonococcus and pneumococcus. The medical investigations at these hospitals were continuing.

BIOS 436. *Enzyme Products and "Acrisin" Finishing Agents for Textiles: Rohm and Haas G.m.b.H., Darmstadt.* [Enzymes for washing]

[...] Concentrated preparations of pancreatic tryptase and diastase were prepared from an aqueous extract by selective precipitation. The concentrated products were diluted with sodium carbonate or sodium chloride respectively before being sold. [...]

No research had been carried out recently on enzyme products although the production of bacterial enzymes had been considered. [...]

The rough powder is ground and laboratory tests are carried out to estimate the enzymatic activity. The products are diluted, if necessary, in order that the final mixture will meet the standard specification for rate of conversion of starch to sugar (diastase) or for rate of liquefaction of gelatine (tryptase).

Care was necessary in handling the concentrated tryptase preparation in view of its rapid attack of animal tissue. Gloves, goggles and dust masks were provided for the workers but it had not always been possible to compel workers to wear them.

These highly concentrated works products are diluted between 40 and 50 times before being marketed. The principle diluent for the diastase is sodium chloride and for tryptase, sodium carbonate with or without sodium sulphate. With the diastase preparation, however, 5% calcium formate and mono- and di-sodium phosphates are added. The calcium formate is used to avoid the effect of varying hardness of different waters and the phosphates buffer solutions of the product to pH 6.6 to 7. The diastase is marketed under the name "Degomma" for desizing cotton fabrics.

The tryptase products were used on a considerable scale for bating and de-hairing hides but a very large mount was used for soaking articles before washing.

In the soaking powder, the concentrated tryptase is diluted with approximately 98% sodium carbonate, and the product is called Burnus or Enzymolin. A ½% solution is used at 35^{o}C (not exceeding 40 ^{o}C) for 10–15 minutes in commercial laundries whilst for household use an overnight soak is given in a similar solution.

It is claimed that much of the soiling matter is attached to fabrics by means of protein, starch or fatty matter and that these cementing materials are attacked and rendered soluble by the enzymes thus simplifying the subsequent washing process.

The maximum production of Burnus has been about 170 metric tons per month.

BIOS 449. ***German Medical Targets.*** [Pharmaceuticals, hormones, antibiotics, cancer, DDT]

[pp. 2–12:]

Report on the Researches of the Scientific Laboratory of C. F. Boehringer & Soehne, Mannheim-Waldhof during the war 1939–1945

[...] The research on producing the thymus hormone was based on the studies of Bomskov, who ascertained that extracts of the thymus glands of guinea-pigs are able to mobilize glycogen stored in different organs such as heart, liver and muscles. [...] He found, that the thymus really is a gland of internal secretion. Tests were made to concentrate the active substance and to establish its constitution. Bomskov made acetone extracts and showed that the active substance, especially after saponifying can be extracted with ether. We used glacial acetic acid and hydrocarbon chlorides as extracting solvents, the latter proved especially advantageous, as shown by the following examples[...]

Together with Prof. Brederick we elaborate a procedure for the manufacture of caffeine from uric acid. The uric acid is to be added in a formamide-melt of about 200^o and so transformed to xanthine, which is easily converted to caffeine by methylating with dimethylsulphate [...]

The greatest obstacle in this process is to procure a sufficiently pure and cheap uric acid.

The process with serpents' excrement which contains more than 80% of uric acid, is very easy and needs no further purification. [...]

Manufacture of Malaria Remedies.

[...] The new compound designated "Amichin" is scarcely inferior to quinine, whilst in general variations in the quinine molecule result in diminishing the anti-malaria efficiency. Many azo-compounds of Amichin were prepare and tested. Of these "Amichinazokairolin" proved especially non toxic and about 30 times more active than quinine in the canary test. This exceedingly favourable result caused us to test this product on man in larger scale. [...] There it proved that the strong increase of efficiency shown in the canary test was not so marked in human experiments, whilst the good tolerableness was maintained. The augmentation of efficiency compared to quinine amounted to only about four fold in the same range of application (that is both compounds act against schizontes only and not against gametes). [...]

In general the yeast was subject to an exact investigation. We are manufacturing on a factory scale nucleic acid from yeast and the resulting protein products were worked up to an animal food. As in wartime there is a large deficit in protein, we tried to transform the protein by-products of the nucleic acid manufacture into products fit for human nourishment. We succeeded in extracting albumen which can be whipped and which could replace the albumen in cooking and baking. This chemical introduced in trade circles under the trade mark "Backalbin" was sold in many thousands of kilos until the shortage of yeast stopped the manufacture. [...]

Furthermore we were producing a preparation of capsaicin to replace pepper. [...]

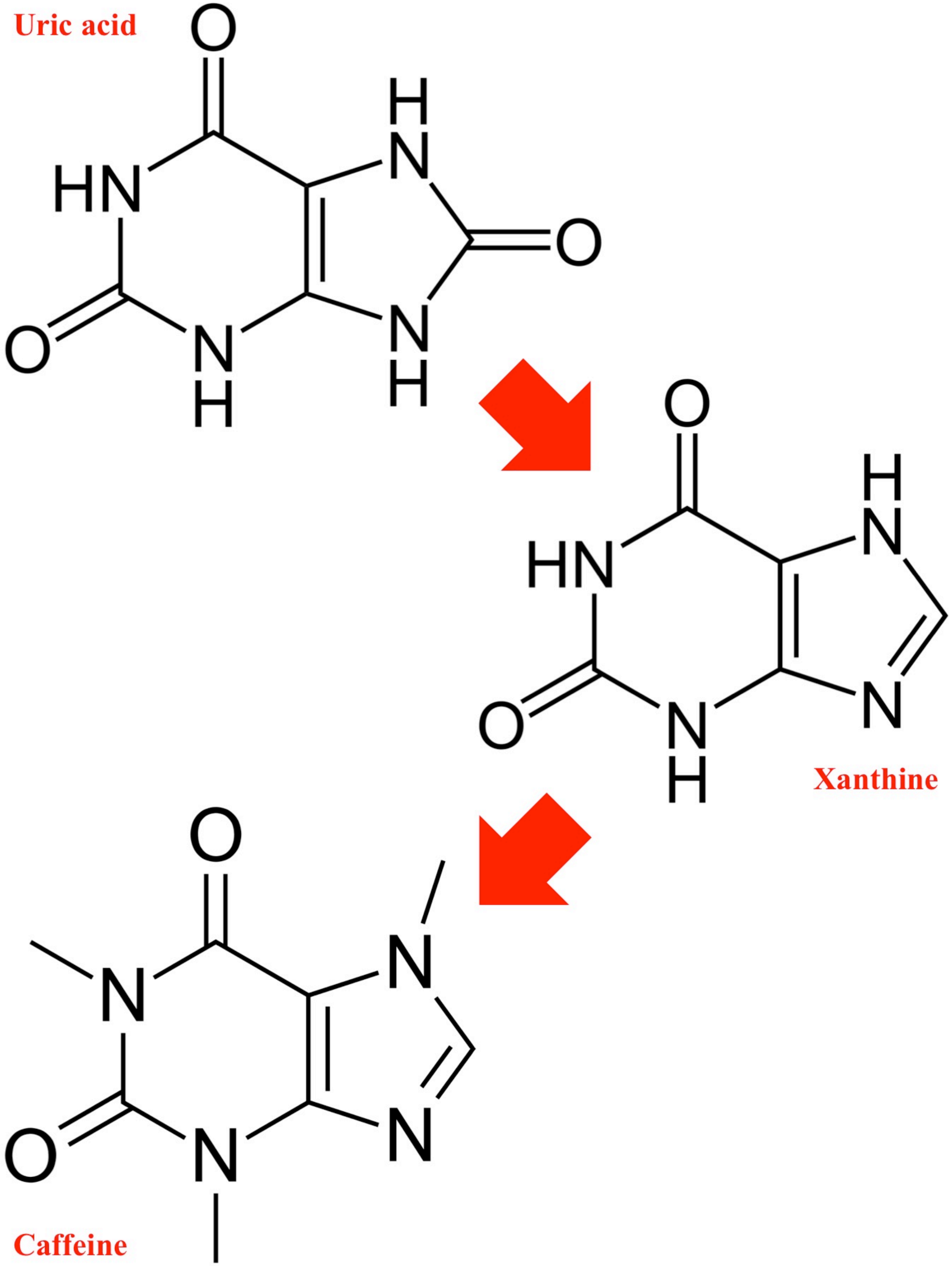


Figure A.32: BIOS 449 described the industrial farming of uric acid from snake urine and the conversion of the uric acid into caffeine.

[pp. 21–23]

Schering A.G., Berlin N 65 Werk Müllerstr. 170/72 [...]

Penicillin This had been mainly on a laboratory scale. The strain they had used was supplied by Prof. Rostock. It was suggested that he might have obtained it from Jena or perhaps Hanover. The unitage they obtained was 5–20 units/c.c. on the 13th and 14th days on a Czapek Dox medium with added lactose or glucose. Even though this was said to have been on a laboratory scale we found that the autoclave they had used was said to weigh 18 tons. The standard used was captured English penicillin and they used the inhibition of growth of Staph. aureus in 50 c.c. of medium. They had supplied some clinics in Berlin and Leipzig with material for trial but there had been little available for the chemical determination of the constitution of penicillin. (We think that this statement is not quite accurate but Dr. Clerc himself was not involved in the various procedures described.)

[p. 37]

EXPERIMENTAL TUMOURS

Various experiments to uncover possible immunity mechanisms were carried out (e.g., immune sera (anti-Ehrlich carcinoma sera in rabbits, etc.) and attempts to breed tumour immune animals). The Ehrlich ascites tumour was fractioned and of the various portions used as antigens the mitochondrial fraction showed the most interesting results. The work ultimately had to be confined within very narrow limits.

DRYING OF SERUM FOR THE WEHRMACHT

Work on the freeze drying of human serum started early in 1941. They were alive to the possibilities for the use of this process not only for war purposes but also for various processes and products required in peace. They devised an apparatus capable of drying some 20 litres a day by the beginning of 1942. Finally in the first six months of 1943 they prepared 348 kg of dried serum and in 1944 607 kg. They planned to have a special serum drying plant at Luckenwalde. In the first three months of 1945 their output of dried serum dropped some 70%. The Military Medical Academy was interested in the amino acid content of blood hydrolysates for use in hunger oedema.

[Please see the following pages for more information from this report on producing freeze-dried human blood, therapeutic antibodies that target cancer cells, and other advanced medical therapeutics.]

46.

Methoden angewendet. Die temperatursteigernde Wirkung mehrerer Präparate wird in grösserem Versuchen am Kaninchen geprüft. Wir hoffen, durch den Vergleich mit der klinischen Verträglichkeit damit einen experimentellen Nachweis der allgemeinen Verträglichkeit des Pernämyl zu erhalten.

II. Serumtrocknung für die Wehrmacht.

Wir haben den Auftrag erhalten, für die Wehrmacht ein Trockenserum aus menschlichem Serum herzustellen, das in gefrorenem Zustand eingetrocknet werden soll. Nach Versuchen des physiologisch-chemischen Institutes in der Scharnhorststrasse werde ein Produkt von den gewünschten Eigenschaften erhalten, wenn man menschliches, mit 7% Glukose versetztes Serum, das keimfrei filtriert wurde, in Schalen in 3mm Schichtdicke bei tiefsten Temperaturen gefriert und dann in Exsikkatoren über Silikagel unter Aufbewahrung im Kühlraum bei minus 5 Grad in einem Vakuum von unter 0,5 mm trocknet. Wir hatten die Aufgabe, dieses Verfahren für eine Tagesproduktion einer 20 Liter Serum entsprechenden Menge von Trockenserum technisch brauchbar zu machen.

Nach unseren bisherigen Versuchen fällt die Verwendung dieses Originalverfahrens für grössere technische Ansätze praktisch aus. Hinderlich ist : Grösse der Trockenschränke die schwer auf ein derart hohes Vakuum zu bringen sind. Notwendigkeit sehr grosser Mengen von Silikagel, die immer wieder regeneriert werden müssten. Langsamkeit der Absorption des Wassers durch das Silikagel, was ein Arbeiten in noch grösseren Tagesansätzen bedingen würde, wodurch die notwendigen Apparate und Räumlichkeiten wiederum vergrössert würden, Schwierigkeit, derartig viele Schalen, die wegen der Sterilisierbarkeit und erforderlichen hohen Sauberkeit aus Glas sein müssten, zu hantieren, dauernd zu reinigen und zu sterilisieren.

Versuche, das Serum im kalten Luftstrom einzublasen, ergaben die Untunlichkeit dieses Verfahrens, da die für die Kühlung der erforderlichen ungeheuren Luftmengen und deren Trocknung Riesen-aggregate an Apparaturen gebraucht würden.

Eine ganze Reihe von Vorversuchen liess als einzig möglicher Weg nur das Eindampfen im hohen Vakuum unter Kondensation des Wasserdampfes in Tiefkühlern erkennen. Derartige Trocknungsverfahren werden besonders in Amerika schon technisch durchgeführt, soweit sich übersehen lässt, aber anscheinend nicht in so grossen Ausmassen, wie sie hier verlangt werden

Ju. 8.

Figure A.33: A report on producing freeze-dried human blood, therapeutic antibodies that target cancer cells, and other advanced medical therapeutics [BIOS 449].

47.

Das Verfahren von Flossdorf, das der I.G. geschützt ist, trocknet Serummengen in Ampullen, die im Hochvakuum an einen Tiefkühler angeschlossen sind. Die Trocknung dauert aber, selbst bei nur 25 ccm grossen Einzelampullen, recht lange. Das wesentlichste dieses Verfahrens ist, dass das Produkt in den Verbrauchsampullen selbst getrocknet wird, die dann, ohne das Vakuum aufzuheben, verschmolzen werden. Ein in letzter Zeit veröffentlichtes amerikanisches Verfahren sieht eine Umwandlung des Serums in Eisgranula vor, die in eine auf 40 Grad beheizte Schale fallen und dort im Hochvakuum gerührt werden, während das Wasser in einem Tiefkühler niedergeschlagen wird. Dieses theoretisch sehr einleuchtende Verfahren, das die Frage des Wärmetransportes in die gefrorenen Massen löst, scheint uns wegen der Schwierigkeit der Anwendung im Grossen (Hochvakuumdichte Stopfbuchsen, oder komplizierte elektromechanische Rührung von aussen, Granulierung des Serums) und wegen der Eiligkeit des Auftrages nicht durchführbar.

Es bleibt also entweder das Eingefrieren des Serums durch Einspritzen in dünnem Strahl in hohes Vakuum und anschliessende Verdampfung, oder das Anfrieren des Serums in dünner Schicht an das Trockengefäss unter-normalem Druck und anschliessende Verdampfung im hohen Vakuum. Das letztere gibt den besseren Wärmetransport und damit raschere Verdampfung. Nach unseren Vorversuchen wird mit der vorhandenen Pfeifferpumpe und einer projektierten Apparatur die gestellte Aufgabe zu lösen sein.

Mit der Errichtung eines geeigneten Raumes wurde begonnen. Hinsichtlich der erforderlichen Kältemaschine, der Solekühler und der gläsernen Eindampfrezipienten schweben die Verhandlungen mit dem Konstruktionsbüro.

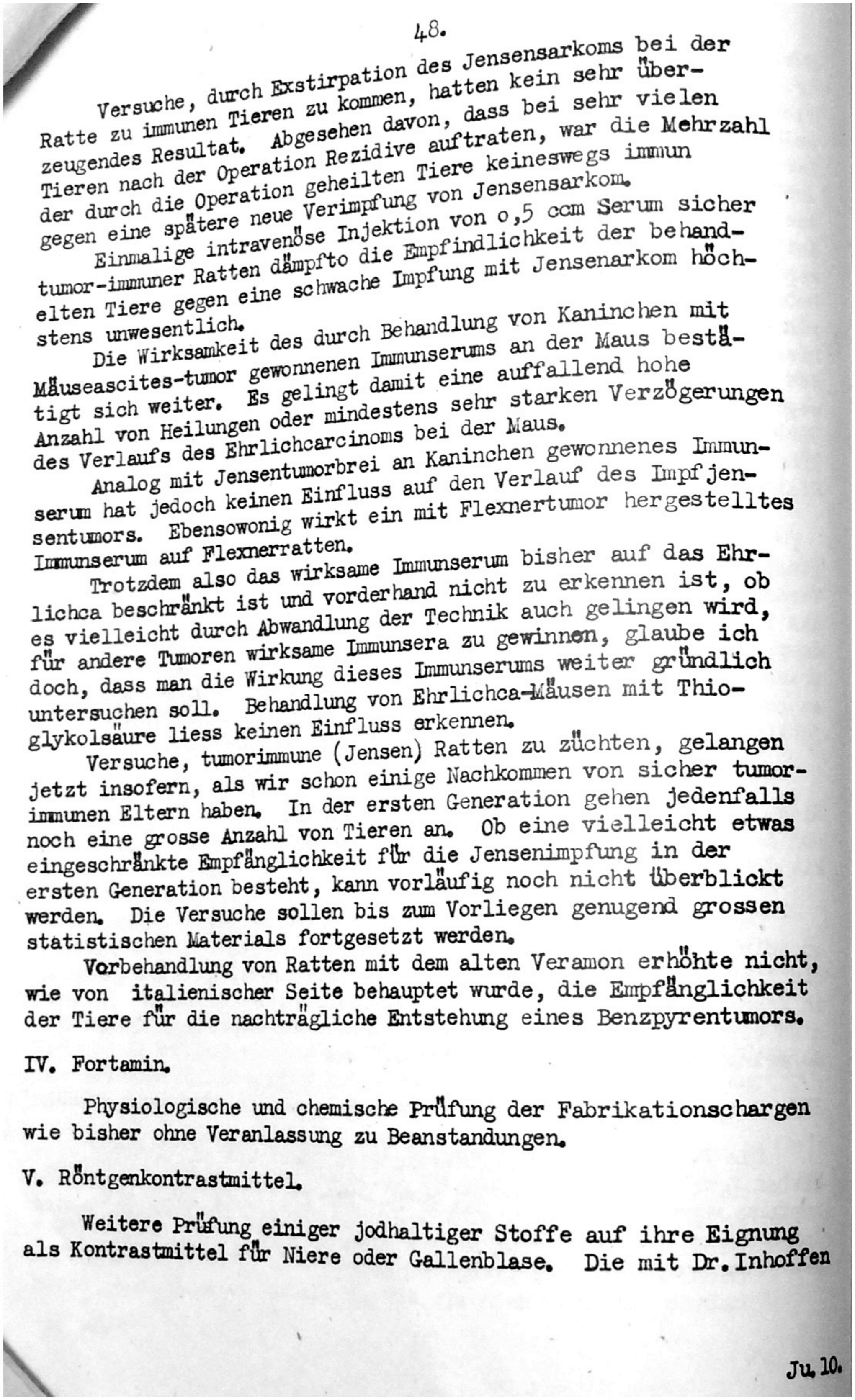
Das Produkt scheint nicht nur für den Kriegsfall wertvoll zu sein. Es ist durchaus möglich, dass ein solches Trockenserum nicht nur bei Friedensunfällen und als Ersatz der Bluttransfusion in Krankenhäusern eine grosse Friedensindikation bekommt. Es wird also vermutlich das Verhandensein eines derartigen Betriebes für Schering auch im Frieden vorteilhaft sein.

III. Carcinomversuche.

Die Weiterverimpfung unserer Versuchstumoren wurde wie bisher fortgeführt. Neben der zur Fortzüchtung üblichen Stückchenimpfung wurde ebenso, wie das früher für Ehrlichcarcinom und Jensentumor durchgeführt wurde, mit der quantitativen Verimpfung des Flexnercarcinoms und des Walkercarcinoms der Ratte begonnen.

Ju. 9.

Figure A.34: A report on producing freeze-dried human blood, therapeutic antibodies that target cancer cells, and other advanced medical therapeutics [BIOS 449].



48.

Versuche, durch Exstirpation des Jensensarkoms bei der Ratte zu immunen Tieren zu kommen, hatten kein sehr überzeugendes Resultat. Abgesehen davon, dass bei sehr vielen Tieren nach der Operation Rezidive auftraten, war die Mehrzahl der durch die Operation geheilten Tiere keineswegs immun gegen eine spätere neue Verimpfung von Jensensarkom.

Einmalige intravenöse Injektion von o,5 ccm Serum sicher tumor-immuner Ratten dämpfto die Empfindlichkeit der behandelten Tiere gegen eine schwache Impfung mit Jensenarkom höchstens unwesentlich.

Die Wirksamkeit des durch Behandlung von Kaninchen mit Mäuseascites-tumor gewonnenen Immunserums an der Maus bestätigt sich weiter. Es gelingt damit eine auffallend hohe Anzahl von Heilungen oder mindestens sehr starken Verzögerungen des Verlaufs des Ehrlichcarcinoms bei der Maus.

Analog mit Jensentumorbrei an Kaninchen gewonnenes Immunserum hat jedoch keinen Einfluss auf den Verlauf des Impfjensentumors. Ebensowonig wirkt ein mit Flexnertumor hergestelltes Immunserum auf Flexnerratten.

Trotzdem also das wirksame Immunserum bisher auf das Ehrlichca beschränkt ist und vorderhand nicht zu erkennen ist, ob es vielleicht durch Abwandlung der Technik auch gelingen wird, für andere Tumoren wirksame Immunsera zu gewinnen, glaube ich doch, dass man die Wirkung dieses Immunserums weiter gründlich untersuchen soll. Behandlung von Ehrlichca-Mäusen mit Thioglykolsäure liess keinen Einfluss erkennen.

Versuche, tumorimmune (Jensen) Ratten zu züchten, gelangen jetzt insofern, als wir schon einige Nachkommen von sicher tumorimmunen Eltern haben. In der ersten Generation gehen jedenfalls noch eine grosse Anzahl von Tieren an. Ob eine vielleicht etwas eingeschränkte Empfänglichkeit für die Jensenimpfung in der ersten Generation besteht, kann vorläufig noch nicht überblickt werden. Die Versuche sollen bis zum Vorliegen genugend grossen statistischen Materials fortgesetzt werden.

Vorbehandlung von Ratten mit dem alten Veramon erhöhte nicht, wie von italienischer Seite behauptet wurde, die Empfänglichkeit der Tiere für die nachträgliche Entstehung eines Benzpyrentumors.

IV. Fortamin.

Physiologische und chemische Prüfung der Fabrikationschargen wie bisher ohne Veranlassung zu Beanstandungen.

V. Röntgenkontrastmittel.

Weitere Prüfung einiger jodhaltiger Stoffe auf ihre Eignung als Kontrastmittel für Niere oder Gallenblase. Die mit Dr. Inhoffen

Ju. 10.

Figure A.35: A report on producing freeze-dried human blood, therapeutic antibodies that target cancer cells, and other advanced medical therapeutics [BIOS 449].

49.

aufgenommene Jodierung einiger als Abführmittel in Aussicht genommener Triphenyl- bezw. Triphenolessigsäuren wird vielleicht brauchbare Gallenschattenmittel liefern. 'Die Abführwirkung der nicht jodierten bisher vorliegenden Produkte liess sich an den üblichen Versuchstieren nicht feststellen. Nach eingehender Ermittlung der allgemeinen Toxizität wird der Versuch am Menschen lehren müssen, ob die Vermutung, dass in dieser Körperklasse Abführmittel vorkommen, richtig ist.

VI. Jucundal.

Es wurden durch Dr. Neuhof vorläufige klinische Versuche begonnen, die zeigen sollten, ob eine Verwendung des Kombinationspartners des Pyramidon aus dem Veramon B als Spasmolytikum für sich allein tunlich ist. Die Wirksamkeit des Spasmolytikums scheint recht gut zu sein. Bedenken gegen die Einführung bestehen jedoch nach wie vor in der eventuellen Gefährdung des Veramon B durch ungünstige Beurteilung oder durch den Rezeptzwang für das Tributyläthylamin.

VII. Nitrokörper.

Zusammen mit Dr. Inhoffen wurde das Trinitrotriäthanolamin hergestollt, das als Diphosphat einen kristallinen, weissen, nicht auf Schlag explodierenden Körper, der als Ersatz für das bei Angina pectoris zur Behandlung übliche Nitroglyzerin in Aussicht genommen ist. Ueberraschenderweise ist das Trinitrotriäthanolamin nicht in der Literatur bekannt. Es handelt sich also um einen neuen und voraussichtlich auch patentfähigen Stoff, der, wie die bisherigen Tierversuche zeigen, als Base vielleicht etwas stärker als Nitroglycerin, als Diphosphat vielleicht wenig schwächer als Nitroglycerin ist. Er hat den Vorteil der Haltbarkeit und der Verarbeitbarkeit zu fertigen Spezialitäten, der dem Nitroglyzerin nicht zukommt. Die Indikation Angina pectoris ist gross. Wir denken daran, den Nitrokörper als solchen oder vielleicht in Kombination mit dem Spasmolytikum als rezeptpflichtiges Spezialpräparat gegen Angina pectoris zu empfehlen.

VIII. Sulfonamide.

Toxizitätsbestimmungen an verschiedenen Sulfonamiden wurden fortgesetzt. Versuche zur Bestimmung der Sulfonamide im Tierkörper wurden aufgenommen. Es ergab sich, dass das mit dem von Werner empfohlenen Verfahren mittlere Sulfonamidmengen unter Verwendung des uns zur Verfügung stehenden lichtelektrischen Kolorimeters mit ausreichender Genauigkeit bestimmbar sind.

Ju. 11.

Figure A.36: A report on producing freeze-dried human blood, therapeutic antibodies that target cancer cells, and other advanced medical therapeutics [BIOS 449].

BIOS 691. ***Some Aspects of Microbiological Research in Germany.***

[pp. 1–2]

Professor Lembke, formerly director of the Bakteriologisches Institut, Preussische Versuchs- und Forschungsanstalt für Milchwirtschaft in Kiel, and now scientifically active again after a period of detention, was interviewed in Sielbeck to obtain a general picture of the work which had been carried out under his direction during the past six years. The Bakteriologisches Institut was totally destroyed by bombing during the war, but a good deal of work was carried on elsewhere, notably in Sielbeck at the temporary quarters of the Institut für Virusforschung of Kiel University. In the past few months new quarters for the Bakteriologisches Institut have been found in Kiel, and its work is gradually being reestablished there.

Professor Lembke and his associates have been active in a large number of fields, some of which have already been covered by previous reports (e.g. ultra-violet pasteurization of milk). However, two aspects of their investigations do not appear to have received detailed attention and seem worth study. These are (a) protein synthesis by yeasts and molds and (b) the production of antibiotics, notably of an alleged penicillin-like substance known as Mycoin C.

[...] The best organisms found for protein synthesis were Oospora lactis, Oospora amycelica, Saccharomyces lactis and Torulopsis sp.

[pp. 13–14]

A visit was also paid to Prof R. Harder at the Botanisches Institut. [...]

The basic concept underlying this approach to the problem of microbial fat production is a fairly obvious one. In the case of fat synthesis by non-photosynthetic microorganisms such as the yeasts, carbohydrates must be used as the raw material, and the process is highly wasteful from the overall standpoint, since a large part of the substrate is lost by respiration. Fat can undoubtedly be obtained, but only by using large amounts of carbohydrate otherwise utilizable as human or animal foodstuffs. On the other hand, if one could find good fat-producing photosynthetic microorganisms, fat could be obtained from them without any depletion of the carbohydrate supply.

Two good groups of fat-producing photosynthetic microorganisms were discovered: certain fresh-water diatoms, and strains of Chlamydomonas. [...] After various techniques of cultivation had been tried, the best proved to the use of tall glass cylinders, 5 cm in diameter and 80 cm high. They were filled almost completely with the culture medium and a slow current of air bubbled through during growth. [...] The algae grew luxuriantly and eventually underwent a “fatty degeneration”, the cells becoming packed with large fat globules. In the case of Chlamydomonas this occurred after 10–14 days’ growth. [...] With artificial illumination there is also the possibility of obtaining a crop in depth.

Fat production by Microorganisms

A systematic investigation of fat production by yeasts and molds was undertaken by Prof Rippel-Baldes and Dr Meyer. During its course, a number of organisms not previously known to be suitable for this purpose were tried out, and it was discovered that strains of Nectaromyces reukaufii, isolated some years previously in a study of the microflora of flowers, were far more promising than the species heretofore known (Endomyces vernalis, Oospora lactis, etc.). N. reukaufii has the following advantages: (a) its rapid growth and sugar utilization; (b) its unicellular structure, which makes is more amenable to culture in deep vessels with aeration than are the filamentous forms * and (c) the fact that fat formation occurs at a very early stage of growth, and is not a late degenerative phenomenon. All experiments were carried out in Kluyver flasks, using 500 ml. of substrate in a 1000 ml. vessel, with very strong aeration. The temperature employed was 25°C., but no experiments with higher temperatures were done. The following data are typical.

Expt. 1. Medium: bran extract, 2.5%, whey 25%, sec. pot. phosphate 0.2%, ammonium phosphate 0.1%, magnesium sulfate 0.05%, iron sulfate 0.001%, Bergius wood sugar 9.32%, pH 6.6.
Analysis after four days.

Initial sugar	9.32%
Final sugar	1.86%
Fat as % of dry wt	28.3%
Protein "	9.22%
Economic coefficient	35.5
Fat coefficient	3.22
Gm. of dry material in 100 ml. of solution	2.65
" fat " "	0.75
" protein " "	0.244

* With modern American methods of submerged culture for filamentous fungi, this not a real advantage.

Figure A.37: Fat production and extraction from yeast cultured in bioreactors [BIOS 691].

Expt. 2. Same formula as precious medium, with exception of whey (10%) and wood sugar (5.4%). Analysis after four days.

Initial sugar	5.4%	
Final sugar	1.1%	
Fat as % of dry wt.	34.15	
Protein "	11.4	
Economic coefficient	44.4	
Fat "	15.2	
Protein "	5.0	
Gm. of dry material in 100 ml. of solution		1.93
Gm of fat " "		0.64
Gm of protein " "		0.22

Expt 3. Bran extract 3%, Bergium wood sugar 5.21%. Analysis after 3 days.

Initial sugar	5.21%	
Final sugar	1.95%	
Fat as % of dry wt.	30.7	
Protein "	6.25	
Economic coefficient	42.7	
Fat "	13.1	
Protein "	2.67	
Gm. of dry material in 100 ml. of solution		1.4
Gm. of fat " "		0.43
Gm. of protein " "		0.09

More recent experiments show that with a heavy inoculum satisfactory yields can even be obtained in 1-2 days. Very strong aeration is necessary for a high fat yield, and this introduces foaming problems, which were overcome in the laboratory by the use of an anti-foam agent known as antispumin. According to Professor Rippel-Baldes, plans were being considered at the end of the war for a trial of large-scale production, but were abandoned after Germany's defeat. Several good fat-producing strains of N.reukaufii were obtained and are available from the National Research Council of Canada to interested investigators.

Figure A.38: Fat production and extraction from yeast cultured in bioreactors [BIOS 691].

Work on fat synthesis at the Botanisches Institut

A visit was also paid to Prof R. Harder at the Botanisches Institut. During the war fundamental work was continued in his laboratory on subjects for which it was previously famous; the aquatic fungi and the influence of external factors in modifying leaf and flower form in flowering plants.

However, a rather novel approach to the question of microbial fat synthesis was also undertaken in the guise of war research, namely an assessment of the possibility of controlled fat production by unicellular photosynthetic organisms. The work was purely on a laboratory scale and no attempts at commercial exploitation were made. Nevertheless, Professor Harder was most enthusiastic about the future potentialities of this work.

The basic concept underlying this approach to the problem of microbial fat production is a fairly obvious one. In the case of fat synthesis by non-photosynthetic microorganisms such as the yeasts, carbohydrates must be used as the raw material, and the process is highly wasteful from the overall standpoint, since a large part of the substrate is lost by respiration. Fat can undoubtedly be obtained, but only by using large amounts of carbohydrate otherwise utilizable as human or animal foodstuffs. On the other hand, if one could find good fat-producing photosynthetic microorganisms, fat could be obtained from them without any depletion of the carbohydrate supply.

Two good groups of fat-producing photosynthetic microorganisms were discovered; certain freshwater diatoms, and strains of Chlamydomonas. They were grown in a variety of mineral solutions with the addition of soil extract; the exact composition of the mineral solution was immaterial, but addition of soil extract was essential for good crops. After various techniques of cultivation had been tried, the best proved to be the use of tall glass cylinders, 5 cm in diameter and 80 cm high. They were filled almost completely with the culture medium and a slow current of air bubbled through during growth. In the case of diatoms, the cylinders were loosely packed with glass wool to provide attachment surfaces, but with Chlamydomonas such a practice was not necessary. No attempt to maintain pure culture conditions was made, and contamination by other microorganisms proved no problem as long as adequate aeration was maintained. The algae grew luxuriantly and eventually underwent a "fatty degeneration", the cells becoming packed with large fat globules. In the case of Chlamydomonas this occurred after 10-14 days' growth. Calculations based on early experiments showed that with a system of spaced glass cylinders operating by natural daylight during the summer months a fat yield per unit area at least twice as great as that obtainable with the usual oil seed plants was possible. By improvements in the conditions of cultivation as well as the discovery of new strains this superiority could certainly be increased many fold. Furthermore, by artificial illumination during the night an additional increase of several fold can be obtained. With artificial illuminations there is also the possibility of obtaining a crop in depth. Studies on the chemical composition and biological value of the fats produced have so far not been made.

Figure A.39: Fat production and extraction from algae cultured in bioreactors [BIOS 691].

BIOS 710. ***Manufacture of Biolase (Starch-Hydrolysing Enzyme) at Kalle & Co. (I. G. Farben A. G.) Wiesbaden, Biebrich.***

The manufacture of Biolase, a starch-hydrolysing enzyme, was carried out by Kalle & Co., Wiesbaden. A request has been made for details of their manufacturing process, and this report describes the information obtained as to the method used by Kalle & Co. as gained from an interrogation of a member of the staff, Dr. Altgelt. A brief description of the plant used is also given, but as this was not in operation when inspected in October 1945, it was not possible to check the statements made. [...]

The capacity of the plant was stated to be 30 tonnes per month, concentrated material, equivalent to 1350 tonnes per month of standard material.

In the building however, there were new plant items awaiting installation and the capacity of these was stated to be four times greater than that of the existing plant. Dr. Altgelt stated however, that the intention was to demolish the existing plant as soon as the new plant was in commission.

BIOS 766. ***The Manufacture of Pharmaceuticals and Fine Chemicals in the U.S. and French Zones of Germany.***

[Please see p. 2378 for the table of contents of this long report, which provides a good overview of the range of biological and chemical pharmaceuticals that were being produced in Germany by the end of the war.]

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Figure A.40: Table of contents listing many biopharmaceuticals being produced in Germany by the end of the war [BIOS 766].

BIOS 770. ***Further Developments in Dairying in Germany.***

[In 1940, German-speaking scientists developed and successfully implemented the use of intense ultraviolet light to sterilize liquids and other materials [BIOS 770; FIAT 50; FIAT 107; FIAT 257].

Some of the most important scientists in the project were Andreas Lembke (German, 1911–2002), Hellmuth Bayha (German?, 19??–19??), Karl Krammer (German?, 19??–19??), and Eugen Sauter (German?, 19??–19??).

See figures on pp. 2380–2385.

This approach is now widely used in modern biology laboratories to sterilize water, the interiors of biosafety cabinets, safety goggles, and other materials.]

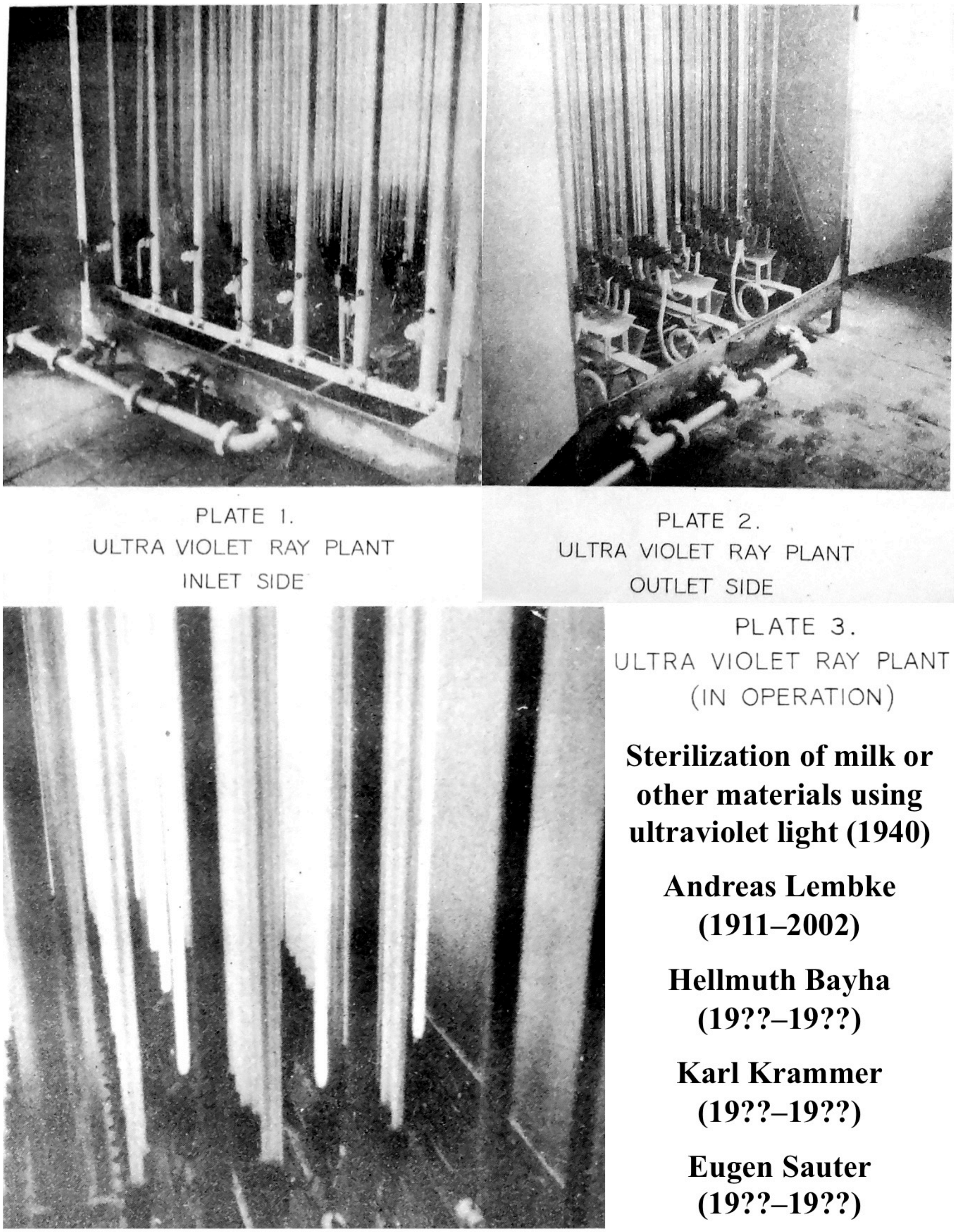
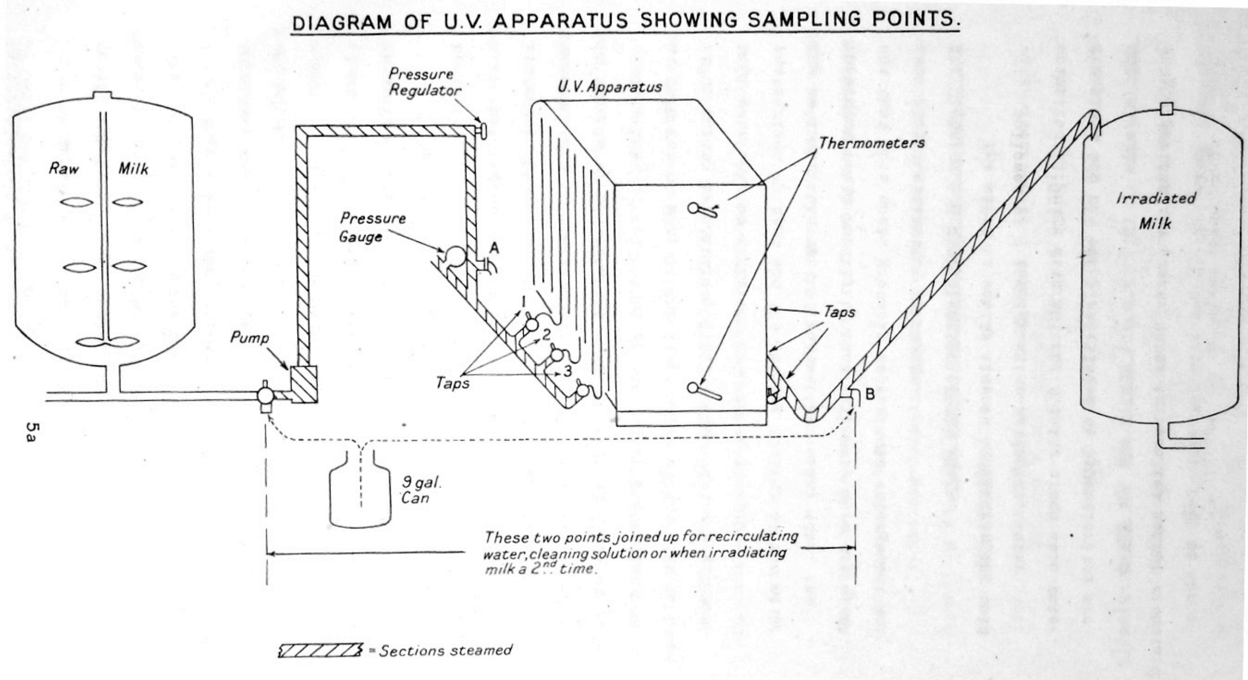


Figure A.41: Andreas Lembke, Hellmuth Bayha, Karl Krammer, Eugen Sauter, and other scientists developed and successfully implemented methods of using intense ultraviolet light to sterilize liquids and other materials [BIOS 770].



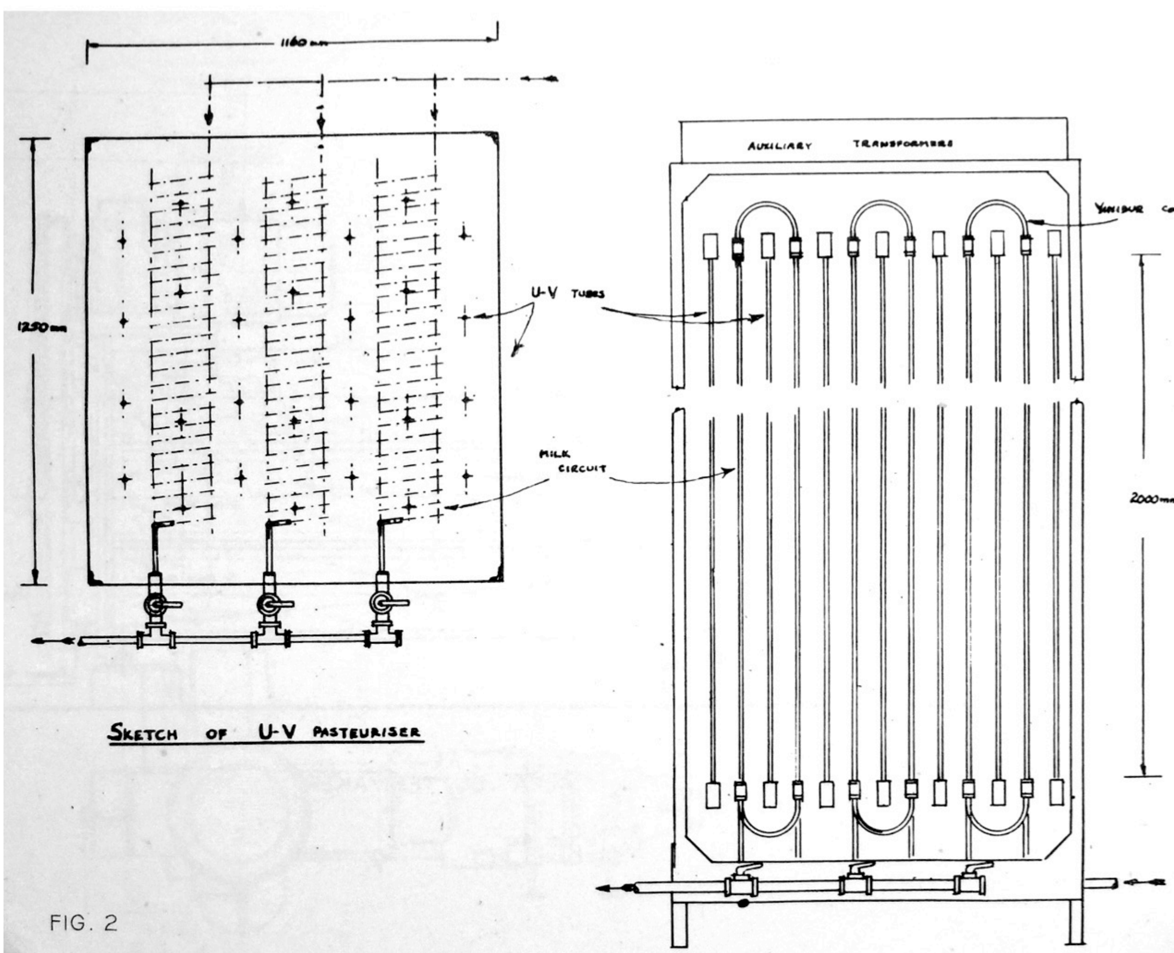


Figure A.42: Andreas Lembke, Hellmuth Bayha, Karl Krammer, Eugen Sauter, and other scientists developed and successfully implemented methods of using intense ultraviolet light to sterilize liquids and other materials [BIOS 770].

Erteilt auf Grund des Ersten Überleitungsgesetzes vom 8. Juli 1949
(WiGBl. S. 175)

BUNDESREPUBLIK DEUTSCHLAND

AUSGEGEBEN AM 29. OKTOBER 1953

DEUTSCHES PATENTAMT

PATENTSCHRIFT

№ 894 956

KLASSE 53e GRUPPE 3

S 5825 IVa/53e

Dr. Andreas Lembke, Sielbeck bei Eutin (Holst.) und
Dr. Hellmuth Bayha, Erlangen
sind als Erfinder genannt worden

Siemens-Schuckertwerke Aktiengesellschaft, Berlin und Erlangen

Einrichtung zur Behandlung von flüssigen Stoffen, insbesondere von Milch, mit UV-Strahlen

Patentiert im Gebiet der Bundesrepublik Deutschland vom 1. Februar 1940 an
Der Zeitraum vom 8. Mai 1945 bis einschließlich 7. Mai 1950 wird auf die Patentdauer nicht angerechnet
(Ges. v. 15. 7. 51)
Patentanmeldung bekanntgemacht am 26. Februar 1953
Patenterteilung bekanntgemacht am 17. September 1953

Die Erfindung betrifft eine Einrichtung zur Behandlung von Flüssigkeiten, insbesondere von Milch, mit UV-Strahlen. Das wesentlichste Kennzeichen der Erfindung besteht darin, daß sowohl die Strahlungsquellen für die UV-Strahlen als auch die Flüssigkeitsleitungen voneinander getrennt angeordnet sind.

Der Gegenstand der Erfindung weist die besonderen Vorteile auf, daß die einzelnen für die Behandlung wichtigen Teile, wie die UV-Lampen und die Rohrleitungen, unter sehr zweckmäßiger Ausnutzung vorhandener Räume leicht im Innern einer z. B. im Querschnitt runden Vorrichtung untergebracht werden können. Vor allem werden durch die voneinander getrennte Ausbildung der Strahlungsquellen und der Flüssigkeitsleitungen eine für manche Stoffe, insbesondere für Milch, schädliche Erwärmung weitgehend vermieden. Die neue Einrichtung gestattet, im gegebenen Fall die UV-Lampen hinreichend zu kühlen und ihre Anordnung in dem Behandlungsraum so zu treffen, daß das zu behandelnde Gut einer möglichst intensiven Beeinflussung durch die UV-Strahlen ausgesetzt ist. Auch die Auswechslung der Strahlenquellen und der Flüssigkeitsleitungen kann bei der neuen Einrichtung in besonders einfacher Weise vorgenommen werden. Die Verwendung der Apparatur im praktischen Betrieb bietet keinerlei

Figure A.43: Andreas Lembke, Hellmuth Bayha, Karl Krammer, Eugen Sauter, and other scientists developed and successfully implemented methods of using intense ultraviolet light to sterilize liquids and other materials [German patent DE 894,956, filed in 1940].

Erteilt auf Grund des Ersten Überleitungsgesetzes vom 8. Juli 1949
(WiGBl. S. 175)

BUNDESREPUBLIK DEUTSCHLAND

AUSGEGEBEN AM
21. MAI 1953

DEUTSCHES PATENTAMT

PATENTSCHRIFT

Nr. 877 100

KLASSE 53e GRUPPE 3

S 5727 IVa/53e

Dr. Andreas Lembke, Eutin (Holst.)-Sielbeck,
Dipl.-Ing. Hellmuth Bayha, Erlangen, Dr. phil. Karl Krammer, Berlin und
Dr. rer. nat. Eugen Sauter, Nürnberg
sind als Erfinder genannt worden

Siemens-Schuckertwerke Aktiengesellschaft, Berlin und Erlangen

Anordnung zur Bestrahlung, insbesondere Ultraviolettbestrahlung, von Flüssigkeiten

Patentiert im Gebiet der Bundesrepublik Deutschland vom 6. Juni 1940 an
Der Zeitraum vom 8. Mai 1945 bis einschließlich 7. Mai 1950 wird auf die Patentdauer nicht angerechnet
(Ges. v. 15. 7. 51)
Patentanmeldung bekanntgemacht am 18. September 1952
Patenterteilung bekanntgemacht am 2. April 1953

Es sind Anordnungen zur Ultraviolettbestrahlung von Flüssigkeiten, beispielsweise Milch, bekannt, bei denen die Flüssigkeit ein Rohr aus Quarz oder einem anderen für Ultraviolettstrahlung durchlässigen Stoff durchläuft und von außen her der Einwirkung der Ultraviolettstrahlung ausgesetzt wird. Die bekannten Anordnungen haben aber alle den Nachteil, daß sich eine ausreichende Abtötung der in der Flüssigkeit, beispielsweise in Milch, befindlichen Mikroben, also der Bakterien und Pilze, nicht erreichen läßt, so daß keine genügend lange Haltbarkeit erzielt werden kann.

Eine besonders vorteilhafte Anordnung ist zur Bestrahlung, insbesondere Ultraviolettbestrahlung, von Flüssigkeiten vorgeschlagen worden, welche aus einer Mehrzahl von in einem Bestrahlungsbehälter zueinander parallel angeordneten strahlungsdurchlässigen Flüssigkeitsdurchflußrohren und stabförmigen Bestrahlungslampen besteht, wobei die Flüssigkeit alle Durchflußrohre oder eine Gruppe derselben nacheinander durchfließt. Diese Anordnung ist den bekannten Anordnungen dadurch überlegen, daß die Milch bzw. die Flüssigkeit den Bestrahlungsraum mehrmals nacheinander durchläuft und in den von den Bestrahlungslampen umgebenen Durchflußrohren besonders gut der Einwirkung der Ultraviolettstrahlung ausgesetzt ist und somit auch in erhöhtem Maße entkeimt wird.

Gegenstand der Erfindung ist eine Anordnung, welche allen bekannten Ultraviolettbestrahlungsein-

Figure A.44: Andreas Lembke, Hellmuth Bayha, Karl Krammer, Eugen Sauter, and other scientists developed and successfully implemented methods of using intense ultraviolet light to sterilize liquids and other materials [German patent DE 877,100, filed in 1940].

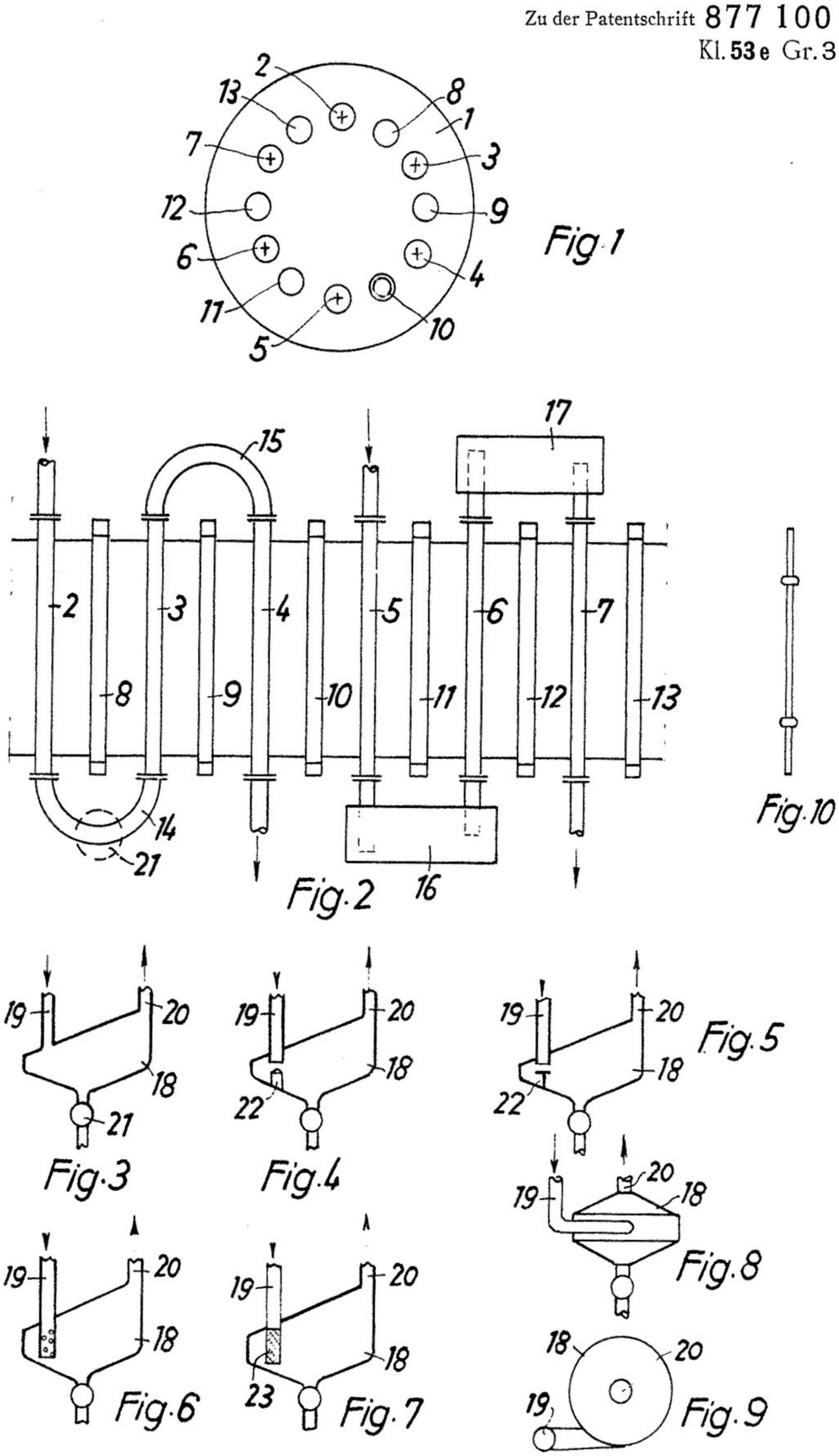


Figure A.45: Andreas Lembke, Hellmuth Bayha, Karl Krammer, Eugen Sauter, and other scientists developed and successfully implemented methods of using intense ultraviolet light to sterilize liquids and other materials [German patent DE 877,100, filed in 1940].

Erteilt auf Grund des Ersten Überleitungsgesetzes vom 8. Juli 1949
(WiGBl. S. 175)

BUNDESREPUBLIK DEUTSCHLAND

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DEUTSCHES PATENTAMT

PATENTSCHRIFT

Nr. 885 954

KLASSE **53e** GRUPPE 3

S 6519 IVa/53e

Dr. Dr. Andreas Lembke, Sielbeck bei Eutin (Holst.),
Dr. rer. nat. Eugen Sauter, Nürnberg und
Dipl.-Ing. Hellmuth Bayha, Erlangen
sind als Erfinder genannt worden

Siemens-Schuckertwerke Aktiengesellschaft, Berlin und Erlangen

Verfahren zur Behandlung von Milch mit Ultraviolettstrahlen

Patentiert im Gebiet der Bundesrepublik Deutschland vom 27. Juli 1943 an
Der Zeitraum vom 8. Mai 1945 bis einschließlich 7. Mai 1950 wird auf die Patentdauer nicht angerechnet
(Ges. v. 15. 7. 51)
Patentanmeldung bekanntgemacht am 4. Dezember 1952
Patenterteilung bekanntgemacht am 25. Juni 1953

Es ist bekannt, Milch zum Zweck der Sterilisierung auf eine höhere Temperatur zu erhitzen und sie mehr oder weniger lange Zeit der Einwirkung der Wärme auszusetzen, d. h. zu pasteurisieren.

Es ist auch bekannt, Milch kalt zu entkeimen, und zwar dadurch, daß man sie der Einwirkung von ultravioletten Strahlen aussetzt. Sofern hierzu die angelieferte Milch unmittelbar verwendet wird, zeigt diese im allgemeinen eine Temperatur von etwa 0 bis 15° C.

Wird nun Milch dieser Art in geeigneten Vorrichtungen der Ultraviolettbestrahlung unterworfen, so treten Schwierigkeiten auf, die den Erfolg der Maßnahme außerordentlich behindern bzw. überhaupt in Frage stellen. So hat es sich z. B. gezeigt, daß bei der Bestrahlung von Milch bei vergleichsweise niedriger Temperatur auf den Flüssigkeitsleitungen, in denen die Milch während der Behandlung geführt wird und in denen die Einwirkung des ultravioletten Lichtes erfolgt, Kondensationserscheinungen, und zwar des in der Raumatmosphäre vorhandenen Wasserdampfes auftreten. Die normalerweise aus Quarzrohren bestehenden Leitungen beschlagen dadurch, was den Durchgang der ultravioletten Strahlen weitestgehend verkleinert bzw. überhaupt verhindert.

Es ist zwar denkbar und technisch ausführbar, Mittel vorzusehen, durch die eine mechanische Entfernung dieses Kondensationsbeschlages auf den Flüssigkeitsleitungen herbeigeführt werden kann.

Figure A.46: Andreas Lembke, Hellmuth Bayha, Karl Krammer, Eugen Sauter, and other scientists developed and successfully implemented methods of using intense ultraviolet light to sterilize liquids and other materials [German patent DE 885,954, filed in 1943].

BIOS 784. ***Interrogation of Dr. Gross, Prof. Flury and Dr. Wirth on Industrial Hygiene and Toxicology.***

[This report includes examples of studies of cancers due to workplace chemical exposure; see pp. 2387–2389.]

BIOS 1229. ***Wool—Its Chemistry & Modification by Chemical Treatment in Germany.*** **pp. 6–7.**

Schöberl has been interested in the chemistry and enzymatic activity of papain as well as its reaction on wool. In connection with the latter effect, the activation of papain by bodies containing mercapto and disulphide groups appears to be of interest. Natural, i.e., unpurified, papain contains its own activators in the form of mercapto bodies. Removal of these, results in a purified papain of increased sulphur content as sulphate and organically bound as cystine and to a less extent as methionine. Studying the activation of the purified papain on the liquefaction of gelatin, Schöberl observed that a mercaptan such as thioglycollic acid was a strong activator of papain and so also was the disulphide dithioglycollic acid. [...]

This work is described in a paper by Schöberl and Fisch 'Über Schwefelgehalt und Aktivierbarkeit von Papain'—Biochemische Zeitschrift, 1939, 302, 310.

(a) Chromate Cancers

In 1910 a Dr. Pfeil at Ludwigshafen reported two cases of lung cancer amongst workers in a plant making quinone in which sodium dichromate was used as the oxidising agent. At that time there was considerable difficulty about diagnosing the complaint, and no more cases were detected for a considerable number of years. However, between 1933 and 1935 some seven or eight cases were reported from Griesheim, all of which had occurred in a plant making sodium dichromate. This was the first clue that dichromates or chromates could themselves be capable of giving rise to this disease, but the matter was complicated by the fact that the plant concerned was a somewhat old one and other hazards might have existed simultaneously. A careful survey was therefore made of all the plants in the I.G. engaged in chromate production, of which the chief were at Leverkusen, Urdingen and Bittefeld. All of these three plants were of modern construction, and this lessened the probability of other factors entering into the hazard. It was, of course, well known at the time of the construction of these plants that chromates possess an aggressive action on the nose and skin; precautions had therefore been taken. However, by means of routine lung x-ray examination, some fifty cases of lung cancer were brought to light over about ten years, involving perhaps 3 or 4% of the total number of workers at risk. All of these died within one or two years, since the disease develops extremely rapidly and in the ordinary way the chances of early recognition are slight. If, however, the disease was detected in time, arrangements were made to take the man concerned off the work and send him to a sanatorium. Secondary cancers, often in the brain and spine, were commonly seen. The most common site of the primary lesion was at the bronchial bifurcation, but occasionally they were also seen at the periphery of the lung, and on at least one of these Professor Sauerbruch carried out a spectacular operative removal, believed by Gross to have been successful.

Of those affected, about a quarter to a third had worked right up to the moment at which the illness had been detected. The duration of exposure varied greatly, from thirty down to about four years, though probably a period between ten and twenty years was most common. As with bladder cancers, to which reference is made below, the latent period may be very long - sometimes up to twenty years.

At first, the impression was gained that these lung cancers occurred only amongst workers engaged on the actual manufacture of chromates, and particularly at the stage at which the mass of sodium chromate is chipped out and dissolved in hot water, since the steam apparently carried off small particules of chromate, but in the latter years about seven cases have been

Figure A.47: Examples of studies of cancers due to workplace chemical exposure [BIOS 784].

found where lead and zinc chromates were used. Zinc chromate is a distinctly hazardous material, apparently, because it is somewhat soluble and both the ions concerned are harmful.

Gross had endeavoured to reproduce the production of these cancers in mice but without success. When the test atmospheres were set up by spraying in aqueous solutions, it was found that the selection of the proper concentration to use was inconveniently critical since concentrations slightly on the high side would kill most of the animals and concentrations on the low side would leave them wholly unaffected. He had also endeavoured to expose mice to the dry chromate dust, using the apparatus described in the Appendix, but this series of experiments had to be discontinued owing to trouble with disease amongst the experimental animals and the opportunity for repetition had not occurred.

In order to keep as close a check as possible, workers were examined clinically monthly and subjected to lung x-ray photography at six monthly intervals. It may be noted that the Italians who had been asked by the I.G. for their experience in this field, asserted that they had seen no chromate cancers, a point on which Gross was evidently unconvinced. He, incidentally, had seen one case of nasal cancer in a chromate worker, which appeared to have commenced in the antrum. (cf. VIII Internationalen Kongress für Unfallmedizin und Berufskrankeiten, Frankfurt a/M, 26-30 September 1938).

No cases of nose or lung cancer had been seen in the nickel carbonyl workers at Oppau.

Gross pointed out that there seems to be quite good evidence that lung cancers are now more common amongst the general population than they were formerly. They had indeed, moved up from fifth to second place amongst the cancers by the end of the war in Germany.

(b) <u>Bladder Cancers.</u>

Gross had made a special study of bladder cancers at Ludwigshafen in 1928 and 1930. This was an old plant which had been originally set up in 1863 and had gradually acquired a bad reputation amongst workers. A survey which he carried out showed that from the foundation of the factory up to 1932 there had been some 78 cases of bladder cancer, of which the first had been reported in 1895. Of these, he stated that, fully half were due to beta-naphthylamine and the majority of the remainder to aniline (but very few in comparison with the number of workers exposed), with a few cases, probably not exceeding three, due to benzidine. It was curious that up to this stage no cases of bladder cancers due to aniline had been reported from the U.S. (Manufacture of dyestuffs on a large scale in the U.S.A. dates from about 1915 - previously the greater part of the dyes used had been imported from Germany and Switzerland).

It seems that these cancers are specifically due to amino aromatic compounds. So far, they have not been encountered

Figure A.48: Examples of studies of cancers due to workplace chemical exposure [BIOS 784].

amongst workers handling the nitro aromatic substances. Both beta naphthylamine and aniline seem to be extremely dangerous in this connection, and as regards the former, Gross gave it as his opinion that one third of those who had been engaged in its production for ten years eventually develop the disease, and there are grounds for believing that nearly all the workers so employed over prolonged periods, develop it in the end. He believed that the cases which had been attributed to alpha naphthylamine are, in fact, due to the beta naphthylamine, which the substance normally contains as an impurity. Similarly he thought that it was uncertain whether the cases attributed to benzidine were not, in fact, due to the aniline, from which it was made. As compared with the age distribution of cancer onset in the normal population, the cases in the I.G. showed a distribution curve of similar shape, but advanced along the time axis by about three or four years. The latent period was often surprisingly long, and cases were known where a worker had been employed for ten to fifteen years in making beta naphthylamine and then had left for other work, but none the less developed bladder cancer after as much as twenty to thirty years later. The disease was scheduled for compensation purposes during the war.

Gross had administered collodium coated capsules of beta naphthylamine to rabbits to see if it would cause bladder cancer, but the animals died too quickly for any results to be obtained.

Haematuria was often seen with acute aniline poisoning, but such cases only rarely developed malignant disease, while on the other hand, cancer often occurred in an individual who had never exhibited haematuria. The disease often begins as a benign papilloma which then passes into a malignant carcinoma. In one interesting case the neoplasm was said to have been malignant from the start, but after operative removal it had re-appeared as a benign papilloma. Haematuria and painful micturition were often reported in workers engaged in handling nitrotoluidine, although no cancers had so far been identified. Gross had no experience with 5:chloro-orthotoluidine or with zylidine.

(c) Chlorinated Naphthalenes and diphenyls

Little trouble had been experienced in the manufacture of chlorinated naphthalenes at Leverkusen, but in the early days of their use at Troisdorf by the Dynamit A.G., the unpleasant skin affection known to the workers as "Pernakrankheit" was well known. The operations concerned had involved the use of large open baths of the material, and the vapours tend to

Figure A.49: Examples of studies of cancers due to workplace chemical exposure [BIOS 784].

BIOS 1253. *A Photoelectric Colorimeter (Photoelectric Absorptiometer) Designed by Professor R. Havemann, Produced by W. Kauhausen in Berlin-Dahlem.*

1. GENERAL.

When visiting the Materialprüfungsanstalt, Unter den Eichen 86 Berlin-Dahlem, we found that the firm W. Kauhausen, laboratory furnishers, has an office in one of the many rooms of that building not used any more for its original purpose.

This firm is producing a photoelectric Colorimeter (photoelectric absorptiometer), designed by Professor R. Havemann, director of the Kaiser Wilhelm Institut für Elektrophysik.

The instrument was seen in the store rooms of the firm and, in operation, in the pharmacological Institute of the University Berlin, the director of which, Professor W. Heubner, has been using it on a large scale for many years and confirmed its excellent performance.

The writer things the instrument presents several interesting features worth reporting. [...]

3. PUBLICATIONS ABOUT THE INSTRUMENT.

The instrument is described in detail and illustrated in Kauhausen's catalogue. Havemann has published papers about it in Biochemische Zeitschrift, vol. 301, 1939, p. 105; vol. 306, 1940, p. 224; 310, 1942, p. 378; Angew. Chemie 54, 1941, p. 105; Zschr. f. physikal. Chemie A vol. 188, 1941, p. 182, Beiheft 48 zur Zeitschrift des Vereins deutscher Chemiker.

4. DESCRIPTION OF THE INSTRUMENT.

The instrument has the form of a horizontal cylinder mounted on short legs. As can be seen in the diagram reproduced at the end as figure 1, the light source is in the left third; it is either a 100 Watt filament lamp, or a mercury, sodium or cadmium vapour lamp (Osram Spectral Lamps). These lamps are easily interchangeable.

Monochromatic light of the following wavelengths (mu) [nanometers] becomes thus available: 326 (Cd); 365 (Hg); 435–6 (Hg); 509 (Cd); 546 (Hg); 577–9 (Hg); 589–95 (Na); 644 (Cd).

Two photocells of the barrier layer type are arranged on either side of the lamp. The left hand one—the compensating cell—is permanently fixed and has an iris diaphragm. The other one, however, on the side of the liquid under test, is mounted on a revolving spindle, the rotation of which varies the distance of the cell from the light source. This is the measuring cell. [...]

Additional equipment for fluorescence measurements can also easily be fitted.

Light-absorbing filters can be inserted on either side, producing more or less monochromatic light according to the light source chosen.

A shunt is provided for varying the sensitivity of the galvo. [...]

7. CELLS FOR THE LIQUID TO BE TESTED.

The cells taking the coloured liquid are kept in position by a spring-loaded ring, enabling a quick interchange of cells of various sizes and guaranteeing exact location of the cell position.

In addition to simple cells with depths of 5, 10, 20, 30 and 40 mm, several cells of special design are available, as shown in figures 2 to 5.

Figure 2 shows a flow through cell with very wide inflow funnel; the side tube on the right is an air outlet. The wide tubes and the absence of bends make the operations of filling and emptying rapid and simple.

Figure 3 shows a cell with a jacket in which liquid from a thermostat fitted with a pump can be circulated, so as to keep the liquid under test at a constant temperature, which is particularly useful for physico-chemical measurements.

Figure 4 shows a cell specially constructed for photometric titrations. It is fitted with a stirring device which is shewn more fully in figure 5.

The side of the cell is joined tangentially at point A and the stirrer thus acts as a centrifugal pump. The contents of the cell are mixed very rapidly and this makes the photometric titration with this apparatus much more speedy than a potentiometric or amperometric titration.

The photometric titration enables colour changes too indefinite or too delicate to be followed by simple observation to be followed with ease and great accuracy. This allows very dilute solutions to be used and the use of indicators becomes unnecessary in some cases, e.g. with iodometric and bromometric methods. [...]

9. FLUORESCENCE MEASUREMENTS.

The light from the mercury lamp first passes the filter UG2, transmitting the UV line 365 mu and some infra-red rays only. The transmitted light then passes the cell with the liquid under test and then impinges upon a filter GG8 which absorbs the UV light but transmits the infra-red and any visible fluorescent light produced in the solution. The infra-red light is then retained by a further filter BG23, so that only the light produced in consequence of fluorescent material being present impinges upon the photocell. [...]

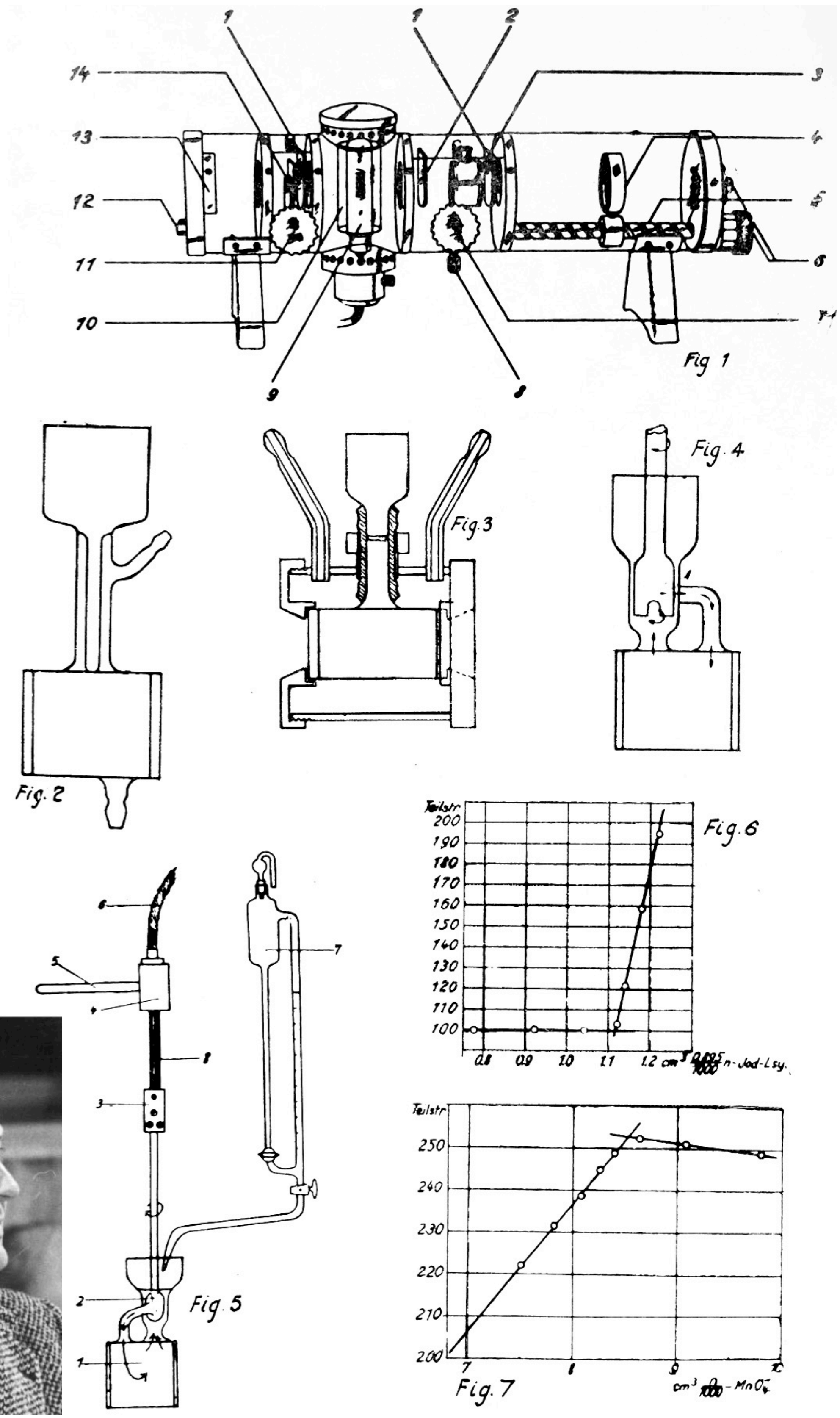
Quartz cells are available for this type of work but it appears from the description, that glass cells can also be used, although the fluorescence of the glass interferes to some extent.

10. ACCURACY CLAIMED.

An overall accuracy of 0.2 to 0.3% is claimed. [...]

[This instrument appears to be the first true spectrophotometer, and it has all of the essential features of modern spectrophotometers. Robert Havemann (German, 1910–1982) invented spectrophotometers no later than 1936, as shown by the patents on pp. 2393–2400. This BIOS report made clear that Havemann's spectrophotometers had been extensively used in Germany for many years before Allied investigators discovered them and sent detailed documentation (and perhaps whole instruments) to the United Kingdom and United States, which presumably copied the technology. Such spectrophotometers are now used worldwide for a wide variety of biochemical and chemical measurements.]

BIOS 1253



Robert Havemann (1910–1982) invented the spectro-photometer (1936)

Figure A.50: Robert Havemann invented the spectrophotometer in 1936 [BIOS 1253].

DEUTSCHES REICH

AUSGEGEBEN AM 23. OKTOBER 1943

REICHSPATENTAMT

PATENTSCHRIFT

№ 740593

KLASSE **42**h GRUPPE 17 02

H 149873 IX a/42 h

Dr. Robert Havemann in Berlin-Charlottenburg

ist als Erfinder genannt worden

Dr. Robert Havemann in Berlin-Charlottenburg

Einrichtung zum Vergleichen von Helligkeitswerten mit Hilfe von zwei Photozellen

Patentiert im Deutschen Reich vom 11. Dezember 1936 an

Patenterteilung bekanntgemacht am 2. September 1943

Die Erfindung betrifft eine Einrichtung zum Vergleichen von Helligkeitswerten, die für photometrische und kolorimetrische Messungen angewendet werden kann. Die hier in Betracht kommende Einrichtung gehört zu den bekannten Anordnungen, bei denen man zur Vermeidung verschiedener Schwierigkeiten zwei Photozellen benutzt. Die eine als Vergleichszelle bezeichnete Photozelle wird mit einer konstanten bzw. sich proportional der zu messenden Lichtintensität ändernden Lichtquelle beleuchtet. Die zweite als Meßzelle bezeichnete Photozelle wird von dem zu messenden Licht bestrahlt, wobei dessen Intensität in gemessener Weise geschwächt wird, z. B. durch eine geeichte Blende oder einen Graukeil. Bei Anwendung der normalen Kompensationsschaltung, die die Differenz der EMK der beiden Photozellen zu bestimmen gestattet, wirken sich die Helligkeitsschwankungen der Lichtquelle, die wegen der sehr steilen Helligkeitscharakteristik der modernen hochgeheizten Glühbirnen schon bei ganz geringen Schwankungen der Betriebsspannungen entstehen, nunmehr auf die Differenz der EMK der Zellen aus, aus deren Größe das Meßresultat sich unmittelbar ergibt. Abgesehen von diesem Fehler treten bei diesen Schaltungen noch die Schwierigkeiten auf, daß die elektromotorische Kraft (EMK) der Sperrschichtzellen der auffallenden Lichtmenge nicht proportional ist und die EMK bei wechselnder Belastung nicht reproduzierbar ist.

Die bisher üblichen Kompensationsschaltungen ergeben nun weitere Schwierigkeiten für die Messung. Einmal wird bei Nichtkompensierung die jeweils überkompensierte Zelle durch einen die Sperrschicht in verkehrter Richtung durchlaufenden Strom geschädigt. Sodann haben die zur Messung verwendeten Sperrschichtzellen die Eigenschaft, daß die EMK einer Zelle, die keine Arbeit über einen Widerstand leistet, nicht linear proportional der Intensität des auf sie auffallenden Lichtes ist. Die Sperrschichtzellen, die in der Technik auch als Gleichrichter Verwendung finden, haben in einer Richtung einen sehr großen, in der anderen Richtung einen kleinen Widerstand. Durchtritt eine belichtete Sperrschichtzelle ein der durch die Belichtung erzeugten EMK entgegengesetzter Strom, so tritt eine Aufhebung des die EMK erzeugenden Vorganges, eine Polarisation der Zelle ein, die bewirkt, daß nach der Polarisation die Photozelle bei der gleichen Belichtung nicht mehr dieselbe EMK erzeugt wie vorher.

Figure A.51: Robert Havemann invented the spectrophotometer in 1936.

Zur Vermeidung dieser Mängel ist eine Meßanordnung bekannt, bei der jede Photozelle für sich mittels eines Widerstandes in einen geschlossenen Stromkreis geschaltet ist und diese beiden Vergleichsstromkreise symmetrisch hintereinander über ein Nullinstrument verbunden sind. Hierbei wird die Lichtquelle, die zwischen der Vergleichszelle und der Meßzelle mit dem Untersuchungskörper angeordnet ist, so lange verschoben, bis die auf beide Zellen fallenden Lichtmengen einander gleich sind. Die auf beide Zellen fallende Lichtmenge ist hierbei jedoch je nach der Durchlässigkeit des Untersuchungskörpers verschieden.

Die angewendete Schaltung hat die Wirkung, daß die Photozellen auch bei Kompensation im Meßkreis dauernd Strom über die angegebenen Widerstände abgeben. Damit ist eine Gleichheit in ihrem Zustand gewährleistet. Außerdem sind die Photozellen gegen Strom verkehrter Richtung geschützt.

Es ist bekannt, daß die Photozellen bei einem ihnen angepaßten äußeren Widerstand maximale Leistungen erzeugen. Dieser Widerstand hängt von der Helligkeit des auf die Zelle fallenden Lichtstromes ab. Um aber bei der bekannten Schaltung maximale Leistung durch Anpassung des äußeren Widerstandes an die Photozelle zu erzeugen, ist notwendig, daß auf die Zelle immer die gleiche Lichtmenge fällt.

Deshalb wird die bekannte Schaltung gemäß der Erfindung dadurch verbessert, daß derjenige äußere Widerstand zu der Photozelle gewählt ist, bei dem sie die optimale Leistung erzeugt, und daß bei gleichbleibender Helligkeit der Lichtquelle jede Zelle bei jeder Abgleichung unabhängig von der Größe der zu messenden Helligkeit die gleiche Lichtmenge erhält. Die Intensität des zu messenden Lichtstromes wird durch ein optisches Regelungsmittel auf einen bestimmten Wert geschwächt, was daran erkannt wird, daß das eingeschaltete Nullinstrument wie bei der bekannten Anordnung keinen Ausschlag gibt. Die Helligkeit der auf die Zellen fallenden Lichtströme wird nur dann geändert, wenn sich die Helligkeit der Lichtquelle ändert oder wenn z. B. eine andere Lampe verwendet wird. Dieser definierte Helligkeitswert ermöglicht außer der Anwendung ideal angepaßter Widerstandswerte für die Ableitwiderstände der Photozellen auch die Durchführung der Messung, ohne daß Störungen durch Änderungen der Photozellencharakteristik entstehen können.

Es sind schon lichtelektrische Photometer mit zwei Photozellen bekannt, bei welchen die auf beide Zellen gelangenden Lichtströme gleichgemacht werden, doch handelt es sich bei ihnen um solche Photometer mit anderer Schaltung oder um solche, bei welchen die einander angeglichenen Lichtströme abhängig von der zu messenden Helligkeit sind.

Gemäß einer weiteren Ausgestaltung der vorliegenden Erfindung sind beide Stromkreise durch Wahl der Photozellen hinsichtlich ihrer Spannung gleich- oder nahezu gleichgemacht.

Auf der Zeichnung ist die Meßeinrichtung in einer beispielsweisen Schaltungsanordnung dargestellt. Im Zusammenhang mit der Erläuterung dieser Schaltung sollen Abänderungen, soweit sie durch die Ansprüche gedeckt sind, behandelt werden.

In dem angegebenen Schema sind mit Z_1 und Z_2 die beiden Photozellen bezeichnet. Jede Photozelle ist über einen Widerstand R_1 bzw. R_2 zu einem selbständigen Stromkreis geschlossen. Diese beiden Stromkreise sind symmetrisch, d. h. gleichliegend mit der Polarität ihrer Photozelle gegeneinander, zum vollständigen Meßstromkreis geschaltet, also Anschlußpunkt a_1 mit a_2 und b_1 mit b_2, wobei beispielsweise ein Nullinstrument G als Anzeigegerät Verwendung gefunden hat. Die Wirkungsweise der Schaltung ist folgende.

Jede der beiden Photozellen leistet über den ihr zugeordneten, ihrem inneren Widerstand angepaßten äußeren Widerstand R_1 bzw. R_2 einen bestimmten Strom. Die auf die Vergleichsphotozelle fallende Lichtmenge ist konstant, die auf die Meßzelle fallende Lichtmenge wird, z. B. in der Anwendung als Kolorimeter, durch gemessene Änderung der Schichtdicke der absorbierenden Schicht oder durch eine andere irgendwie geartete meßbare Änderung der die absorbierende Schicht durchtretenden Lichtmenge in ein bestimmtes Verhältnis zu der auf die Vergleichszelle fallenden Lichtmenge gebracht. Dieses Verhältnis wird in der Regel bei der Verwendung von gleichen Photozellen und gleichen Widerständen in beiden Kreisen bei l liegen und wird durch die Nullstellung des Instruments G angezeigt. Vor Erreichung dieses Helligkeitsverhältnisses kann kein Strom aus der stärker beleuchteten Zelle in verkehrter Richtung durch die schwächer beleuchtete fließen, sondern dieser fließt infolge der Ventilwirkung der Zelle des anderen Kreises durch deren parallelen Außenwiderstand ab.

Durch diese bekannte Schaltung wird erreicht, daß nicht die schlecht reproduzierbaren EMK der Zellen verglichen werden, sondern die der Belichtung linear proportionalen Stromstärken in den beiden durch die verwendeten Widerstände R_1 und R_2 gebildeten Stromkreisen. Der durch das Nullinstrument G bei Nichtkompensation fließende Strom fließt also durch den nebengeschlossenen Außen-

Figure A.52: Robert Havemann invented the spectrophotometer in 1936.

widerstand der jeweils überkompensierten Zelle und nicht durch diese Zelle selbst ab.

Es ist auch schon bekannt, Photozellen, die bei Belichtung einen Strom abgeben, in der Wheatstone-Brückenschaltung zu verwenden, wobei aber zu beachten ist, daß die Stromrichtung der Photozellen in ihren Brückenzweigen mit der Stromrichtung der Stromquelle für die Brückenspeisung übereinstimmt. Der Nachteil dieser Schaltung liegt darin, daß man die Photozellen mit Fremdstrom beschickt. Es wurde eben erörtert, welche Nachteile damit verbunden sind, und die Erfindung lehrt, daß man bei Verwendung von Photozellen mit eigener durch die Belichtung verursachter Stromabgabe überhaupt keiner fremden Stromquelle zum Erzeugen des Meßstromes bedarf.

Die zugeschalteten Widerstände R_1 bzw. R_2 jedes Stromkreises werden vorteilhaft der Eigenschaft der zugehörigen Photozelle nach EMK und innerem Widerstand angepaßt. Hierdurch kann beispielsweise erreicht werden, daß die beiden Zellen, die von ungleicher EMK sind, Stromkreise mit gleichen Leistungen ergeben, um die Zellen in bestimmter Höhe zu belasten.

Bei dieser Anpassung der Widerstandswerte muß, wie schon oben gesagt, der für die Messung gewählten Lichtintensität Rechnung getragen werden. Werden Messungen mit Hilfe verschieden intensiver Lichtquellen ausgeführt, so ist es zweckmäßig, den Ableitwiderstand gegen einen anderen zu vertauschen, der den neuen Lichtverhältnissen optimal angepaßt ist.

Der eine Stromkreis kann auch ein Stromregelungsmittel erhalten, z. B. dadurch, daß sein Widerstand regelbar ist. Man kann auch den Widerstand der beiden Stromkreise regelbar machen, wodurch man bei der Auswechslung der Photozellen von ihren Eigenschaften, ihrem inneren Widerstand und ihrer EMK unabhängig ist.

Man kann auch für einen Sonderfall beide Stromkreise durch bestimmte Auswahl der Photozellen mit festen Widerständen vollständig oder nahezu vollständig gleichmachen, um für die Werkstatt eine Meßeinrichtung zu schaffen, an der nach der Abgleichung für den Verwendungszweck keine unbefugten Änderungen vorgenommen werden können.

Mit der neuen Meßanordnung, deren Empfindlichkeit und Genauigkeit nur von der Lichtempfindlichkeit der Photozellen und von der Empfindlichkeit des Nullinstruments abhängt, lassen sich erfahrungsgemäß Resultate erreichen, deren Fehlergrenze nur etwa den zehnten Teil der bisher üblichen exakten Methoden beträgt.

Patentansprüche:

1. Einrichtung zum Vergleichen von Helligkeitswerten mit Hilfe von zwei durch dieselbe Lichtquelle bestrahlten Photozellen, von denen jede für sich mittels eines Widerstandes in einen geschlossenen Stromkreis geschaltet ist und diese beiden Vergleichsstromkreise symmetrisch hintereinander über ein Anzeigegerät verbunden sind, dadurch gekennzeichnet, daß derjenige äußere Widerstand zu der Photozelle gewählt ist, bei dem sie die optimale Leistung erzeugt, und daß bei gleichbleibender Helligkeit der Lichtquelle jede Zelle bei jeder Abgleichung unabhängig von der Größe der zu messenden Helligkeit die gleiche Lichtmenge erhält.

2. Einrichtung nach Anspruch 1, dadurch gekennzeichnet, daß beide Stromkreise durch Wahl der Photozellen hinsichtlich ihrer Spannung gleich- oder nahezu gleichgemacht sind.

Zur Abgrenzung des Anmeldungsgegenstandes vom Stand der Technik sind im Erteilungsverfahren in Betracht gezogen worden:

amerikanische Patentschrift Nr. 2 042 281;
B. Lange, Die Photoelemente und ihre Anwendung, 2. Teil, Leipzig 1936, S. 7.

Hierzu 1 Blatt Zeichnungen

BERLIN. GEDRUCKT IN DER REICHSDRUCKEREI

Figure A.53: Robert Havemann invented the spectrophotometer in 1936.

Zu der Patentschrift **740 593**
Kl. **42h** Gr. **17 02**

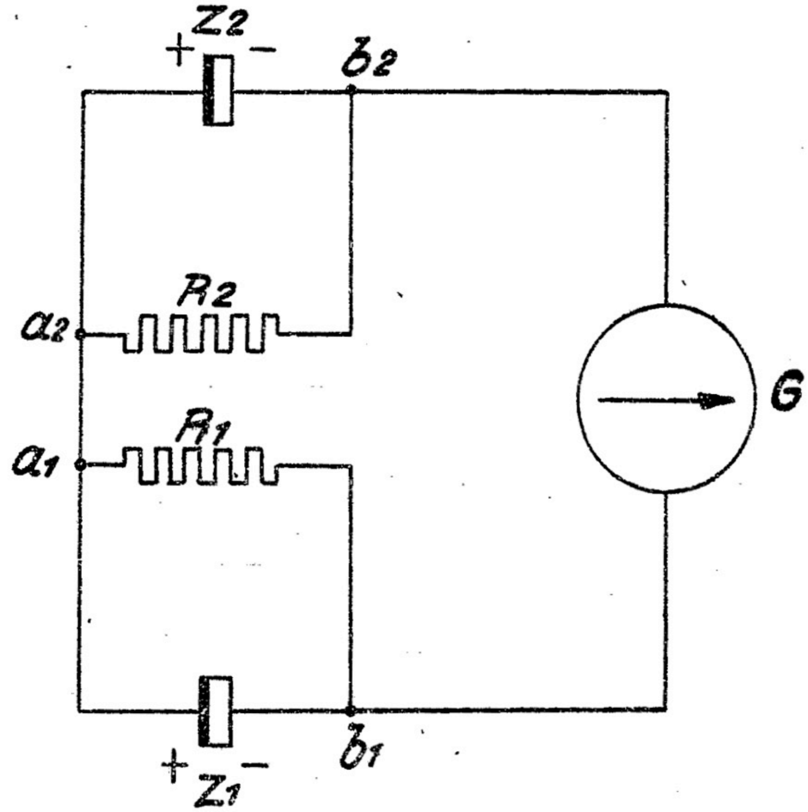


Figure A.54: Robert Havemann invented the spectrophotometer in 1936.

DEUTSCHES REICH

AUSGEGEBEN AM 10. FEBRUAR 1943

REICHSPATENTAMT

PATENTSCHRIFT

№ 731 494

KLASSE **42h** GRUPPE 17 02

H 158265 IX a/42 h

Dr. Robert Havemann in Berlin-Charlottenburg

ist als Erfinder genannt worden.

Dr. Robert Havemann in Berlin-Charlottenburg

Einrichtung zum Messen von Helligkeitswerten mit Hilfe von zwei lichtelektrischen Zellen

Patentiert im Deutschen Reich vom 11. Januar 1939 an

Patenterteilung bekanntgemacht am 7. Januar 1943

Es sind Einrichtungen zum Messen von Helligkeitswerten mit Hilfe von zwei lichtelektrischen Zellen und einer optischen Abgleichung der Lichtwege bekannt. Hierbei werden als zu vergleichende Helligkeiten beleuchtete, lichtzerstreuende Flächen, z. B. Matt- oder Milchglasscheiben, verwendet, die durch eine gemeinsame Glühlampe beleuchtet werden, um den Einfluß von Helligkeitsschwankungen der Lichtquelle auszuschalten. Zwar sind beleuchtete Mattscheiben als sekundäre Lichtquelle bei lichtelektrischen Messungen bekannt, jedoch dient diese Verwendung nur dem Zweck, die störenden Wirkungen der ungleichmäßigen Lichtempfindlichkeit der Zellen in den verschiedenen Punkten ihrer Oberfläche auszugleichen.

Bei dem Gegenstand der vorliegenden Erfindung dagegen ist als eigentliches Ziel gesetzt, eine für die Meßzellen maßgebliche Lichtquelle zu schaffen, die in der Art ihrer Lichtausstrahlung unabhängig ist von der Schichtdicke und der Art der zu untersuchenden lichtabsorbierenden Substanzen.

Bei Einrichtungen zum Messen von Helligkeitswerten mit Hilfe von zwei lichtelektrischen Zellen für photometrische oder kolorimetrische Messungen wurde bekannt, daß die Stellung der Mattscheibe für die Zuverlässigkeit der Messung von wesentlicher Bedeutung ist. Auf Grund dieser Erkenntnis wird gemäß der Erfindung bei einer Einrichtung zum Messen von Helligkeitswerten mit Hilfe von zwei lichtelektrischen Zellen und einer optischen Abgleichung der Lichtwege, bei welcher die zu vergleichenden Helligkeiten durch Beleuchtung von lichtzerstreuenden Mattscheiben erzeugt werden, die Milchglas- oder Mattscheibe feststehend zwischen der verschiebbaren Meßzelle und dem zu untersuchenden Medium angeordnet. Bei der Messung wird demnach die Milchglasscheibe von dem Licht beleuchtet, das, von der Lichtquelle kommend, die zu untersuchenden lichtabsorbierenden Schichten durchdrungen hat. Infolge der lichtzerstreuenden Eigenschaften der Milchglasscheibe ist der Strahlengang zwischen ihr und der Photozelle unabhängig vom

Figure A.55: Robert Havemann invented the spectrophotometer in 1936.

2 **731 494**

Strahlengang zwischen Lichtquelle und Milchglasscheibe, der seinerseits stark von der Schichtdicke, Brechkraft usw. der lichtabsorbierenden Schicht abhängt. Von der Art der zu untersuchenden lichtabsorbierenden Schicht hängt also bei dieser Anordnung nur die Helligkeit und nicht die Ausbreitung des die Photozelle treffenden Lichtes ab. Dies ist, wie gesagt, für die Zuverlässigkeit der Messung und für die Reproduzierbarkeit der Eichkurve von entscheidender praktischer Bedeutung.

Um den zu untersuchenden Körper in den Strahlengang zwischen der der Meßzelle zugeordneten Mattscheibe und der Lichtquelle einzuordnen, ist an dieser Stelle eine entsprechende Vorrichtung, z. B. ein Küvettenhalter, eingebaut.

Für die Messung der zu untersuchenden lichtabsorbierenden Körper oder Schichten ist für die Eindeutigkeit der Mattscheibe als sekundäre Lichtquelle von Bedeutung, daß die Küvette oder der zu untersuchende Stoff bei allen Messungen genau an derselben Stelle, nämlich möglichst nahe an die Mattscheibe herangerückt, zu stehen kommt. Diese Stellung wird nach weiterer Verbesserung der Erfindung dadurch gesichert, daß von den auf den beiden Seiten des Küvettenschalters angeordneten Blenden die der Lichtquelle zugeordnete Blende derart verschiebbar angeordnet ist, daß die zwischen ihr und der festen Blende eingesetzte Küvette in einer festen Stellung gegenüber der der Meßzelle zugekehrten Mattscheibe eingestellt wird.

Zur weiteren Erläuterung der Erfindung sollen an Hand der beiliegenden Zeichnung zwei Meßeinrichtungen beschrieben werden, bei welche folgendes Prinzip benutzt wird. Die auf die Meßzelle fallenden Lichtintensitäten sind durch ein optisches Regelungsmittel auf einen bestimmten festgelegten Wert zu bringen, während die Helligkeit an der Vergleichszelle unverändert gelassen wird. Mit Meßzelle ist diejenige der beiden lichtelektrischen Zellen bezeichnet, welche im Strahlengang der zu messenden Helligkeit liegt. Die Messung des Helligkeitswertes besteht darin, daß die Meßzelle in meßbarer Weise gegenüber der lichtzerstreuenden Fläche bewegt und derjenige Abstand der Meßzelle bestimmt wird, bei welchem die Meßzelle einen festgelegten elektrischen Zustand erreicht.

Die Meßzelle, auf deren Seite in bezug auf die die Beleuchtung abgebende Glühlampe die zu messende Helligkeit liegt, besitzt eine meßbare Verschiebung, aus der der Helligkeitswert nach erfolgter Abgleichung durch Einstellung der Meßzelle bestimmbar ist.

Auf der Zeichnung ist in Fig. 1 ein solches Meßgerät mit der erfindungsgemäßen Anordnung der Mattscheiben, der Blenden und der Küvette in einer für den Gebrauch in wissenschaftlichen Laboratorien zweckmäßigen Ausführung im Längsschnitt dargestellt. Fig. 2 zeigt ebenfalls im Längsschnitt eine geschlossene Ausführungsform, die für den allgemeinen praktischen Gebrauch bestimmt ist.

Nach Fig. 1 ist auf einer optischen Bank die lichtelektrische Vergleichszelle 1 in einem Rohr 2 eingebaut. Das für die Messung erforderliche Licht wird einer elektrischen Glühlampe 3, einer Natrium- oder Quecksilberdampflampe, entnommen, die von einem Gehäuse 4 mit Öffnungen 5 und 6 in Richtung der optischen Achse eingeschlossen ist. Vor die Vergleichszelle 1 ist eine lichtzerstreuende Scheibe, z. B. eine Milchglasscheibe 7, gesetzt. Für die Einstellung des Nullpunktes vor der Messung finden einstellbare Blenden, z. B. Irisblenden, Verwendung, und zwar ist eine Blende 8 für grobe Einstellung und eine Blende 9, die mit Hilfe eines Schraubentriebes 16 verstellt werden kann, für feine Einstellung vorgesehen. Die Meßzelle 10 ist in einem Rohr 11 mit Hilfe eines Triebes 12 und einer Zahnstange 13 verschiebbar gelagert. An dem der Lichtquelle 3 zugewandten Ende des Rohres 11 befindet sich eine Milchglasscheibe 18 und die Blende 19. Zwischen der Milchglasscheibe 18 und der Lichtquelle 3 ist eine Vorrichtung 14 zum Einsetzen einer Küvette für flüssige Stoffe oder zum Einschieben von festen Körpern, deren Lichtdurchlässigkeit oder Absorption untersucht werden soll, und die Blende 20 angeordnet. Die Blenden 19 und 20 sind feste Blenden und sollen dazu dienen, die durch Reflexe in der Küvettenwand entstehenden Randstörungen unwirksam zu machen. Mit Hilfe eines Handrades 15, das auf seinem Umfang eine Meßteilung trägt, kann an dem zugehörigen Zeiger 17 der Meßwert entsprechend der Einstellung der Meßzelle 10 abgelesen werden.

Die beiden lichtelektrischen Zellen 1 und 10 werden durch eine geeignete Meßschaltung nach dem Abgleichungsprinzip, z. B. Kompensation, Wheatstonbrücke und einem Nullinstrument, zusammengeschaltet.

Zum Einstellen der Meßeinrichtung wird die Meßzelle 10 mit Hilfe des Zahnstangentriebes 12 und 13 in die Nullstellung gebracht. Sodann wird die Helligkeit für die Vergleichszelle 1 mit Hilfe der Blenden 8 und 9 so eingestellt, daß das Nullinstrument keinen Ausschlag zeigt.

Sodann wird der zu untersuchende Körper, z. B. eine mit einer Flüssigkeit gefüllte Küvette, in den Halter 14 eingesetzt. Nun wird mit Hilfe des Zahnstangentriebes 12, 13 die Meßzelle 10 so weit verschoben, daß wiederum gleiche Helligkeit an der Meßzelle be-

Figure A.56: Robert Havemann invented the spectrophotometer in 1936.

steht, was daran erkannt wird, daß das Nullinstrument der Meßschaltung die Abgleichung anzeigt. Der Meßwert der Verschiebung der Zelle 10 wird nun an der Meßtrommel 15 abgelesen.

Die in Fig. 2 veranschaulichte Ausführung ist in einem rohrförmigen Gehäuse 21 vollständig eingeschlossen, das an den Enden kreisflächenförmige Stirnwände 22, 23 besitzt. An der Stirnwand 22 ist die Vergleichszelle 24 angeordnet. Vor dieser befindet sich eine mit Schraubentrieb 25 verstellbare Blende 26. In dem anschließenden Raum 27 des Gehäuses 21 ist eine Glühlampe 28 eingesetzt. Dieser Raum 27 wird auf der Seite der Vergleichszelle durch die Milchglasscheibe 29 abgeschlossen. Um ein Überheizen des Lampenraumes zu vermeiden, hat dieser eine Ventilationskappe 30 erhalten, die einen Schutz gegen austretende Lichtstrahlen besitzt. Anschließend an den Lampenraum 27 ist im rohrförmigen Gehäuse 21 ein Ausschnitt 32 ausgebildet, unter dem der Küvettenhalter 31 angebracht ist. Auf diese Weise können die Küvetten mit den zu untersuchenden Flüssigkeiten von oben her eingeschoben werden. Der Ausschnitt 32 ist durch Seitenwände 33, 34 des Küvettenhalters 31 lichtdicht abgeschlossen.

Die nach der Lichtquelle gekehrte unverstellbare Blende 45 ist im Küvettenhalter 31 verschiebbar angeordnet und mit einer Stellvorrichtung versehen und dient auf diese Weise zum Feststellen der in den Küvettenhalter 31 eingesetzten Küvette, so daß diese bei jeder Messung die gleiche Stellung gegenüber der vor der Meßzelle 35 liegenden Milchglasscheibe 44 erhält. Die Verschiebbarkeit der Blende 45 kann dadurch erreicht werden, daß sie mit einer Geradführung, bestehend aus einem Schlitz 46 und einem Stein 48, versehen ist. Um einen Zapfen des Steines 48 greift eine Gabel 47 eines Stellhebels 50, der bei 49 drehbar gelagert ist. Auf den Lagerzapfen 49 ist eine Schraubenfeder geschoben, die den Stellhebel 50 derart unter Spannung hält, daß die Blende 45 in den Küvettenhalter 31 axial hineingeschoben wird, so daß diese unter Federkraft gegen die eingesetzte Küvette gedrückt wird. Auch hier ist zwischen der Küvette und der Mattscheibe 44 eine Blende 52 zum Abfangen von Randreflexen vorgesehen.

Der übrige Raum des Gehäuses 21 schließt die verschiebbare Meßzelle 35 ein. Er ist gegenüber dem Küvettenhalter durch eine in die Querwand 34 eingesetzte Milchglasscheibe 44 abgeschlossen. Die Meßzelle 35 ist an einem Halter 36 angebracht, der an einer Führung 37 mit Hilfe einer Schraubenspindel 38 eine parallele Längsverschiebung erhalten kann. Die Schraubenspindel 38 ist zwischen der Küvettenwand 34 und der Gehäusestirnwand 23 drehbar gelagert. Zu ihrer Verdrehung ist an ihrem aus der Stirnwand 23 heraustretenden Ende ein Handrad 39 aufgesetzt. Zum Messen der axialen Verschiebung der Meßzelle 35 durch Verdrehen der Schraubenspindel 38 dienen Meßtrommeln 40 und 41. An der Meßtrommel 40 wird die Verschiebung entsprechend einer vollen Umdrehung der Spindel 38 und an der Meßtrommel 41, die mittels einer Zahnradübersetzung 51 zweckmäßig im dekadischen Verhältnis verdreht wird, die Verschiebung entsprechend einem Teil einer Umdrehung gemessen. Die Einstellung der Teilung an den Meßtrommeln kann an den Zeigern 42 und 43 abgelesen werden.

Die Anordnung ist so getroffen, daß die Vergleichszelle 24, die Glühlampe 28, der Küvettenhalter 31 und die Meßzelle 35 in der optischen Achse der Meßeinrichtung liegen. Durch das rohrförmige Gehäuse 21 und die kreisförmigen Stirn- und Zwischenwände sind die lichtelektrischen Zellen vollständig eingeschlossen, so daß Meßfehler durch fremdes Licht vermieden werden und die Messungen bei vollem Tageslicht ausgeführt werden können.

PATENTANSPRÜCHE:

1. Einrichtung zum Messen von Helligkeitswerten mit Hilfe von zwei lichtelektrischen Zellen und einer optischen Abgleichung der Lichtwege, bei welcher die zu vergleichenden Helligkeiten durch Beleuchtung von lichtzerstreuenden Mattscheiben erzeugt werden, dadurch gekennzeichnet, daß die auf der Seite der zu messenden Helligkeit angeordnete Mattscheibe (18, 44) zwischen dem zu untersuchenden Körper (Küvette) und der Meßzelle (10, 33) angeordnet ist.

2. Einrichtung nach Anspruch 1, dadurch gekennzeichnet, daß von den auf den beiden Seiten des Küvettenhalters (31) angeordneten Blenden (45, 52) die der Lichtquelle zugekehrte Blende (45) derart verschiebbar angebracht ist, daß die zwischen ihr und der festen Blende (52) eingesetzte Küvette in einer festen Stellung gegenüber der der Meßzelle (35) zugekehrten Mattscheibe (44) eingestellt wird.

Hierzu 1 Blatt Zeichnungen

BERLIN. GEDRUCKT IN DER REICHSDRUCKEREI

Figure A.57: Robert Havemann invented the spectrophotometer in 1936.

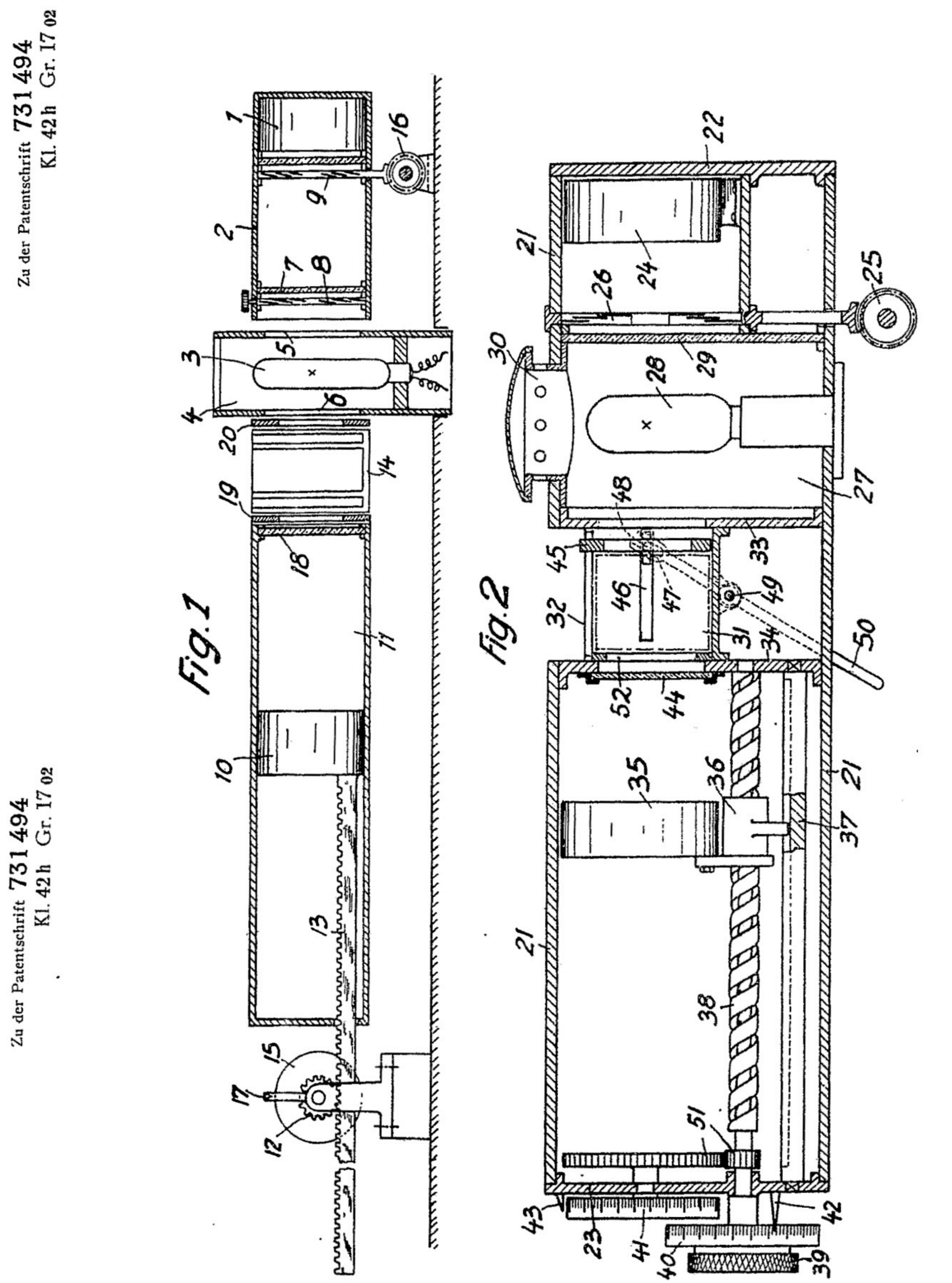


Figure A.58: Robert Havemann invented the spectrophotometer in 1936.

BIOS 1320. ***Preparation of Biological Products at Selected Targets in Germany.*** [Lots of vaccines, hormones extracted from organs, serums, etc.]

[pp. 81–82:]

Professor Kuhn was interviewed at FIAT Main-Hoechst[...]

3065 (i) Kuhn maintained that he at no stage proposed the oral administration of this drug. The substance is inactivated by protein (e.g. broth) with which it combines, and must be tested in a synthetic medium. It has been used effectively in local applications particularly in combination with sulpha drugs (for burns) as it is not inactivated by p-amino benzoic acid. Recent clinical reports are very favourable and Kuhn promised to have a summary of these prepared.

(ii) For intestinal infections experimental work and clinical trials have been carried out with the colourless diacetyl derivative of di-bromsalicil. This substance has a very low toxicity so that large doses can be given. It is however, very rapidly hydrolysed in the gut and thus a high local concentration of the hydrolysed drug can be achieved in amount above that rendered inactive by protein combination. A clinical trial on children with intestinal infections is being carried out under the supervision of Fr. Dr. Knöwenagel. Both drugs are, according to Kuhn, more expensive to produce than the usual sulpha drugs.

Other Investigations:

(i) The alkaloid claimed by Kuhn and co-workers to be present in Colorado beetle resistant strains of the potato plant and to be responsible for the protection of the plant has been isolated in a crystalline condition. It appears to be of the solanine type. The pure alkaloid has been shown to be markedly toxic to larvae of the Colorado beetle.

(ii) Work is being continued on the biochemistry of differential growth control but this was not discussed in detail. [...]

[pp. 85–86:]

Experimental work on the production of penicillin had been going on for at least 3 years at Elberfeld under the direction of Dr. Auhagen. During this time little progress appears to have been made, probably due to concentration by this firm on Marfanil [a sulfonamide antibiotic] and related compounds. In previous reports Auhagen had claimed to have produced penicillin assaying 200 units per mg. and to have obtained 50 units per ml. in broth with surface cultures. [...]

The strain he was using had been locally isolated and had been identified in England as Penicillium bruneo rubrum. [...]

It was intended to freeze dry the purified penicillin in bulk and weigh out into ampoules aseptically.

BIOS 1417. ***Food Preservation with Special Reference to Its Domestic Application.***

2. Plenora-Werke, Neuekampstrasse, Hamburg.

Herr Speck, the Manager, took us round and explained the process very thoroughly. We also spoke to several heads of departments, the laboratory director, and bakery manager. The firm was concerned entirely with the manufacture of a dried egg substitute from blood plasma. The process was started on an experimental scale in 1934, and went into production on a large scale on the outbreak of war in 1939. The factory was almost completely destroyed by bombs but was largely rebuilt in 1943. This was said to be the only factory in the world making this product from blood.

The blood came in from the slaughterhouses, some of which were close by, but a good deal also came from Denmark in casks (aluminium or lacquered) and preserved with ammonia. Every animal was vetted before slaughtering. The blood was first mixed with sodium phosphate or citrate to prevent coagulation, strained, then separated by centrifuging into the red and white fractions. Both parts were then cooled at a temperature of 2^oC. to 4^oC. in a refrigerator. It must not reach freezing point. The blood was stored at this temperature until required. Blood received from any distance was separated into red and white fractions and cooled before transport.

The two fractions were heated separately in an open steam-jacketed pan to remove about 50% of the water. Each part was then dehydrated in a spray-dryer of the type generally used for drying eggs or milk. The dried red fraction was sold for sausage-making[...]

The factory had been producing 5,000 Kg. of "Plenora" per day but could produce ten times that quantity if sufficient raw materials were available.

This process certainly produces a very useful and nutritious substitute for egg from slaughterhouse blood, which is wasted in this country [U.K.] in large quantities.

BIOS 1481. ***Albumen Substitutes from Fish: Further Report on Deutschen Eiweiss Gesellschaft.***

For the production of first grade high protein Eiweiss for medical and culinary purposes fresh skinned fillets of cod and haddock are used. This raw material gives a final product of little taste or smell and of high grade quality and solubility and is said to be better than egg albumen for most purposes where this material was formerly used. [...]

The whole process can be separated into the following stages:

(i) Preparation of raw material

(ii) Initial cooking and washing

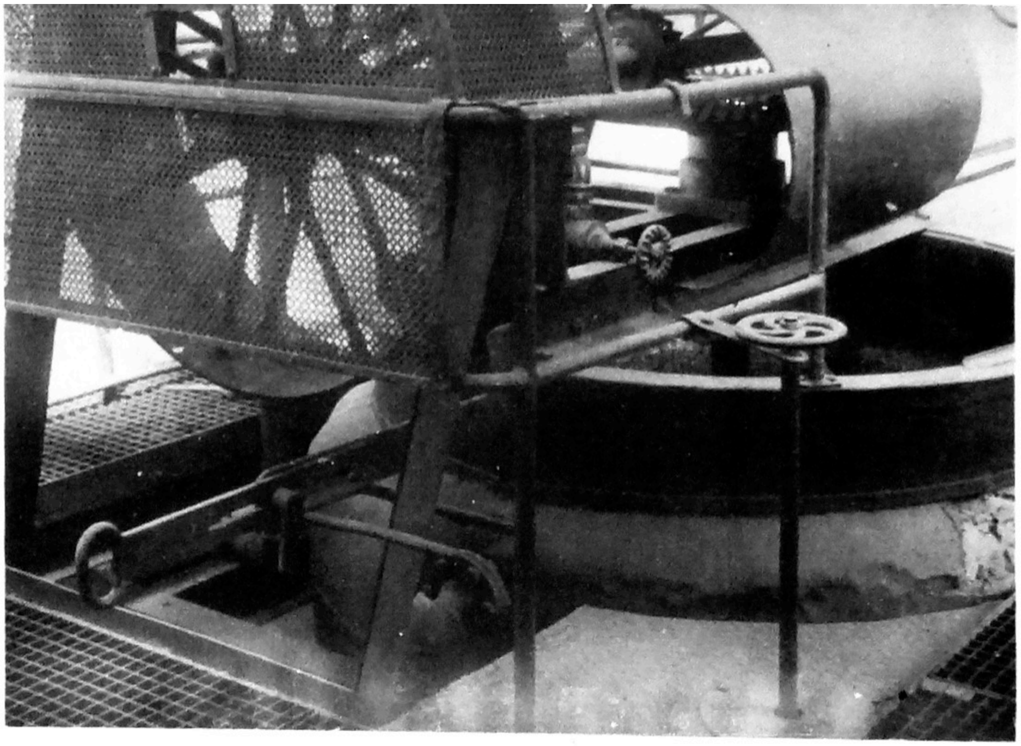
(iii) Pressing

(iv) Solvent extraction

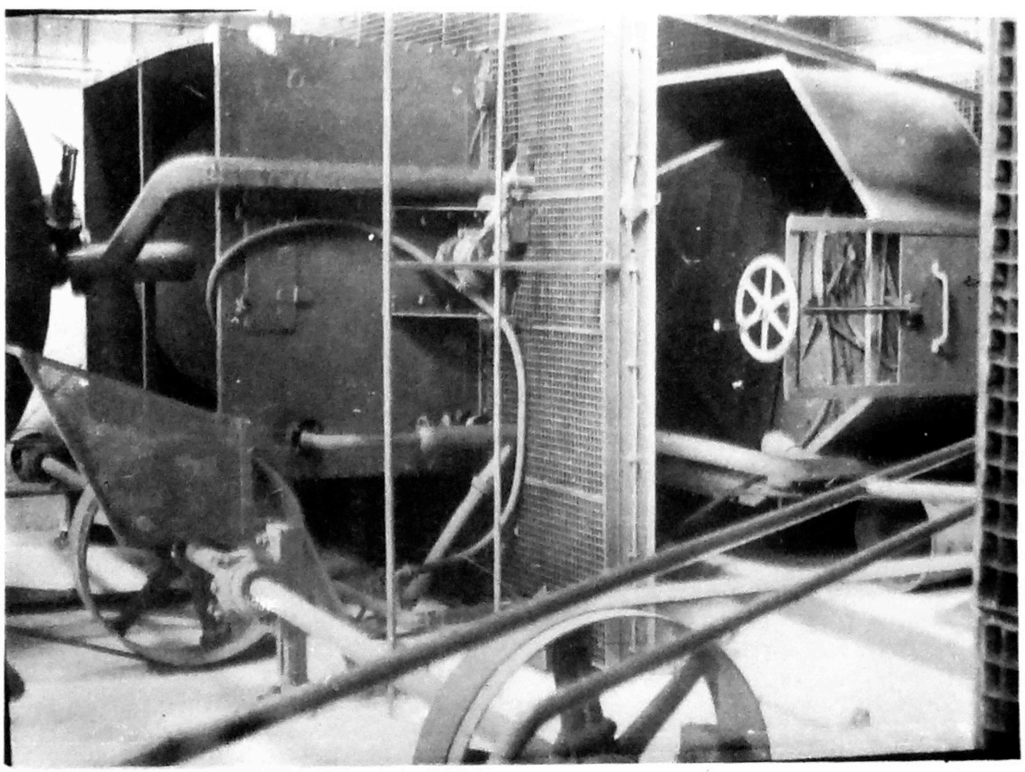
(v) Solvent recovery

(vi) Hydrolization (i.e. conversion of insoluble protein into soluble Eiweiss)

and it is therefore proposed to deal with these stages in their respective order. [...]



Steam Jacketted Acid Treatment Tank.



Perforated Reel Washer above, draining tank below.

Figure A.59: Protein purification and processing equipment for industrial manufacturing of artificial albumen products for medical and culinary applications [BIOS 1481].

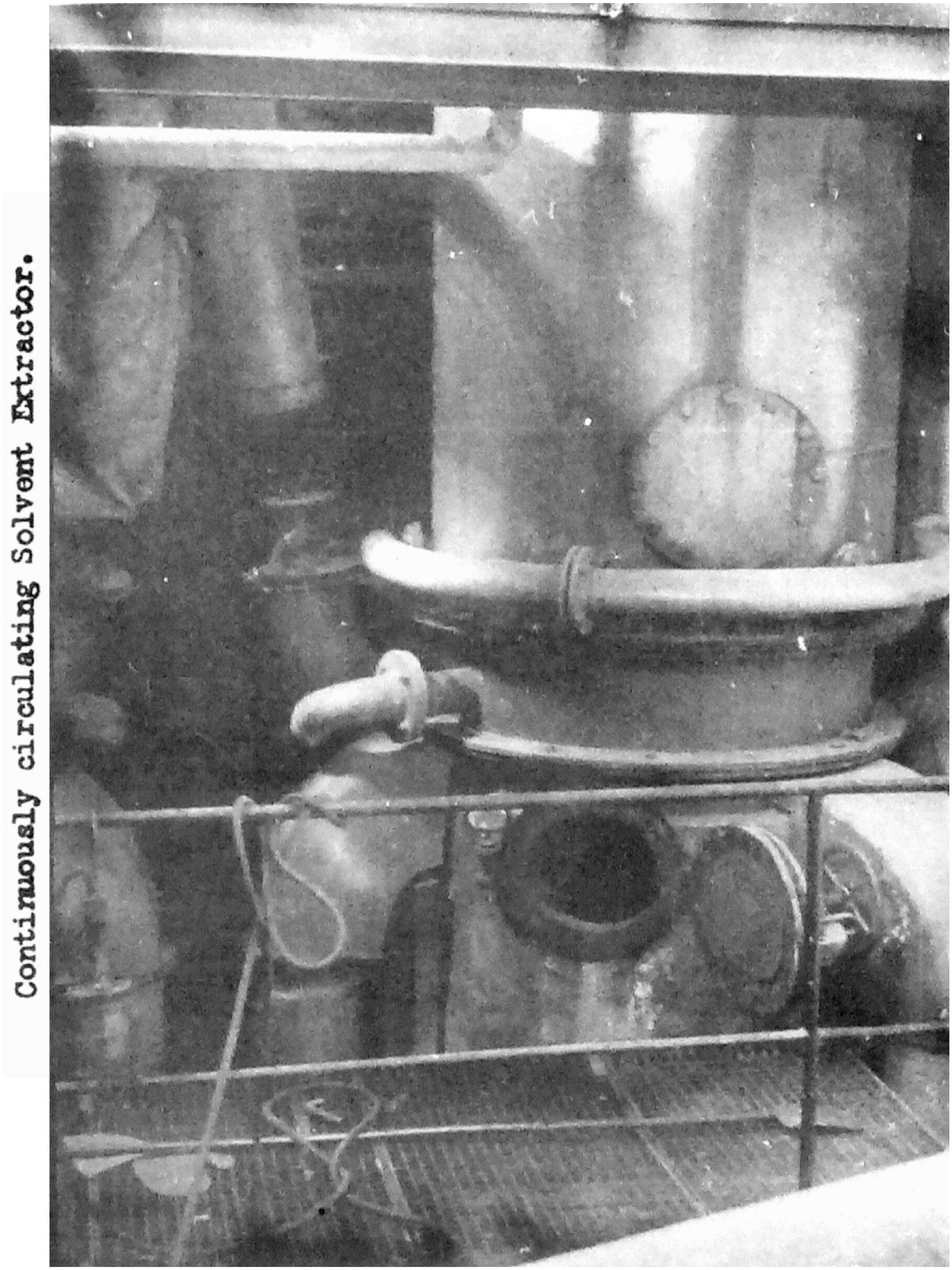
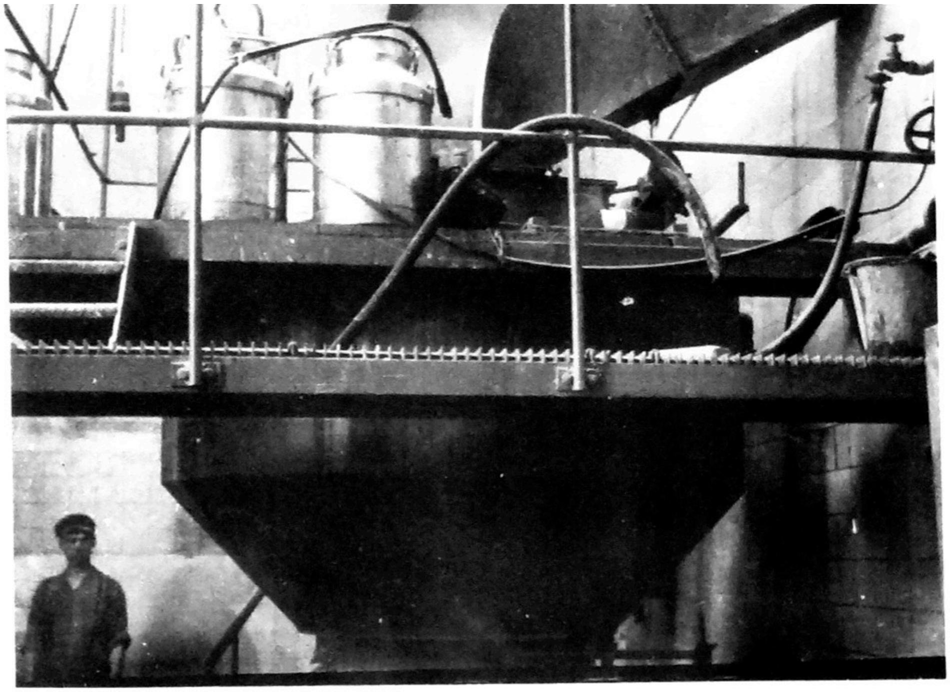
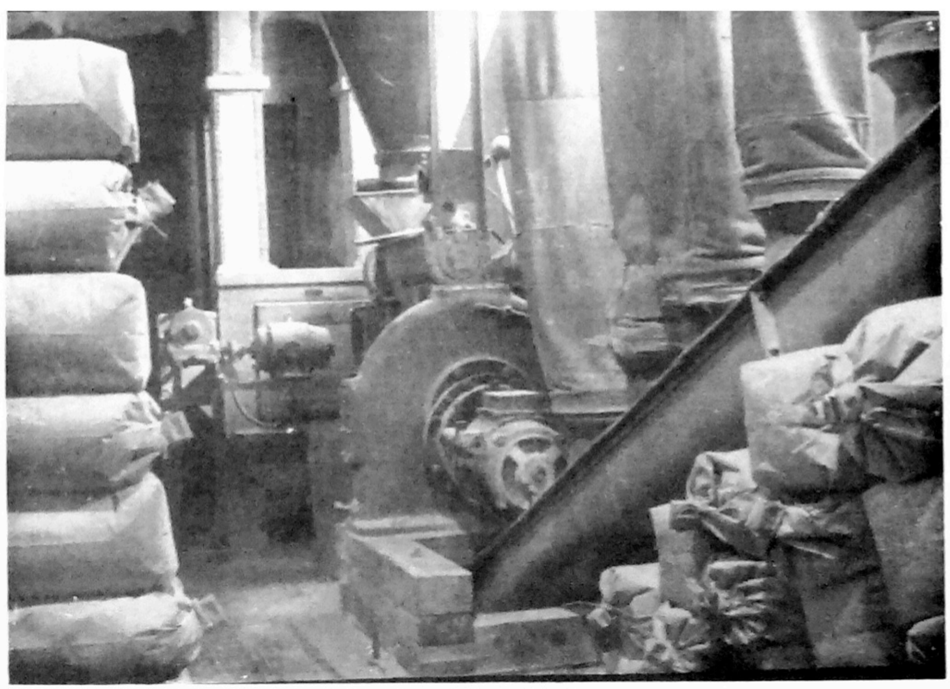


Figure A.60: Protein purification and processing equipment for industrial manufacturing of artificial albumen products for medical and culinary applications [BIOS 1481].



Steam Jacketted conical Petzholdt Mixer or
Digestion Tank.



Alpine Collople Mill 14,000 r.p.m.

Figure A.61: Protein purification and processing equipment for industrial manufacturing of artificial albumen products for medical and culinary applications [BIOS 1481].

Johanna Vogel-Prandtl. 2014. *Ludwig Prandtl: A Personal Biography Drawn from Memories and Correspondence.* Göttingen: Universitätsverlag Göttingen. pp. 3–4. http://library.oapen.org/handle/20.500.12657/31848

In the merchant's house in Hauptstraße, Alexander Prandtl [father of Ludwig Prandtl] rented a room from the widow Maria Ostermann as, at the age of 29, he started to work as a university teacher at the central agricultural school in Weihenstephan in Freising. He came from Munich, where he had been to school and then studied. After attending the polytechnic school, he gained the qualification of cultural engineer and obtained an appointment in this capacity with the federal state in Lower Bavaria. He subsequently received an appointment as professor of applied mathematics and amelioration2. In Weihenstephan, the following subjects were also taught: agricultural chemistry, agricultural equipment drawing and botanical drawing, the anatomy and physiology of domestic animals, forestry, meteorology, as well as other subjects. A brewery for study purposes was attached to the institution. Alexander carried out scientific work in the laboratory of the dairy research station. In the period between 1870 and 1875, he mostly worked on the construction of a continuously operating milk centrifuge. The idea of studying the separation of cream from milk using centrifugal force came from his brother Antonin, who had published a work on this subject eleven years previously in the polytechnic journal. He initially approached the practical task of making it possible to concentrate milk using his knowledge of chemistry. Alexander was successful in adding some significant improvements to his brother's discovery and, in 1875, he demonstrated his cream separator at the World's Fair in Frankfurt am Main, Germany. This machine, which was the first continuously operating milk centrifuge in the world, attracted great attention and provided the impulse for further developments. The same model was later exhibited in the *Deutsches Museum* (German Museum), in the Department of Dairy Farming. In the next few years, he developed a new piece of equipment: a milk separator that could be used to produce milk in parts without it creaming. In addition, Alexander published a number of scientific papers in the Weihenstephan Milk Journal, whose themes I would like to mention here for reasons of completeness. In 1877 the article "On the theoretically expected effect of creaming caused by centrifugal forces" and, in 1879, "The effect of currents caused by heating or cooling milk" were published.

Max Hupfauer. 1972. Milchgeräte. *Bayerisches Landwirtschaftliches Jahrbuch* 49:1: 105–124. https://mediatum.ub.tum.de/1554376

Die Erfindung der Zentrifuge wurde mit Recht als die Erlösung der Milchwirtschaft bezeichnet. An ihren Anfang darf man die 1864 von ANTONIN PRANDTL, einem Eleven der Technologischen Abteilung der Weihenstephaner Königlichen Landwirtschaftlichen Zentralschule, gebaute Eimer-Zentrifuge stellen. Ihm folgten WILHELM LEFELDT mit einer auf der Landwirtschaftlichen Weltausstellung in Bremen 1874 gezeigten Eimer-Schleuder. Einen weiteren Impuls erhielt diese Entwicklung wiederum aus Weihenstephan durch den Professor für Landwirtschaft, Dr. ALEXANDER PRANDTL, einem Bruder des vorhin erwähnten, der 1875 eine Milchschleuder konstruiert hatte, welche bereits den Gedanken der ununterbrochenen Entrahmung verwirklichen sollte (Abb. 1). Dieses Ziel erreichte jedoch erst 1878 der schwedische Ingenieur Dr. GUSTAV PATRlK DE LAVAL, welcher durch Veröffentlichungen über LEFELDT's Milchschleuder zu seiner bahnbrechenden Erfindung angeregt worden war (Abb. 2).

Absatzgebiete waren aber nur größere Molkereien, bis es DE LAVAL 1886 gelang, eine Ausführung für Handbetrieb herzustellen. Ausschlaggebend für die weitere Verbreitung wurde 1890 die Erfindung des Münchener Ingenieurs CARL FREIHERR VON BECHTOLSHEIM (Abb. 3), mit deren Hilfe störende Strömungen in der umlaufenden Zentrifugentrommel beseitigt und damit die Stundenleistung, die Entrahmungsschärfe sowie die Ausbeute wesentlich erhöht werden. DE LAVAL erkennt die weittragende Bedeutung dieser Erfindung und kauft das Deutsche Reichspatent Nr. 48 615 für die von ihm inzwischen gegründete Separatorenfabrik in Stockholm auf. Um die Jahrhundertwende hatten bereits mehr als 150 000 Maschinen das Werk verlassen und erst, als am 14. Juli 1903 das ALFA-LAVAL-Patent erlosch, konnten auch andere Fabrikanten gleichwertige Geräte liefern. Über die stürmische Entwicklung der Milchverarbeitung mit Hilfe von Zentrifugen gibt Professor MARTINYS Bericht Auskunft, wonach im Jahre 1907 bei einer Gesamtzahl von 347 649 landwirtschaftlichen Betrieben 336 906 Milchschleudern benutzten und in gewerblichen Betrieben außerdem 10 743 Molkerei-Zentrifugen gezählt wurden. Diese Mechanisierung der Rahmgewinnung war die Grundlage der weithin verbreiteten bäuerlichen Butterherstellung.

The invention of the centrifuge was rightly described as the salvation of the dairy industry. It began with the bucket centrifuge built in 1864 by ANTONIN PRANDTL, a student in the technology department of the Royal Agricultural College in Weihenstephan. He was followed by WILHELM LEFELDT with a bucket centrifuge exhibited at the World Agricultural Exhibition in Bremen in 1874. This development received further impetus from Weihenstephan through the Professor of Agriculture, Dr. ALEXANDER PRANDTL, a brother of the aforementioned, who had constructed a milk centrifuge in 1875, which was already intended to realize the idea of continuous operation (Fig. 1). However, this goal was not achieved until 1878 by the Swedish engineer Dr. GUSTAV PATRlK DE LAVAL, who had been inspired by publications on LEFELDT's milk extractor to make his groundbreaking invention (Fig. 2).

However, only larger dairies sold them until DE LAVAL succeeded in producing a version for manual operation in 1886. In 1890, the invention of the Munich engineer CARL FREIHERR VON BECHTOLSHEIM (Fig. 3) eliminated the disturbing currents in the rotating centrifuge drum, thus significantly increasing the hourly output, the skimming sharpness, and the yield, which was decisive for further distribution. DE LAVAL recognized the far-reaching significance of this invention and bought the German Imperial Patent No. 48,615 for the separator factory he had since founded in Stockholm. By the turn of the century, more than 150,000 machines had already left the factory and it was only when the ALFA-LAVAL patent expired on 14 July 1903 that other manufacturers were able to supply equivalent devices. Professor MARTINY's report provides information on the rapid development of milk processing with the aid of centrifuges, according to which in 1907 336,906 milk centrifuges were used on a total of 347,649 farms and 10,743 dairy centrifuges were also counted on commercial farms. This mechanization of cream production was the basis of widespread farm butter production.

Sonderdruck aus „Bayerisches Landwirtschaftliches Jahrbuch", 49. Jahrgang, Heft 1/1972

Milchgeräte

Von Max Hupfauer, Weihenstephan[1])

Die Erfindung der Zentrifuge

Die Erfindung der Zentrifuge wurde mit Recht als die Erlösung der Milchwirtschaft bezeichnet. An ihren Anfang darf man die 1864 von Antonin Prandtl, einem Eleven der Technologischen Abteilung der Weihenstephaner Königlichen Landwirtschaftlichen Zentralschule, gebaute Eimer-Zentrifuge stellen. Ihm folgten Wilhelm Lefeldt mit einer auf der Landwirtschaftlichen Weltausstellung in Bremen 1874 gezeigten Eimer-Schleuder. Einen weiteren Impuls erhielt diese Entwicklung wiederum aus Weihenstephan durch den Professor für

Abb. 1: Milchzentrifuge von A. PRANDTL, 1875
Abb. 2: Milchseparator von G. DE LAVAL, 1879
Abb. 3: Milchschleuder mit Tellereinsatz von C. FREIHERR VON BECHTOLSHEIM, 1890

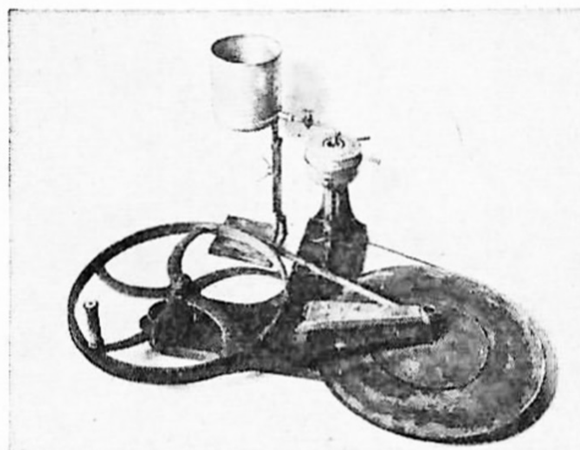


Abb. 2

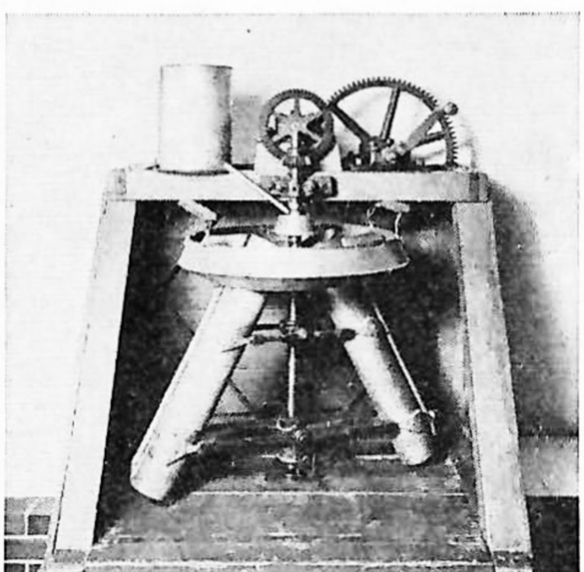


Abb. 1

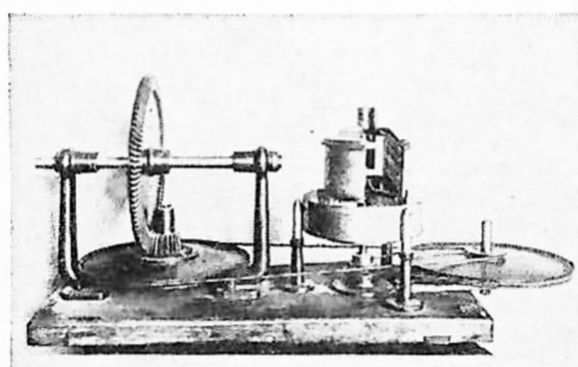


Abb. 3

1) Siehe „Geschichte der Landtechnik", DLG-Verlag, Frankfurt 1969, S. 1 ff.

Figure A.62: Centrifuges for milk separation and other applications were first developed in the German-speaking world, beginning no later than 1864 [https://mediatum.ub.tum.de/1554376].

BIOS 1487. *Chemical Laboratory Instrumentation in Germany.* pp. 101–109.

APPENDIX 2

TRANSLATION

THE PHYWE Ultracentrifuge

Physikalische Werkstatten A.G. Göttingen (Hann.)

Development of the Ultracentrifuge

In 1923, The Svedberg and J. B. Nichols built a centrifuge in which optical observation of the sedimentation of dissolved particles was possible during the rotation. [...]

Characteristics of the PHYWE Ultracentrifuge

Phywe A.G., Göttingen, and G. Schramm (Kaiser Wilhelm Institut für Biochemie, Berlin-Dahlem) developed jointly an ultracentrifuge, with air drive, which is simple to operate and within the means of every laboratory, but which, nevertheless, possesses a sufficiently high separating power. The choice of an air drive, in conjunction with a special damping device, ensured smooth running of the centrifuge. In its simplest form, the Phywe ultracentrifuge is suitable for preparative work. It can, however, also be fitted with a second rotor for optical observation and hence for analytical work. The optical method adopted is the “schlieren” method, but the apparatus is constructed so that the scale method can also be used. [...]

General Considerations on Measurements with the Ultracentrifuge

The ultracentrifuge is one of the most important instruments for the investigation of high molecular or colloidal substances. The field of application lies in the region where most chemical and physical methods of separation and characterisation of the substances fail. The ultracentrifuge serves for the determination of the size and the homogeneity of a molecular species. For this purpose two methods are used: (1) Determination of the sedimentation velocity, (2) the sedimentation equilibrium. [...]

Applications of the Ultracentrifuge

The ultracentrifuge can be used for the investigation of the most varied range of substances. Doubtless the greatest successes have been obtained in the field of the proteins, but promising work has also been done in the case of the carbohydrates, polystyrols, and similar organic products, inorganic colloids and inorganic salts.

The work on the proteins has shown that the naturally occurring proteins are, in respect of molecular weight, always homogeneous substances. Even complex systems such as serum (References 9 and 10) or milk proteins (Reference 11) can be analysed with the aid of the ultracentrifuge. They are always resolved into a limited number of homogeneous components. Systematic investigations of the proteins from different species have led to interesting genetical relations. In the examination of enzymes, sera and antibodies, snake venom and other physiologically active proteins, the ultracentrifuge has strikingly proved its value (Reference 3). The newer developments in the field of virus proteins and bacteriophages would be inconceivable without the ultracentrifuge. (For the application of the ultracentrifuge in virus research see Reference 12). [...]

References: [...]

3. T. Svedberg, Koll. Zeit., 1938, 85, 119.

9. P. von Matzenbecher, Biochem Z, 1933, 266, 226.

10. A. S. McFarlane, Biochem. J., 1935, 29, 660.

11. K. O. Pedersen, Biochem. J., 1936, 30, 948.

12. Handbuch der Virusforschung, R. Doerr u C. Hallauer, Julius Springer (1938).

[Centrifuges for milk separation and other applications were first developed in the German-speaking world, beginning no later than 1864 (pp. 2406–2408).

The ultracentrifuge described in BIOS 1487 was one of several that were developed by Gerhard Schramm for his groundbreaking research on viruses and proteins.

Ultracentrifuges are now extensively used in biology and chemistry laboratories worldwide.

The next page shows a diagram of the ultracentrifuge from BIOS 1487.]

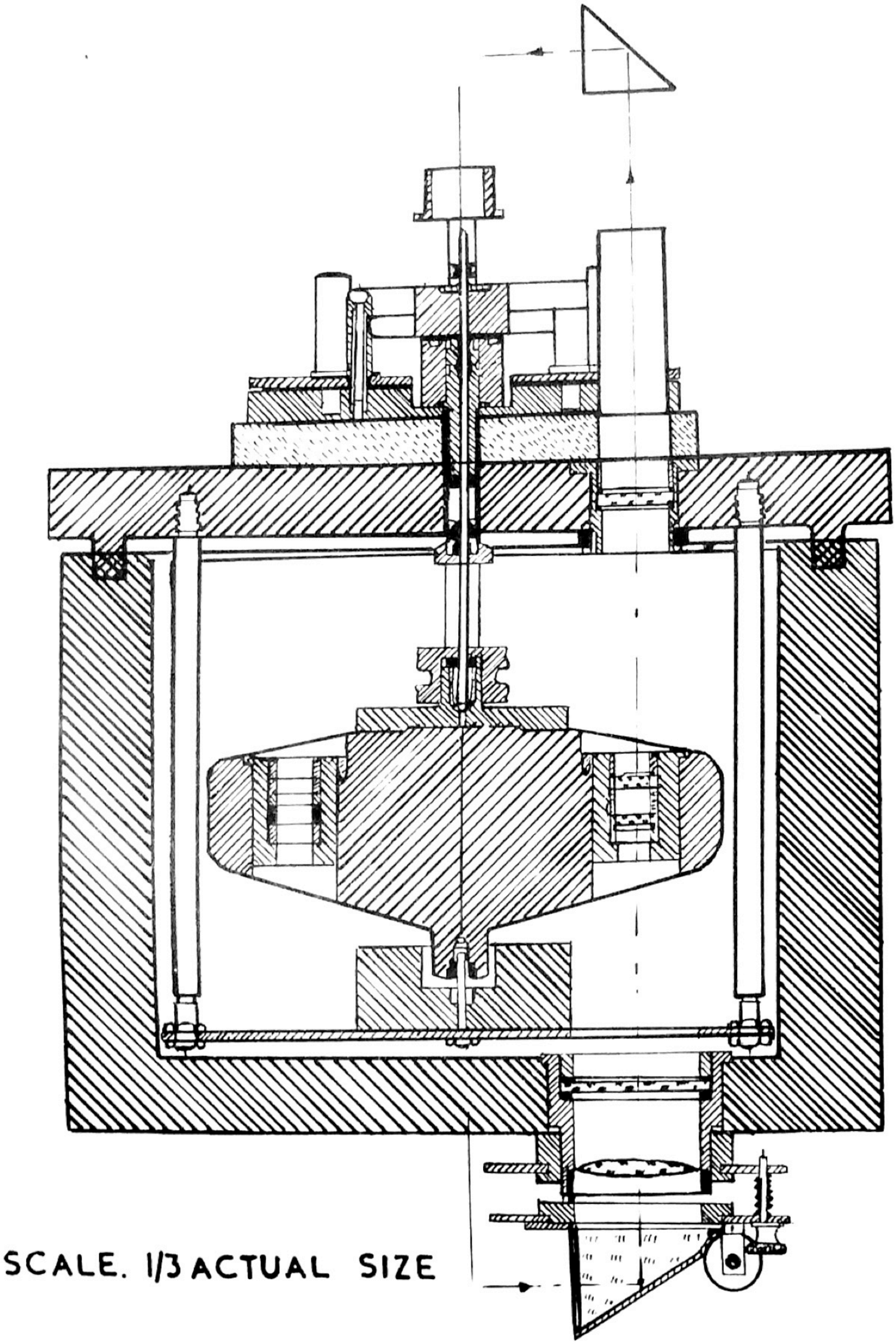


Figure A.63: Ultracentrifuge developed by Gerhard Schramm and collaborators beginning in the 1930s [BIOS 1487].

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Table 1

Viscosity at 20°C, as determined in a Hoeppler Falling Ball Viscosimeter, of various Milei additives in 2% Aqueous Solution.

Additive	Viscosity centipoises
Fruchtkernmehl	1300 - 2000
Tylose	200
Bohnenmehl	50
Kefir-Kasein	20
Starch	10 - 20
Wheat Flour	6 - 10

On these figures and apparently also in practical experience the Fruchtkernmehl was greatly superior to any of the substitutes in performance. At the time the plant was visited the additive in use was Bohnenmehl (bean meal).

The steps in the process for making Milei G are as follows:-

1. The starting product is skim-milk; whey is not satisfactory. The milk should not be more acid than 8 S.H. units (0.18% lactic acid, see below) and it should be neutralised with sodium bicarbonate to an acidity of 7 S.H. units.

2. The skim-milk is concentrated in vacuum evaporators to approximately 40% solids. The degree of concentration at this stage determines the specific volume of the final dried product. A lower concentration gives a "fluffy" product (specific volume = 50 cc., see below) which is the form preferred for baking purposes, while a higher concentration gives a more dense powder (specific volume = 20 cc). Milei G is at present produced in the latter form since it is more economical in packaging materials which are in short supply.

At the Stuttgart plant the evaporating equipment consisted of 2 aluminium vacuum pans and 1 stainless steel pan, each evaporating about 2000 litres of water per hour at a temperature of 50-60°C and a vacuum of 50-100 mm. Hg.

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3. The condensed milk is cooled on an open-type cooler to 10-15°C., then run into a mixing pan with a propeller-type agitator. There are added the following ingredients:-

(a) Bohnenmehl (bean meal) as a slurry in a small amount of water and in the proportion 3-5 kg. per 1000 litres of original skim-milk.

(b) Color in the form of a water-soluble edible yellow dyestuff in the proportion 300 g. per 1000 litres of original skim-milk.

(c) Disodium hydrogen phosphate ($Na_2H PO_4$) in an amount sufficient to bring the pH value to 7.5. This adjustment is made with the aid of "Lyphan" test papers and the accuracy of the control is probably not better than ± 0.2 pH units.

According to Dr. Demmler, the optimum pH to which the milk should be adjusted at this stage may be different for different milks. Apparently during Milei manufacture in Normandy it was necessary to adjust the pH of the milk to a level different to that adopted in Germany. However, the pH must not be lower than 7.0 otherwise difficulties are encountered in drying.

It is not necessary to hold the mix at this stage any longer than is necessary for pH adjustment and mixing and it was stated that it is desirable to carry through the whole process without delays.

4. The mix is roller-dried to 3-4% moisture. Three types of roller dryers were in use at the Stuttgart plant, single roller and double roller conventional types and also a new type of double roller dryer built by Escher Wyss, Ravensburg, 1946. The novel feature of the latter machine is the means by which the milk is applied to the rollers (see figure). The condensed milk is fed into narrow half-cylindrical troughs running parallel with the rollers and is picked up from these troughs on a large number of small discs rotating on a horizontal shaft. Then the milk is blown off the discs on to the dryer drum by means of small air-jets mounted on each side of each disc. The air pressure in the jets is only 2-3 lb/sq.in.

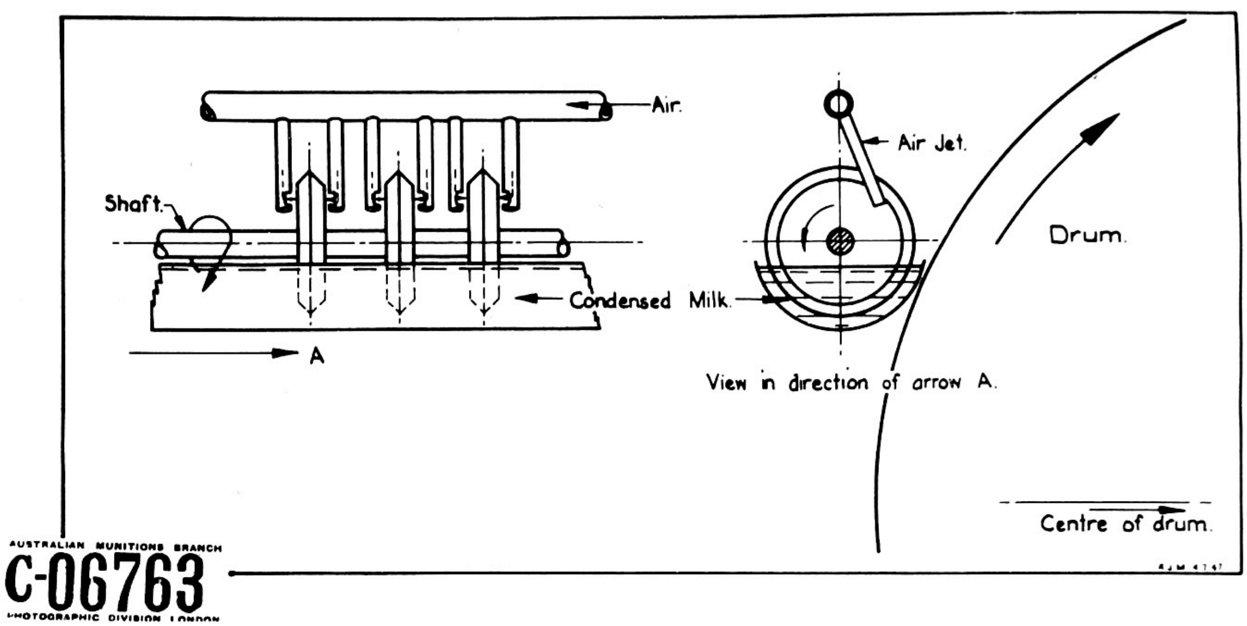

Figure A.64: Protein purification and processing for industrial manufacturing of Milei artificial albumen products [BIOS 1513].