Chapter 6
Research and Use of Nuclear Energy—Its Ambivalence(s) in Historical Context

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Abstract The discovery of a scientific fact is initially not ambivalent; only in its possibilities of use does its ambivalence become apparent. But the socially evaluated positive uses and negative misuses of scientific knowledge cannot be clearly distinguished, and both can also appear ambivalent in turn. In this sense, consequently, scientists already bear responsibility for their discoveries. Moreover, in the case of experimental research, the question must be asked, to what extent its realization already interferes with what is happening and thus acquires an ambivalent character (which, however, must be distinguished from the ambivalence of its use). With those issues in mind, the article discusses the questions raised by the discovery and early use of nuclear energy.

Throughout the history of science, it has been repeatedly discussed and stated that scientific knowledge may be used for both good and evil (metaphorically: blessing and/or curse, etc.) for humanity, whose organized cognitive activity it represents, and that the perception and analysis of this phenomenon has consequences both for the individual and collective behavior of scientists and for the social regulation of scientific activity at the cognitive as well the applicative levels.

The approach to this problem was essentially on two levels. On the *first*—relatively superficial—level, science itself appears to be neutral (neither good nor bad),

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while its applications can be qualified as either good (use) or bad (misuse). It is assumed that the use (for the good) and misuse of scientific knowledge can be clearly distinguished from each other and that the problem can in principle be solved if the misuse is reliably prevented—whether by legal regulations, rational decisions of conscience by scientists or the interaction of both.

On the *second*—deeper—level, it becomes clear that the distinction between good and evil in relation to science is only feasible up to a certain limit, which depends on and changes with historical circumstances, but not absolutely. In its core zone, scientific recognition is always *both* an enabler of and a threat to human and social existence and evolution, because—not unlike the human work from which it has grown—it inevitably intervenes in the integrity of nature (and society). One cannot have one without the other, but must accept and deal with the contradictory unity of these two polar provisions. The ambivalence concept has its place on this level.[1] It remains weakly defined and controversial. The intention of this essay is not to intervene directly in these controversies with definitional efforts. Rather, the aim is to enrich the material basis for relevant efforts in the theory of science by presenting and discussing some "features" from the recent history of science. Whether or not the ambivalence concept may be more precisely defined or concretized for specific situations—what is decisive is not the duality of the two polar aspects alone, but their interrelation, their contradictory unity.

When we speak of good/bad or benefit/damage in everyday language, it is quite clear that we are dealing here with *evaluations*, references to human interests, or even to existential determinations of human existence. This fundamental reference is often obscured when the term "ambivalence" comes into play, which should probably be understood more as an expression of the attempt to reflect theoretically on an intuitively perceived and everyday-language problem of science and its social existence. If one assumes that the ambivalence concept in scientific analysis does not replace, but rather explicates, everyday language term pairs such as good/evil or benefit/harm, then one must at least demand that such an explication relates the *cognitive* and *ethical* aspects of science. If this does not happen, then the reflection is under-complex, and there is no reason to use the term "ambivalence" here. But if one establishes such a relationship, then extremely complex relationships arise.

The history of nuclear energy research is, as will be shown below, a prime example of such complications. A widespread but naive way of dealing with the ambivalence problem in nuclear physics is, for example, to claim that the use of nuclear physics knowledge for weapons development is evil, but its use for energy

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[1] The term ambivalence was first introduced at the beginning of the 20th century by the Swiss psychiatrist Eugen Bleuler (1857–1939) [Bleuler, E.: Die Ambivalenz. Zürich: Schulthess & Co., 1914]. Actually, it simply means ambiguity or polyvalence, especially in psychology the coexistence of opposing feelings and thoughts. In the meantime, the term has found its way into colloquial language and is used in a wide variety of fields, especially by science and technology, and—as is so often the case—this term is usually interpreted only one-sidedly and is used primarily to indicate negative consequences of technical developments. Cf. e.g., Fratzscher, W.: Zu Risiken und Nebenwirkungen lesen Sie den Sicherheitsbericht oder fragen Sie… In: Sitzungsberichte der Leibniz-Sozietät 112 (2011), pp. 131–141 (here p. 131 f).

production is good. In the historical–political reality, however, the creation and further development of nuclear weapons took place in confrontational situations between hostile states or blocs with the consequence of an extreme relativization of the good–evil polarity: one's own weapons are good, whereas the (similar) weapons of the enemy are evil. In the use of nuclear physics for energy production, the ambivalence of cognition and action becomes apparent in a different but no less drastic way: (positively evaluated) energy production is inextricably linked to non-eliminable side- or consequential effects, which in some countries, including Germany, are considered so negative that they justify the phasing out of nuclear energy. Other countries, on the other hand, do not share this assessment and continue to develop and build new generations of nuclear power plants.

In a conversation in 1941 with Friedrich Houtermans (1903–1966) about the possibility of an atomic bomb, Max von Laue (1879–1960) is credited with the statement: "[…] an invention you don't want to make, you don't make either."[2] Here, Laue spoke wisely of invention and not of discovery. This is because the issue of impact assessment is much more complicated and complex for basic research than for applied research and technological developments, but this does not mean that the latter is "simpler." Nevertheless, Meyer-Abich stated unequivocally and correctly with regard to the year 1945:

> The atomic bomb was a direct result of basic research. So *there is no basic research* in the sense of a space free of responsibility, but whoever contributed to the discovery of nuclear fission is jointly responsible for the deaths of Hiroshima and Nagasaki. Otto Hahn and the others involved knew this and suffered under the burden of this responsibility.[3]

Carl Friedrich von Weizsäcker (1912–2007) made this observation already in 1970 and realized:

> Science cannot afford not to consider the effects it exerts on life under the motto that it seeks the truth and nothing else. Personally, I have never found it understandable that scientists have been of the opinion that if what science produces in technology is used by politicians or the military in such a way that scientists are unhappy, to say that science has been misused here.
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> After all, science has provided these means, and it is of course responsible for the means it puts into other hands. If it delivers into a political structure which is not adequate to these means, means which are ominous in this structure, the least that can be asked of science is that it should think about how to change the structure which apparently cannot avoid producing these ominous effects. In this sense, then, self-reflection of science is a demand on science.[4]

So far, so good. But how can this work in daily practice?

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[2] Quoted from Hoffmann, K.: Schuld und Verantwortung: Otto Hahn. Konflikte eines Wissenschaftlers. Berlin etc.: Springer 1993, p. 169.

[3] Meyer-Abich, K. M.: Die Idee der Universität im öffentlichen Interesse. In: M. Eigen et al: Die Idee der Universität: Versuch einer Standortbestimmung. Berlin etc.: Springer 1988, pp. 23–39 (here p. 25 f). (translation by the author)

[4] von Weizsäcker, C. F.: Die Macht der öffentlichen Meinung im Kampf gegen Einzelinteressen. In: Süddeutsche Zeitung, No. 166/1970 of 13. 7. p. 7. (translation by the author)

The different disciplines are differently sensitive to discourses on the ambivalence problem, and each one is so to a different degree at different stages of its development. Nuclear physics is a field in which these discourses have become spectacularly explosive in the twentieth century and, far beyond the experts, affect the general public. They are still current. The approach of this essay is not *systematic*, but *historical,* in view of the ambivalence problem. It traces the history of this area since the emergence of ideas about the atomic nucleus–shell structure, marks the places where relevant discourses arose, and sheds light on them more closely in their historical context. Another question is to what extent the conceptual tool of the ambivalence concept is already sufficient to analyze the phenomena, here presented from the perspective of the history of science, from the perspective of the theory of science.

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Since the beginning of the twentieth century, scientists have been studying the structure of atoms and the properties of their components in greater detail;[5] until then, the question of the existence of atoms was still controversial among scientists. The first atomic models were created around 1910, including Joseph J. Thomson (1856–1940) with his raisin cake or plum pudding model (1904), Ernest Rutherford (1871–1937) in 1911 with his model of a positive (not yet further structured) nucleus and negative electrons orbiting around it, followed by Niels Bohr (1885–1962) with the further development of Rutherford's model on a quantum theoretical basis into a kind of planetary model, which in turn was refined by Arnold Sommerfeld (1868–1951) in 1915/16. The electron had already been introduced as a concept around 1874 and was first experimentally verified by J. J. Thomson in 1897;[6] there were still no plausible ideas about a possible structuring of the atomic nucleus. The Bohr–Sommerfeld atomic model, as we know it today (with a structured nucleus), only came into existence in the 1930s, and although it is only of historical significance today, it remains a vivid illustration in everyday life.

Finally, in 1919, Rutherford brought about the first artificial atomic transmutation by bombarding nitrogen atoms with alpha particles, observing that the nitrogen was transformed into oxygen, releasing a hydrogen nucleus; for this positively

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[5] The presentation of the scientific–historical contexts partly follows the author's paper "Die Entdeckung der nuklearen Energie – Einige wissenschaftshistorische Betrachtungen." In: Technik & Technologie techne cum episteme et commune bonum (= Sitzungsberichte der Leibniz-Sozietät der Wissenschaften, Vol. 131). Edited by L.-G. Fleischer & B. Meier. Berlin: trafo Wissenschaftsverlag 2017, pp. 189–207. I would like to refer to two further short articles on this history that are worth reading: Szilard, L.: Creative Intelligence and Society: The Case of Atomic Research, The Background in Fundamental Science. In: The Collected Works Vol. 1, Scientific Papers; The MIT Press 1972, pp. 178–189; Stamm-Kuhlmann, Th.: Die Internationale der Atomforscher und der Weg zur Kettenreaktion 1874–1942. In: Salewski, M. (Ed.): Das nukleare Jahrhundert. Stuttgart: Franz Steiner 1998, pp. 23–40.

[6] Among others by Wilhelm Weber (1804–1891), Hermann von Helmholtz (1821–1894) and George Johnstone Stoney (1826–1911); the latter also proposed the term *electron* in 1891.

charged hydrogen nucleus he introduced the term *proton* in 1920. While the previously known natural nuclear transformations through alpha and beta decay led to elements in which the atomic weight decreased or remained the same, a nuclear transformation was now realized in which an increase in atomic weight occurred (i.e., an element was created that was higher in the periodic table than the original element).[7] For nuclear transformation experiments it now became necessary to use high-energy elementary particles, especially protons and electrons (Rutherford had still used natural alpha emitters for his experiments), and so Rutherford stimulated the development of electrical acceleration facilities, which succeeded in the early 1930s.

The year 1932 is often referred to as the *annus mirabilis* of nuclear physics: deuterium and the neutron and positron were discovered, which independently inspired Werner Heisenberg (1901–1976) in Leipzig and Dmitri Dmitrievich Ivanenko (1904–1994) in Moscow to develop a proton–neutron concept of the atomic nucleus, and in the USA the cyclotron was developed as a particle accelerator by Ernest O. Lawrence (1901–1958) and collaborators. Also in 1932, John D. Cockcroft (1897–1967) and Ernest T. S. Walton (1903–1995) succeeded with a slightly different accelerator design at Rutherford's laboratory in Cambridge, England, in achieving the first nuclear transformation using artificially accelerated particles: Lithium nuclei were converted into two helium nuclei by bombarding them with accelerated protons. This was at the same time an experimental confirmation of Albert Einstein's (1879–1955) equivalence relationship of mass and energy, formulated in 1905 as part of his special theory of relativity. Einstein derived this relationship for electromagnetic radiation, but concluded that it must also apply to all other forms of energy turnover. However, this Einsteinian relationship did not yet play a role in the first considerations about atomic energy. Only in the 1920s did it become relevant in atomic physics considerations (mass defect) and could then be experimentally confirmed in 1932 in the light of the new discoveries.

With these first transmutations of atomic nuclei, a new variant of the alchemists' old dream of producing gold through transmutation of elements came into focus. However, it must be clearly stated that physicists (and chemists) at that time were actually neither looking for this special possibility nor for a practically usable source of energy based on transmutation of atomic nuclei, but that it was primarily a matter of grasping the components and structure of atoms and their nuclei and understanding the mechanisms of such nuclear transmutations—i.e., in the truest sense of the claim, by Goethe's Faust, to "…detect the inmost force which binds the world, and guides its course."[8] The energetic relationships, insofar as they are important for the cohesion of the various components, were also discussed. However, the question of whether this energy could be used practically was still of secondary importance. Although it was recognized that enormous amounts of energy are

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[7] In 1925 Rutherford's student Patrick S. Blackett (1897–1974) was able to visualize this process with the help of a Wilson cloud chamber and thus verified it experimentally.

[8] Goethe, Faust I (1808) lines 382–383; english translation by Bayard Taylor (1912) [The Project Gutenberg EBook: https://gutenberg.org/files/14591/14591-h/14591-h.htmI]

converted in relation to the quantities of substances involved, several orders of magnitude greater than the reaction heat of chemical reactions, no thought was given to this fact—with a few exceptions, which we will discuss in a moment.

The term *atomic energy*[9] was coined by the meritorious grammar school teachers Julius Elster (1854–1920) and Hans Geitel (1855–1923). In a lecture to the *Verein für Naturwissenschaften* in Braunschweig titled "Bemühungen, die Energiequelle der Bequerelstrahlen zu finden"[10] they concluded in 1899 that:

> […] one will rather have to derive the energy source from the atom of the element in question itself. The thought is not far away that the atom of a radioactive element […] will change into a stable state by releasing energy.[11]

The prescience of this insight becomes clear when one considers that at that time the idea of an atomic structure of matter was only just beginning to gain acceptance. Indeed, the first thoughts on the use of nuclear energy occurred relatively early on, but such ideas appeared overly utopian and were therefore not really taken seriously by the majority of the research community.[12]

Rutherford's student Frederick Soddy (1877–1956) gave a series of public experimental lectures in 1908, titled "The Interpretation of Radium."[13] In these he concluded by suggesting in vague terms that radium or radioactivity could in future help to identify and control the original sources of energy—thereby anticipating radium as an inexhaustible source of energy. Many of the basic ideas in Soddy's book are absolutely correct, even if the atomic models were still very poor: Bohr's atomic model would not be proposed until 1913, and no one yet had any idea of the structure of atomic nuclei.

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[9] Today, when it comes to energy production from the atom, one prefers to speak of nuclear energy, because in fact it is about the energetic relationships in the nucleus and not between the nucleus and the "atomic shell"; but often, both expressions are used synonymously.

[10] In 1896, Antoine Henri Becquerel (1852–1908) in Paris—shortly after the discovery of X-rays by Wilhelm Conrad Röntgen (1845–1923)—had discovered radioactive radiation, thus opening up a new field of research. Among the pioneers of radioactivity research were Marie (1867–1934) and Pierre (1859–1906) Curie, Ernest Rutherford (1871–1937), Frederick Soddy (1877–1956), Otto Hahn (1879–1968) and Hans Geiger (1882–1945).

[11] Elster, J. & Geitel, H.: Weitere Versuche an Becquerelstrahlen. Annalen der Physik, 305(9) N.F. 69(1899)1, pp. 83–90, here p. 88. See also Fricke, R.: J. Elster & H. Geitel – Jugendfreunde, Gymnasiallehrer, Wissenschaftler aus Passion. Braunschweig: Döring 1992, p. 116.

[12] Nevertheless, this realm of utopia flourished and was found to differ only slightly from reality. In 1910, for example, the American radium researcher Everard Hustler described both the possibility of a nuclear weapon (albeit on the basis of a completely different operating principle) and radium as a medical panacea for the expected "century of radium" [in: Brehmer, A. (Ed.): Die Welt in 100 Jahren. Berlin 1910, pp. 245–266 (new edition Hildesheim etc.: Olms 2012)]. For a discussion of these predictions see, among others, Steger, F. & Friedmann, H.: Radium – Ein faszinierendes Element: Segen oder Fluch? part 3: Radium in der Medizin, in Industrieprodukten und im privaten Bereich. In: Strahlenschutz aktuell 46(2011)1, pp. 7–47 (esp. pp. 44–45).

[13] Soddy, F.: The interpretation of radium. 1909. – German: Die Natur des Radiums. [1909] (= Ostwalds Klassiker der exakten Wissenschaften Bd. 289). Frankfurt am Main: Harri Deutsch 2002.

Soddy's description inspired the well-known British utopian writer H. G. Wells (1866–1946) to write his novel "The World Set Free," which was published in 1914 (in German only in 1985). The book begins with the statement: "The history of mankind is the history of the attainment of external power."[14] A few pages later, it states: "The latent energy of coal and the power of steam waited long on the verge of discovery, before they began to influence human lives."[15] Wells understood human history here as energy history. In Wells' novel, the professor character[16] states:

> Radium is an element that is breaking up and flying to pieces. […] And we know now that the atom, that once we thought hard and impenetrable […], is really a reservoir of immense energy. […]

Wells then lets his lecturer show a bottle of uranium oxide and continues:

> And in this bottle […] there slumbers at least as much energy as we could get by burning a hundred and sixty tons of coal. […] But at present no man knows, […] how this little lump of stuff can be made to hasten the release of its store. […].[17]

The novel mainly deals with the consequences of unleashing the newly discovered nuclear energy, both in its civil applications and military use as atomic bombs. In Wells' novel the decisive discovery that enabled this was made by a chemist in 1935![18] The English edition contains a dedication (unfortunately omitted from the German version): "To Frederick Soddy's 'Interpretation of Radium' […]."[19]

After Soddy, Francis William Aston (1877–1945) was one of the few scientists who took the possibility of using atomic energy seriously.[20] As early as 1919 he postulated the extremely high-energy fusion of hydrogen into helium. In 1922, Aston was awarded the Nobel Prize in Chemistry; and he concluded his acceptance lecture by pointing out that the fusion of hydrogen atoms could be the energy source for the Sun, and finished by remarking:

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[14] Here cited after the English Ebook edition: Wells: The world set free. Project Gutenberg 2006 [http://www.gutenberg.org/ebooks/1059] (Accessed: 28 February 2017). – In German: Wells, Herbert G.: Befreite Welt. Wien/Hamburg: Paul Zsolnay 1985, p. 7.

[15] Ibid, section 4.

[16] Soddy corresponds to the character Rufus in Wells' novel.

[17] Ibid, section 8.

[18] This is surprisingly close to the actual year of discovery.

[19] The complete dedication reads: "This Story, which owes long passages to the eleventh chapter of that book, acknowledges and inscribes itself." [http://www.gutenberg.org/ebooks/1059] (Accessed: 28 February 2017).

[20] We should also mention the German physicochemist Walther Nernst (1864–1941), Nobel Prize winner in 1920, who in 1912 at the *Versammlung Deutscher Naturforscher und Ärzte* in Münster i.W. remarked in his lecture "Zur neueren Entwicklung der Thermodynamik": "The discovery of the radioactive decay of the elements has introduced us to sources of energy of a power of which we had no conception before." (Nernst, Walther: Das Weltgebäude im Licht der neueren Forschung. Berlin: Springer 1921, p. 2, translated). In 1921, however, he added: "However, one should beware of the illusion that the technical extraction of the energy quantities available here has come within reach." (Ibid, p. 23, translated).

> Should the research worker of the future discover some means of releasing this energy in a form which could be employed, the human race will have at its command powers beyond the dreams of scientific fiction; but the remote possibility must always be considered that the energy once liberated will be completely uncontrollable […].[21]

But the reality was still completely different. Although, as mentioned above, Rutherford had first demonstrated nuclear transmutation in 1919, the process was far from releasing energy. On the contrary, the energy released in this process was actually less than the energy required by the alpha particle.

And so, it is not surprising that Rutherford said in a lecture at the *British Association for the Advancement of Science* meeting in Leicester in September 1933:

> These transformations of the atom are of extraordinary interest to scientists but we cannot control atomic energy to an extent which would be of any value commercially, and I believe we are not likely ever to be able to do so. A lot of nonsense has been talked about transmutation. Our interest in the matter is purely scientific, and the experiments which are being carried out will help us to a better understanding of the structure of matter.[22]

This was reported as the famous "moonshine" quotation: *Nature* wrote that Rutherford had said that anyone who sees atomic transformations as a source of energy talks "moonshine."[23] He confirmed this opinion again in 1936, although perhaps not quite so emphatically:

> […] here seems to be little hope of gaining useful energy from the atoms by such methods. […] At the moment, however, the natural radioactive bodies are the only known sources for gaining energy from atomic nuclei, but this is on far too small a scale to be useful for technical purposes.[24]

Other eminent scientists, such as Einstein and Bohr, were of the same opinion. Finally, the important Croatian-American inventor Nikola Tesla (1856–1943) should be mentioned here, certainly someone who was open to unusual ideas, who is also credited with stating, in 1931, that the idea of atomic energy is illusory and that it can be used for neither civilian nor military purposes.[25] Even the leading

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[21] Aston, F. W.: Mass spectra and isotopes. Nobel lecture 1922. In: Nobel Lectures Chemistry 1922–1941. Amsterdam: Elsevier 1966, p. 20.

[22] Quoted from Eve, A. S.: Rutherford—Being the life and letters of the Rt. Hon. Lord Rutherford, O.M. The Macmillan Company New York & The University Press Cambridge/England 1939, p. 374. Rather jokingly, however, Rutherford had already in 1903 expressed the "disturbing idea" that with a suitable detonator a huge explosion wave could be started by atomic decay, which could turn the whole mass of the globe into helium (see Weart, Sp.: Nuclear Fear. A History of Images. Harvard University Press 1988, p. 18).

[23] [A.F.]: Atomic Transmutation. In: Nature 132(1933)3333, Sept. 16, pp. 432–433 (here p. 433). See also: Jenkin, J. G.: Atomic Energy is "Moonshine": What did Rutherford *Really* Mean? In: Physics in Perspective 13(2011)2, pp. 128–145.

[24] Rutherford, E.: The Transformation of Energy. In: Nature 137(1936, Jan 25)3456, S. 135–137 (here p. 137).

[25] Quoted after [http://www.nur-zitate.com/autor/Nikola_Tesla](Accessed: 6 October 2016). Analogous in: Tesla, 75, Predicts New Power Source. In: New York Times of 5 July 1931. Cf. also Cheney, M.: Nikola Tesla – Erfinder, Magier, Prophet. Aachen: Omega 2005, p. 258 f.

Soviet physicist Pyotr L. Kapiza (1894–1984), who had worked for several years in Rutherford's laboratory, was still convinced at the beginning of 1940—when nuclear energy had already become a reality—that the use of nuclear energy was not to be expected, and in doing so referred to Rutherford. Restrictively, he remarked that perhaps something else would be discovered, but that this seemed unlikely.[26]

However, a young Hungarian physicist, Leo Szilard (1898–1964), who first emigrated to Germany in 1921 then subsequently to England when the Nazis came to power, had just read H. G. Wells' novel; he also read the aforementioned statement by Rutherford in the *Times*, but did not consider the prospect of atomic energy at all unrealistic. Szilard then developed the idea of the atomic chain reaction (which Wells could not yet envision in his fiction) and was even secretly granted a patent through Britain's Royal Navy a year later.[27] However, even Szilard was unable to specify which elements might be suitable for such a process. Also, Ernest O. Lawrence (1901–1958), for example, the creator of the cyclotron, said: "I have no opinion as to whether it can ever be done, but we're going to keep on trying to do it."[28]

So much for the visions or fictions of nuclear energy, which certainly existed in the first decades of the twentieth century.[29] But most of the "serious" scientists did not really believe in the prospect of nuclear energy nor see any way of testing its feasibility. In science fiction literature, however, this possibility of energy production was still being considered, although mostly not as profoundly as in Wells' work.[30] So the question is, to what extent scientists should or should not have taken these fictions seriously? Szilard at least tried.

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The latest results of nuclear research also inspired a young German physicist. Carl Friedrich von Weizsäcker had studied at the then physical centers of Germany: Berlin, Göttingen, and Leipzig. Weizsäcker received his doctorate from Leipzig in the summer of 1933 with a thesis on nuclear physics under Werner Heisenberg, who had been physics professor there since 1927. In 1936 Weizsäcker habilitated there with a thesis on nuclear forces. He then went to Berlin, to the newly founded Kaiser Wilhelm Institute for Physics, which was headed by the Dutch physicist Peter

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[26] Cf. interview for the children's magazine "Detskaja Literatura" 1940, No. 4, pp. 18–23, excerpts printed in: Atomnoj Proekt SSSR, Vol. 1, Part I. Moskva: Izd. Nauka 1998, pp. 93–94.

[27] Szilard, L.: Creative Intelligence and Society: The Case of Atomic Research, The Background in Fundamental Science. In Szilard, L: The Collected Works Vol. 1, (loc. cit.)., pp. 178–189 (here p. 183).

[28] Lawrence expressed this as a comment on the report on Rutherford's statement in the *New York Harold Tribune* of 12.9.1933. (Quoted after Weiner, Ch.: Physics in the Great Depression. In: Physics Today 23 (October, 1970), pp. 31–38 (here p. 35)).

[29] See also Strub, E.: Soddy, Wells und die Atombombe. In: Physik Journal 4(2005)7, pp. 47–51.

[30] It is not possible to go into these aspects in greater depth here; reference is only made as an example from German-language literature to Hans Dominik (1872–1945) and his novel "Der Brand der Cheopspyramide" (1925/26).

Debye (1884–1966), who had also previously worked in Leipzig.[31] As the KWI for Physics was still under construction and would not start work until spring 1937, Weizsäcker took the opportunity in autumn 1936 to spend a quarter of a year at the Kaiser Wilhelm Institute of Chemistry, where he was to represent Max Delbrück (1906–1981), whom he knew from Copenhagen meetings at the Bohr Institute.[32] Delbrück was then a so-called "house theorist" for Lise Meitner (1878–1966) and Otto Hahn, the leading German researchers in the field of radioactivity, but was already more interested in biochemistry. At the end of 1936 Weizsäcker's monograph on nuclear physics "Die Atomkerne—Grundlagen und Anwendungen ihrer Theorie" [The atomic nuclei—basics and applications of their theory] appeared, which attempted to bring together the latest findings of recent years.[33] In his preface written in Berlin in September 1936, he outlined his concern:

> The rapidly growing body of experience about atomic nuclei does not yet permit the formulation of an exhaustive theory, but it does consistently show the correctness and fertility of certain basic theoretical ideas. This book addresses on the one hand readers with an experimental background who want to gain an overview of the secure part of this core theory, and on the other hand theoreticians who are interested in its further development.[34]

In his review of this book, Delbrück wrote that the study of atomic nuclei is currently the most popular field of work for physicists and stated that Weizsäcker's book is "[…] the first theoretical account of the subject" and offers "[…] a concise summary in clear, understandable language of our present knowledge of atomic nuclei and all the theoretical aspects which have proved useful in their analysis […]."[35]

Remarkable for our consideration here is the illustration on p. 51 of Weizsäcker's book (see Fig. 6.1), because it shows (in today's terms) the magnitude of the nuclear binding energy as a function of the nuclear mass. It follows from the curve that useful energy can be obtained in the area of light nuclei by nuclear fusion, whereas in the area of heavy nuclei it can be obtained by nuclear fission (into two medium-heavy nuclei). However, physicists at that time did not seriously consider these possibilities, because other convictions stood in opposition, including the basic statement that nuclear transformations can only occur between elements that are

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[31] Originally, the KWI for Physics was founded in 1917 under Einstein's leadership, but at that time without institutional buildings and laboratories. At the latest since the end of the 1920s the idea of an institute building was pursued. (Cf. inter alia Kant, H.: Max-Planck-Institut für Physik Berlin – München. In: Denkorte. Max-Planck-Gesellschaft und Kaiser-Wilhelm-Gesellschaft. Brüche und Kontinuitäten 1911–2011. Edited by P. Gruss & R. Rürup. Dresden: Sandstein 2010, pp. 316–323).

[32] Cf. inter alia Kant, H.: Vom KWI für Chemie zum KWI für Radioaktivität: Die Abteilung(en) Hahn/Meitner am Kaiser-Wilhelm-Institut für Chemie. In: Dahlemer Archivgespräche, vol. 8, Berlin 2002, pp. 57–92.

[33] von Weizsäcker, C. F.: Die Atomkerne – Grundlagen und Anwendungen ihrer Theorie. (= Physik und Chemie und ihre Anwendungen in Einzeldarstellungen. Vol. 11). Leipzig: Akademische Verlagsgesellschaft 1937.

[34] Ibid. (translation by the author)

[35] Delbrück, M.: Review of von Weizsäcker, C. F.: Die Atomkerne. In: Physikalische Zeitschrift 38(1937) p. 388. (translation by the author)

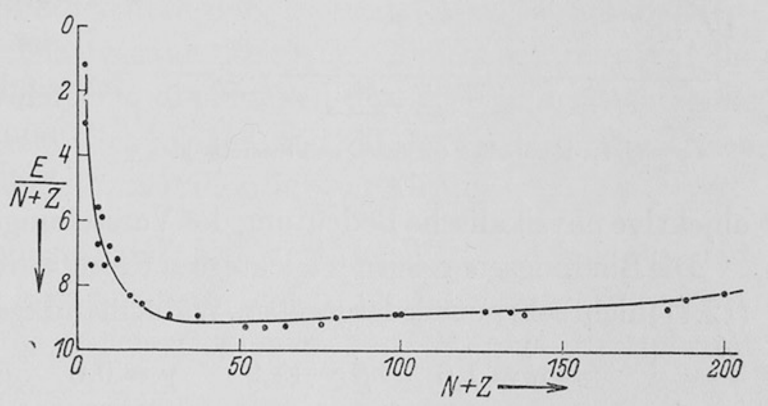

Fig. 6.1 Magnitude of the nuclear binding energy as a function of the nuclear mass. Weizsäcker referred in the ordinate to the packing fraction, which is the quotient of mass defect and nucleon number. It is a measure of the relative stability of atomic nuclei (N = number of neutrons, Z = number of protons; N + Z = nucleon number). (Source: von Weizsäcker, 1937, Die Atomkerne – Grundlagen und Anwendungen ihrer Theorie, p. 51)

close together in the periodic table of elements.[36] This "omission" can be observed from a historical perspective, but probably none of the scientists involved can be blamed for it.

Weizsäcker was very much interested in astronomy from his earliest youth. Since the common atomic models showed parallels to planetary systems, he also looked for connections there. And since nuclear physics was now "in," he thought that the energy source of the stars might be a nuclear reaction (Aston had already postulated this); that question was also "in" among astrophysicists at that time.[37] Weizsäcker published his thoughts on this in the journal *Physikalische Zeitschrift* and also presented them to the *Berlin Physical Society* [Physikalische Gesellschaft zu Berlin] in 1938.[38]

Astrophysicists assumed that the Sun mainly consisted of hydrogen and helium. The energy production mechanism therefore had to be based primarily on the nuclei of those elements. Weizsäcker suggested several possible basic reactions, and ultimately it was found that helium is produced from hydrogen—releasing large amounts of energy—by a fusion reaction. Weizsäcker also indicated various other

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[36] In other words, their atomic numbers (equal to the number of protons in the nucleus) differ only by 1.

[37] At that time Weizsäcker had just read the book by the eminent British astrophysicist Sir Arthur Eddington (1882–1944) *The Internal Constitution of Stars* (published in 1926), and Eddington had made a similar conjecture.

[38] von Weizsäcker, C. F.: Über Elementumwandlungen im Innern der Sterne. In: Physikalische Zeitschrift 38(1937)6, pp. 176–191 & 39(1938)16, pp. 633–646.

possible reactions. However, he did not calculate how much energy was generated nor whether the result corresponded to the energy output of our Sun.[39]

Another scientist to be mentioned in this context is Hans Bethe (1906–2005). Bethe had studied physics in Frankfurt am Main and with Arnold Sommerfeld in Munich. In the winter term of 1932/33 he was assistant professor of theoretical physics at Tübingen but lost this post after the National Socialists came to power because his mother was of Jewish descent. In 1935 he got a position at Cornell University in the USA.[40]

Bethe came to work on problems of nuclear fusion rather by chance. The Hungarian Edward Teller (1908–2003) and the Russian George Gamow (1904–1968), one a student of Heisenberg, the other of Bohr and Rutherford and both also emigrants, organized an annual meeting on theoretical physics in Washington, in which Bethe also took part.[41] Bethe had not originally planned to participate in the conference of March 1938, since it was to deal with astrophysical questions, but Teller had persuaded him to do so because the aim of this 4th conference was to familiarize as many physicists as possible with current astrophysical problems, so that they might perhaps be able to contribute something to them.[42] Bethe remembered with the following words:

> At this conference the astrophysicists told some of us physicists what stars are about, how they are made, what distribution of density and pressure they have and so on, and then they ended up with the question where does the energy come from? Everybody of course agreed that the energy must come from nuclear reactions but what nuclear reactions? They were searching at the time for too much, viz. they were trying at the time to solve simultaneously the problem of the buildup of elements and the problem of production of energy in the stars. It was just the removal of this coupling that made it possible to solve the problem.[43]

First Bethe had worked out the simple fusion reaction between two hydrogen nuclei with Charles L. Critchfield (1910–1994), a student of Gamow and Teller, referring to Weizsäcker's article of 1937.[44] The result was quite consistent with the value given by the astrophysicists for the energy production of the Sun, but with larger stars this simple reaction was not possible. Bethe then calculated systematically through the periodic table and looked for nuclei that could react with hydrogen nuclei. Finally, he found what he was looking for in carbon. In this process, the carbon merely serves as a catalyst by first fusing with a hydrogen nucleus to form a nitrogen isotope, which then decays again into another carbon isotope, which in the

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[39] There is insufficient space here to provide further details.

[40] Bethe received a professorship there in 1937, became a US citizen in 1941 and was involved in the Manhattan Project, including as head of the Department of Theoretical Physics there.

[41] Coincidentally, Bethe and Teller had been on the same ship on the passage to the USA. Cf. Hargittai, I.: Judging Edward Teller. Prometheus Books 2010, p. 103.

[42] Cf. inter alia Bethe, H. A.: Energy on Earth and in the Stars. In: From a Life of Physics. World Scientific 1989, pp. 1–18.

[43] Ibid., p. 11.

[44] Bethe, H. A. & Critchfield, C. L.: The Formation of Deuterons by Proton Combination. In: Physical Review 54(1938)4, pp. 248–254.

next step fuses again with a hydrogen nucleus and so on. Finally, the overall result of such a carbon–nitrogen cycle is the fusion of four hydrogen nuclei to form a helium nucleus (alpha particle), whose mass is about 1% less than the mass of the four hydrogen nuclei (protons). This mass defect is almost entirely converted into energy according to Einstein's equation $E = mc^2$. This carbon–nitrogen cycle is also known today as the Bethe–Weizsäcker cycle. It only occurs at temperatures in excess of 14 million Kelvin.

Further possible fusion processes are not discussed here. The high temperatures make it clear that it was completely illusory to think of a practical use at that time. That is why the physicists did not pursue the matter any further, because the astrophysicists' question was first solved for them in principle.

Bethe was awarded the Nobel Prize in Physics in 1967 for his work; Weizsäcker was left empty-handed because he had essentially only looked at the matter qualitatively, and since both had worked independently, Bethe had thus made the more complete achievement. Weizsäcker saw it that way himself.[45]

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The discoveries made in the *annus mirabilis* 1932 prompted the young Italian physicist Enrico Fermi (1901–1954) to set his newly constituted research group in Rome an interesting task. Fermi had quickly realized that the neutron discovered by James Chadwick (1891–1974) should be better suited to bringing about atomic transformations because of its neutral charge than the positively charged alpha particle previously used for such purposes. The final impetus for his concrete investigations came with the discovery of artificial radioactivity in early 1934 by Irène (1897–1956) and Frédéric (1900–1958) Joliot-Curie.[46] In the following years Fermi's group showed that almost all elements can be transformed into radioactive elements by bombarding them with neutrons. This was based on the following model: when a low-energy (i.e., "slow") neutron collides with an atomic nucleus, it can be absorbed into the nucleus; in the newly formed nucleus, it is then transformed into a proton, emitting a beta particle, and the atomic number of the element increases by one unit.[47]

The observed transformation mechanism led, among other things, to the assumption that when bombarding uranium, the heaviest naturally occurring element—and thus the last element in the Periodic Table of Natural Elements with the atomic

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[45] Cf. Schaaf, M.: Weizsäcker, Bethe und der Nobel Prize. In: Carl Friedrich von Weizsäcker: Physik – Philosophie – Friedensforschung. (= Acta Historica Leopoldina No. 63), edited by Klaus Hentschel and Dieter Hoffmann. Stuttgart: Wissenschaftliche Verlagsgesellschaft 2014, pp. 145–156.

[46] In Detail cf. inter alia De Gregorio, A.: Neutron physics in the early 1930s. In: Historical Studies in the Physical and Biological Sciences 35(2005)2, S. 293–340.

[47] Kant, H.: Von den falschen Transuranen zur Kernspaltung – die Atomphysiker Enrico Fermi und Lise Meitner. In: Italien und Europa. Der italienische Beitrag zur europäischen Kultur. Edited by Franziska Meier & Italien-Zentrum der Universität Innsbruck; Innsbruck: Studien Verlag 2007, pp. 171–186.

number 92—so-called transuranium elements would have to be created, i.e., “artificially produced” elements that would follow uranium in the Periodic Table.

Initial reactions to Fermi’s papers pointed out, inter alia, that it could not be excluded that instead of the element 93 (as claimed by Fermi), element 91 could have been created. But element 91 (i.e., protactinium) was a domain of the Berlin researchers Otto Hahn and Lise Meitner, who had discovered it in 1918. So, at the end of 1934, they also turned to this research.

It was not least the political circumstances in Germany that forced Hahn and Meitner to resume closer direct cooperation again after 1934.[48] Meitner persuaded Hahn to carry out a joint review of the Fermi results; Fritz Straßmann (1902–1980), Hahn’s assistant since 1929, was called in for the necessary chemical analyses. The assertion of the possible creation of protactinium was soon disproved, but the question remained as to what really occurs during neutron irradiation.[49]

Between 1934 and 1938, Hahn, Meitner, and Straßmann published 15 papers on questions of the artificial transmutation of uranium by neutrons. On the basis of the Fermi hypothesis, transuranium elements were expected as transmutation products. In 1937, the three scientists seemed to have found a solution and presented three possible decay series of uranium in two papers—one chemically and one physically oriented.[50] The reaction products resulting from the irradiation of uranium (and other elements) with neutrons first had to be separated chemically in order to then determine their radioactivity by physical means. Since the quantities involved were very small—almost “imponderable”—particularly difficult chemical analysis methods were necessary, but which Hahn and his staff in particular mastered excellently.

The nuclear transformations also produced radioactive products that could only be separated with barium and in which radium isotopes were therefore suspected;[51] this part of the research program, however, raised more questions than answers could be found. The classification difficulties were not least due to the fact that at that time the so-called actinide series in the periodic table of the elements was not yet known and therefore the classification of the last three natural elements was somewhat different than today.[52]

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[48] Meitner was Austrian and came from a Jewish family, but had already converted to the Protestant faith in 1908.

[49] Kant, H.: Die radioaktive Forschung am Kaiser-Wilhelm-Institut für Chemie von den Anfängen bis zum deutschen Uranprojekt. In: Kant, H. & Reinhardt, C. (Ed.): 100 Jahre Kaiser-Wilhelm-/Max-Planck-Institut für Chemie (Otto Hahn Institut). Facetten seiner Geschichte. (= Veröffentlichungen aus dem Archiv der Max-Planck-Gesellschaft, Vol. 22) Berlin 2012, pp. 53–98.

[50] Hahn, O., Meitner, L. & Straßmann, F: Über die Transurane und ihr chemisches Verhalten. In: Berichte der Deutschen Chemischen Gesellschaft 70(1937) pp. 1374–1391; Meitner, L., Hahn, O. & Straßmann, F.: Über die Umwandlungsreihen des Urans, die durch Neutronenbestrahlung erzeugt werden. In: Zeitschrift für Physik 106(1937)3/4, pp. 249–270.

[51] Barium is a so-called homologue of radium, i.e., it is located in the 2nd main group below radium in the periodic table.

[52] At that time uranium was classified in the 6th subgroup of the 7th period; today it is found at the 3rd position in the actinide series.

That barium could indeed have been formed, as some analysis results suggested, was beyond any reasonable assumption at the time. It is interesting to refer in this context to an episode from the KWI for Chemistry: Straßmann reported that as early as 1936, between two routine measurements that he carried out as part of the research program, he also carried out a measurement with barium at night, which he found interesting. But Lise Meitner said the next morning: "Oh, you had better leave that to us physicists—you can toss this into the wastebasket."[53] And Straßmann stated: "What I threw away at that time was already the proof of the formation of barium from uranium after bombarding with slow neutrons—that is, nuclear fission."[54] Is this really an example of ambivalence in experimental research, as for instance Parthey argues,[55] when rejecting an experimental result that obviously contradicts the accepted theory about the process? After all, at this point in time at least the first foundations of an "alternative" theory already existed, which then confirmed this result. From my point of view this remains an open question.

Although the chemist Ida Noddack (1896–1978) had already expressed doubts about Fermi's transuranium results in 1934, and had just expressed the suspicion that they might also be fission products of uranium, she had no possibility at that time to verify this experimentally. And the physicists concluded, from the theories about the nucleus, that nuclear transformations into neighboring elements were possible, but not a "bursting" of the nucleus. When Ida Noddack's publication was taken up by physicists at the time, a memoir by Emilio Segrè (1905–1989) from the Fermi group shows how dubiously they regarded Noddack's publication:

> We did not seriously entertain the possibility of nuclear fission, although it had been mentioned by Ida Noddack, who sent us a reprint of her work. The reasons for our blindness, shared by Hahn and Meitner, the Joliot-Curies and everybody else working on the subject, is not clear to me even today.[56]

Soon after the publication of Hahn and Meitner's decay series, astonishing news came from Paris. Irène Joliot-Curie and her colleagues had found a reaction product with a slightly different method of analysis than was customary in Berlin, a product that the Berliners had probably overlooked until then; but in interpreting this product, the Parisians indulged in "wild speculations" that Meitner found theoretically untenable, and soon lost all interest in the reaction product, which she dubbed "Curiosum."[57] In mid-1938, she was forced to leave Germany as a result of the German annexation of Austria, and found asylum and a modest research opportunity in Sweden.

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[53] Straßmann, F.: Kernspaltung. Privatdruck, Mainz 1978, p. 31. (translation by the author)

[54] Krafft, F.: In the Shadow of the Sensation. Life and Work of Fritz Straßmann. Weinheim etc.: Publisher Chemie 1981, p. 218. (translation by the author)

[55] Cf. Parthey, H.: Institutionalization, interdisciplinarity, and ambivalence in research situations. See Ch. 7 of this volume).

[56] Segrè, E.: A Mind Always in Motion. The Autobiography of Emilio Segrè. Berkeley & Oxford: University of California Press 1993, p. 91; Lise Meitner, too, was very critical of Noddack's considerations; cf. Krafft, Fritz: Im Schatten der Sensation. op. cit.

[57] Krafft, F.: Im Schatten der Sensation; op. cit., p. 79.

In the autumn of 1938 a new surprising publication came from Paris about possible new reaction products in the transuranium search, and Hahn and Straßmann decided, after initial reluctance, to resume their series of experiments. In late October 1938 Hahn wrote to Meitner that they had now actually found this Parisian "body." Several letters were exchanged between them. On Monday December 19, 1938 Hahn wrote the following famous lines to Meitner:

> […] It is now just 11 p.m.; […] Actually there is something about the "radium isotopes" that is so remarkable that for now we are telling only you. […] We are coming steadily closer to the frightful conclusion that our Ra isotopes do not act like Ra, but like Ba […] Perhaps you can come up with some sort of fantastic explanation. We know ourselves that it *can't* actually burst apart into Ba.[58]

This was now the famous actual discovery of uranium nuclear fission.

Hahn was well aware of the significance of this discovery—although certainly not yet all its consequences—as well as of the competitive situation in which he found himself, at least with the Paris research group. On December 23, 1938 he submitted the manuscript of the corresponding article to the journal *Die Naturwissenschaften* and, thanks to his good relations with the editor, this article was printed in the first issue of 1939, which appeared on Friday 6 January.[59] Hahn had also sent the manuscript to Meitner and it reached her on December 30, 1938.

Together with her visiting nephew Otto Robert Frisch (1904–1979), who—also an emigrant—worked at Bohr's institute in Copenhagen, Meitner then succeeded in those days around the turn of the year 1938/39, taking into account the droplet model[60] that had been known for several years and Bohr's theory of the so-called "compound nucleus" developed from it 3 years earlier, in achieving the "fantastic explanation" that Hahn had hoped for—in other words: nuclear fission could indeed be explained within the framework of the physical theories that were already available! Thus, the joint work of the 1930s came to a crowning conclusion after all—Hahn and Straßmann provided the irrefutable chemical–experimental results, Meitner and Frisch the physical–theoretical explanation. However, they had found something other than what they were originally looking for!

The corresponding work by Meitner and Frisch was sent to the English journal *Nature* on January 16, 1939.[61]

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[58] Quoted after Krafft, F.: Im Schatten der Sensation; op. cit., p. 263 f.

[59] Hahn, O. & Straßmann, F.: Über den Nachweis und das Verhalten der bei der Bestrahlung des Urans mittels Neutronen entstehenden Erdalkalimetalle. In: Die Naturwissenschaften 27(1939, 6. Jan)1, S.11–15.

[60] First introduced by George Gamow, further developed by others. Weizsäcker's comments in his 1937 book are also based on this.

[61] Meitner, L. & Frisch, O. R.: Disintegration of Uranium by Neutrons: A New Type of Nuclear Reaction. In: Nature 143(1939, Feb. 11) 3615, pp. 239–240. Following his return to Copenhagen, Frisch had by then been able to demonstrate nuclear fission in a physical experiment: If one assumes the fact of fission and bases the corresponding calculations on it, the expected amount of energy released can be measured relatively easily. His corresponding article appeared a week after the joint essay with Meitner.

After the paper by Hahn and Straßmann had been published, Weizsäcker at the KWI for Physics had also soon found the correct theoretical explanation, as had Siegfried Flügge (1912–1997), since 1937 Delbrück's successor as the new "house theorist" at the KWI for Chemistry, together with Meitner's long-time assistant Gottfried von Droste (1908–1992), whose corresponding paper was submitted on January 22, 1939 (published at the beginning of March), i.e., only 1 week after Meitner and Frisch.[62] Since Hahn had not revealed anything about the discovery at the Institute—in order to give Meitner the chance to find the physical explanation and thus somehow bring together "the old team" in this discovery—Berlin colleagues were, understandably, somewhat "angry" about this "secrecy."[63]

It was also Flügge who then published a more scientific article in *Die Naturwissenschaften* in June 1939 and 2 months later a popular article in the *Deutsche Allgemeine Zeitung* on the possibilities of exploiting atomic energy, thus drawing the attention of a wider public to the new possibility of energy production.[64]

Niels Bohr left Copenhagen at the beginning of January 1939 for a research stay of several months in Princeton, USA. A few days before his departure, Frisch returned from Sweden and informed Bohr about the latest findings.[65] On January 16, 1939, Bohr arrived in New York, i.e., even before the said issue of *Die Naturwissenschaften* arrived there. Bohr had promised Frisch that he would not make any announcements before the corresponding publications appeared, but as it is, Bohr—who of course was concerned with this sensational discovery during the entire sea-crossing—had already told John Archibald Wheeler (1911–2008), who had received him, the news on the quay under the seal of secrecy, and—as is usual with such confidential information—it spread like wildfire.[66] As surprising and

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[62] In Vienna, it was Josef Schintlmeister (1908–1971) and Werner Czulius (1913–2008) who made corresponding considerations in Jan/Feb 1939 and presented them to the Vienna Academy on February 23, 1939. [Cf. Nagel, G.: Atomversuche in Deutschland. Zella-Mehlis: Heinrich Jung Verlagsgesellschaft 2003, p. 24 f].

[63] In 1949 Flügge remarked somewhat smugly: "When we returned from the Christmas vacations at the beginning of 1939, everything had already been decided." (Flügge, S.: Zur Entdeckung der Uranspaltung vor zehn Jahren. In: Zeitschrift für Naturforschung 4a(1949), pp. 82–84). According to the entry in his pocket diary, Hahn had discussed the discovery with von Weizsäcker, Flügge and others on Monday, January 9, 1939.

[64] Flügge, S.: Kann der Energieinhalt der Atomkerne technisch nutzbar gemacht werden? In: Die Naturwissenschaften 27(1939)23/24 (published on 9.6.1939), pp. 402–410; Flügge, S.: Die Ausnutzung der Atomenergie. In: Deutsche Allgemeine Zeitung of August 15, 1939. At the same time (on June 16, 1939) Georg Stetter (1895–1988) from Vienna applied for a patent at the German Reich Patent Office on how nuclear fission can be used to generate energy (cf. Nagel, G.: Atomversuche in Deutschland. Zella-Mehlis 2003, loc. cit., p. 29).

[65] Frisch, O. R.: What little I remember. Cambridge University Press 1979, p. 116; Röseberg, U.: Niels Bohr. Leben und Werk eines Atomphysikers. Berlin: Akademie-Verlag 1985, p. 215.

[66] The records are not entirely clear on whether Bohr had already informed Wheeler and possibly Fermi, who had also welcomed him on the quay, that same evening; certainly, however, he had not told his accompanying assistant Leon Rosenfeld (1904–1974), with whom he had discussed the matter during the passage of the ship, that silence was still to be maintained, and Rosenfeld

unexpected as the discovery had been, after it had become known everyone working in the field of atomic research was immediately aware not only of the significance of this discovery, but it could also be understood relatively quickly, both experimentally and theoretically.

Consequently, Bohr had no choice but to officially report on this at the Washington Conference on Theoretical Physics, which that year was already taking place at the end of January and was actually concerned with low-temperature physics.[67] However, this meant that the attention paid to the Meitner–Frisch publication a few weeks later remained low, and Lise Meitner's contribution to this work in particular was therefore initially underestimated in the scientific world.

In the following weeks Bohr continued to work with Wheeler on the theory of nuclear fission, and their fundamental article appeared in *Physical Review* on September 1, 1939—a date which, as is well known, is also of fundamental political and historical importance—namely the outbreak of the Second World War.

The global political situation in the spring of 1939 led to the consequence that physicists all over the world were not only enthusiastic about the new findings and fascinated by the possibility of almost unlimited energy production; they also recognized that this release of nuclear energy held the possibility of immense destruction and was therefore a candidate for a new type of bomb. In this new type, however, scientists and military officers alike saw merely a "common" bomb with "only" much greater destructive power—the fact that this was to be an absolutely new type of weapon, which would also require new military–political thinking, became clear to most of them only after the first terrible use over Japan.[68]

In my opinion, the relatively short period of time between the discovery of nuclear fission in mid-December 1938 and the publication of their theory at the beginning of September 1939 is an essential aspect for discussing the ambivalence of this scientific result. All the scientists involved were obviously aware of this ambivalence, but none of them drew the conclusion that they should not continue to participate in this research. Some scientists were considering stopping publication, whereas others opposed this as a threat to the freedom of basic research. Thus, Szilard already asked Frédéric Joliot-Curie in early February 1939 whether he would join a voluntary embargo on further publications, for he was aware of Joliot-Curie's research on neutron multiplication.[69] Joliot-Curie replied that although he

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divulged the news to Wheeler as well as to the Princeton club of scientists that same evening: See Röseberg, U.: Niels Bohr; loc. cit.; also Wheeler, J. A.: Geons, Black Holes & Quantum Foam. A Life in Physics. New York/London 1998, Chapter 1.

[67] Interestingly, although Bohr's remarks are mentioned on the corresponding commemorative plaque at George Washington University, the names of Hahn, Straßmann and Meitner are not mentioned. Cf. https://physics.columbian.gwu.edu/1939-fifth-washington-conference-theoretical-physics-low-temperature-physics-and-superconductivity (accessed: 10 April 2018).

[68] Cf. inter alia Kant, H.: J. Robert Oppenheimer. Leipzig: Teubner 1985.

[69] Goldsmith, M.: Nuclear Fission and War. In: New Scientist (1976, June 17), pp. 646–647.

agreed in principle with Szilard's intention, it could not be assumed that all laboratories would adhere to it, and therefore he too would continue to publish.[70]

From mid-1940 onwards, however, nothing more appeared in American or other journals on this subject, particularly given the understandable rationale that no further information should be made available to the Germans.[71] However, especially in Germany and the Soviet Union—i.e., countries at a comparable level of research at that time—it was naturally concluded from this hiatus in publication that the USA was working on an atomic bomb.[72] The question arises of whether the pause in publication really had a "positive" effect.

Especially the scientists who emigrated from Germany and Italy before fascism soon realized the danger posed by an atomic bomb in the hands of the German fascists. This was true for those who emigrated to the USA as well as to England and France, and they endeavored—sometimes in cooperation with scientists from those countries—to make the respective governments aware of this danger.

Leo Szilard, who had worked closely with Einstein and others in Berlin in the 1920s and who, as mentioned above, had already patented the principle of the nuclear chain reaction in 1934, made a first attempt—without success—in March 1939, together with Fermi and others, to gain the interest of American government agencies. In order to make a second attempt more successful, Szilard assured himself of Einstein's support in the summer of 1939, which is how the famous letter of August 2, 1939, written by Szilard and signed by Einstein, to U.S. President Franklin D. Roosevelt (1882–1945) came about. From this—to put it very simply—the US American atomic bomb program finally resulted, which, however, was not specifically coordinated by the state until the end of 1940 and did not even begin in its full complexity until the summer of 1942, when the military took over the organizational management and overall responsibility, then under the codename of the *Manhattan Project*. How would Szilard, Einstein, and others view this effort from today's perspective; what should they possibly have done differently?

The fears of those scientists were well founded. By the end of April 1939, a number of leading German nuclear researchers had already gathered in the German *Reichserziehungsministerium* [Ministry of Science, Education and National Culture] to coordinate the relevant research. After the beginning of the war, Germany's most important nuclear researchers were called to the *Heereswaffenamt* [Army Ordnance Office], including Hahn, Heisenberg, and von Weizsäcker. Unofficially, this group was referred to as the *Uranverein* [Uranium Association],

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[70] Ibid., p. 647.

[71] In general, the considerations regarding the publication suspension only referred to the possible military use, i.e., to the actual "abuse" of such technology. But at that time, this was ultimately only seen in the case of the political–military opponent (to whom no information was therefore to be given), whereas their own military application was approved, as the following comments show.

[72] In addition, there was corresponding secret service information, for example in the Soviet Union (cf: Atomnyj proekt SSSR. Documenty i materialy. Tom 1.1 (1938–1945), Moskva 1998; various materials, including pp. 121–122 the letter from three Academy members of June, 12 1940 to the Deputy Chairman of the Council of Ministers of the USSR).

and at the opening of this project it was made clear that the question of the technical use of nuclear energy was not only of general military interest, but was also directly related to possible new weapons.[73] The first thing Heisenberg was asked to do was to work out the theoretical principles of a nuclear reactor—in Germany at that time they called it an *Uranmaschine* [Uranium engine]. In this context, it is important to emphasize that this military uranium project was not at first explicitly a bomb program, although the background was clear.

In a 1984 interview about the German uranium project, Weizsäcker also asks the question, what would we have done if we had realized that we could make the bomb? “That we said: Dear Führer, we know how to make the bomb, but we will not tell you? I'd like to see how we would have done that.”[74]

In the spring of 1942, when decisions were due on whether to continue the German project, it did not become a direct atomic bomb program. This had nothing to do either with the sometimes-alleged incompetence of the scientists involved or with possible ethical and moral concerns. The reasons behind this were mostly due to other political, military, and economic contexts. Consequently, from summer 1942 onwards, the German uranium program ran largely as a more “civilian” program for the construction of a uranium reactor. Nevertheless, interested parties from the Wehrmacht and SS had not abandoned the idea of an atomic bomb.[75]

Ten of the leading German nuclear scientists—among them Hahn, Heisenberg and Weizsäcker—learned about the first use of atomic bombs by the USA over Japanese cities after the European end of the Second World War at the British Farm Hall, where they spent 6 months in Western Allied captivity, as the American secret service in particular wanted to get an idea of what progress the Germans had actually made in the development of atomic bombs and whether they could still be used productively for the Manhattan Project. This is not the place to discuss this aspect in more detail. As a result of the protagonists' conversations at Farm Hall, their individually diverse entanglements in the German uranium project became the collective experience of an illegitimate appropriation of science by political power. From the retrospective construction of resistance to this use would soon arise—in connection with the rearmament of West Germany after the war—the further potential of real resistance amongst scientists to such indoctrinations.

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[73] Bagge, E., Diebner, K. & Jay, K.: Von der Uranspaltung bis Calder Hall. Hamburg: Rowohlt 1957, p. 23.

[74] Die Atomwaffe. Interview 1984 with H. Jaenecke from *Stern*. Reprinted in: von Weizsäcker, C. F.: Bewußtseinswandel. München/Wien: Carl Hanser 1988, pp. 362–383 (here p. 367). (translation by the author)

[75] Numerous studies on the German nuclear project from recent years make this clear. Cf. among others: Karlsch, R.: Hitlers Bombe. Die geheime Geschichte der deutschen Kernwaffenversuche. München: Deutsche Verlags-Anstalt 2005; Nagel, G.: Atomversuche in Deutschland. Geheime Uranarbeiten in Gottow, Oranienburg und Stadtilm. Zella-Mehlis/Meiningen: Heinrich-Jung-Verlagsgesellschaft mbH 2003; Nagel, G.: Wissenschaft für den Krieg. Die geheimen Arbeiten der Abteilung Forschung des Heereswaffenamtes. (= Pallas Athene, Vol. 43) Stuttgart: Franz Steiner 2012.

Hahn always emphasized that his research during the war had nothing to do with an atomic bomb, as only the products of uranium fission were studied at his institute. In principle, that's true, but a little naïve. For Hahn, for example, was a member of the Uranverein and knew—at least in principle—about the work, even on the assumption that he had relatively little understanding of the physical phenomena that were dealt with there (which is certainly not completely wrong). In autumn 1945 Hahn was awarded the 1944 Nobel Prize in Chemistry "for his discovery of the fission of heavy nuclei"; the award was presented at the Nobel celebration in December 1946, since Hahn was still interned at the British Farm Hall in 1945. Whether Meitner as well as Straßmann and Frisch should also have been included is another topic I have discussed elsewhere.[76]

Hahn, Meitner and Straßmann were then jointly awarded the Enrico Fermi Prize of the US Atomic Energy Agency in 1966.

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Like most scientists of his generation, Hahn believed that the peaceful and military applications of scientific knowledge could be separated relatively clearly. He was convinced of the blessings of science for mankind, and so there was no question in his mind that the peaceful use of atomic energy was one of the most promising tasks for the future of mankind. At the end of his Nobel Lecture in December 1946, he therefore expressed himself very firmly in this sense:

> […] The energy of nuclear physical reactions has been given into men's hands. Shall it be used for the assistance of free scientific thought, for social improvement and the betterment of the living conditions of mankind? Or will it be misused to destroy what mankind has built up in thousands of years? The answer must be given without hesitation, and undoubtedly the scientists of the world will strive towards the first alternative.[77]

Due to the Allied Control Council Law No. 25, however, nuclear physics research was largely prohibited in post-war Germany.[78] However, the scientists around Heisenberg early on began to look for ways and means to mitigate or completely

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[76] Cf. among others: Kant, H.: "… der Menschheit den größten Nutzen geleistet …"!? 100 Jahre Nobelpreis, eine kritische Würdigung aus historischer Perspektive. In: Physikalische Blätter 57(2001)11, pp. 75–79 (esp. pp. 77 f); Kant, H.: Die radioaktive Forschung am Kaiser-Wilhelm-Institut für Chemie von den Anfängen bis zum deutschen Uranprojekt. 2012, loc. cit. (here pp. 96–99).

[77] Hahn, O.: From the Natural Transmutations of Uranium to its Artificial Fission. (Nobel Lecture, 1946). In: Nobel Lectures, Chemistry 1942–1962, Elsevier Publishing Company, Amsterdam, 1964, pp. 51–66 (here p. 64).

[78] Allied Control Council Act No. 25 "Regulation and Supervision of Scientific Research" of 29.4.1946 [http://www.verfassungen.de/de45-49/kr-gesetz25.htm] (accessed: 4 October 2017), specified by Act No. 22 of the Allied High Commission "Supervision of Substances, Facilities and Equipment in the Field of Atomic Energy" of 2.3.1950.

circumvent this ban, and Hahn, by then president of the Max Planck Society, also supported these efforts.[79]

As far as the peaceful use of nuclear energy was concerned, in the 1950s, nuclear reactors based on the fission reaction had been developed to the extent that they could supply electrical energy. The first grid-connected power plant went online in 1954, and was located in Obninsk near Moscow. The fact that the Soviet Union was a pioneer in this field had more than just a political background. The Soviet Union was more dependent than the USA, for example, on developing new energy sources. On the other hand, it has to be said that this nuclear power plant was not a purely civilian foundation, but offered the possibility that some leading Soviet nuclear scientists, who were against military development for various reasons, could cleverly be involved in the relevant research. It had emerged from "Labor V" of the Soviet atomic bomb project, founded in 1945.

Britain and the USA followed a few years later, and here too the first nuclear reactors had emerged from military research. The development of the nuclear energy industry will not be further discussed here.

The nuclear weapons available in the 1950s were atomic bombs and hydrogen bombs, both fission bombs as well as fusion bombs. The international development of nuclear weapons was also regarded with concern by many people in post-war West Germany—especially with regard to the development of atomic and hydrogen bombs—but they were initially more concerned with their own reconstruction and also saw the nuclear weapons issue as a problem for the major powers. The coming international wave of protest at the beginning of the 1950s therefore hardly touched the Federal Republic of Germany. Activities such as those of the World Peace Council, founded in 1949 under Frédéric Joliot-Curie—for example the appeal to ban nuclear weapons, known as the Stockholm Appeal of 1950, to which millions of people around the world signed up—remained largely unnoticed in the FRG, due not least to fear of communist influence.

This changed around the turn of the year 1954/55, and at least three aspects are of particular importance at that time. Firstly, the Paris Treaties were signed in October 1954, which, among other things,[80] sealed the entry of the Federal Republic of Germany into NATO and thus the reconstruction of a German army. On the other hand, at the international level, the escalation of the Cold War and the consequences of the Korean War had led to a growing anti-nuclear war movement, which now reached Germany. And finally, the plans of the German nuclear scientists to be able to conduct nuclear research again within the "normal framework" came closer and closer to their realization, and the German scientists realized that it would be beneficial for their cause to make it clear that they were *only* interested in "peaceful nuclear research." That such peaceful nuclear research is beneficial to human society was a consensus not only among the Federal German scientists.

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[79] The Control Council Law No. 25 was officially repealed for the FRG in May 1955 as a consequence of the Paris Treaties; in the GDR, it was subsequently repealed in September 1955.

[80] The Paris Treaties entered into force in May 1955.

In the spring of 1955, Hahn—inspired by correspondence with Max Born (1882–1970) and Bertrand Russell (1872–1970)—first held a radio lecture and then published a brochure entitled "Cobalt 60—Gefahr oder Segen für die Menschheit" [Cobalt 60—Danger or Blessing for Mankind]; Hahn had probably spoken more clearly than others before him about the dangers of misusing nuclear energy.[81]

In an exchange of ideas with Born, Heisenberg and Weizsäcker, he decided to take the initiative of using the Lindau Conference of Nobel Laureates, which has been held annually since 1951, to launch an appeal *against* military and *for* peaceful use of nuclear energy. Hahn succeeded in persuading all 16 Nobel Prize winners present in Lindau to sign.[82]

In connection with the question of equipping the West German Bundeswehr with nuclear weapons as a consequence of joining NATO, the so-called *Göttinger Erklärung* [Göttingen Declaration] was issued in 1957. The initiators here were, above all, Hahn and Weizsäcker. Important aspects of the Göttinger Erklärung were that the signatories were against nuclear armament of the Bundeswehr, that they made clear the dangers of nuclear weapons and that they declared that they would not participate in the production or testing of nuclear weapons; at the same time, they advocated research into the peaceful use of nuclear energy. This declaration was addressed exclusively to the German Federal Government, so it did not claim an international dimension like the *Mainauer Erklärung* [Mainau Declaration][83] and, for example, it explicitly did not oppose nuclear weapons tests.[84] An important result was the future participation of German scientists in the international Pugwash movement; for the anti-nuclear movement of the 1950/60s "on the street," however, the influence of the Göttingen Declaration was ultimately only slight, because the scientists involved were not prepared to "take themselves to the streets."

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[81] Cf. Kant, H.: Otto Hahn und die Erklärungen von Mainau (1955) und Göttingen (1957). In: Vom atomaren Patt zu einer von Atomwaffen freien Welt. Zum Gedenken an Klaus Fuchs. (= Abhandlungen der Leibniz-Sozietät der Wissenschaften Vol. 32) Edited by Günter Flach & Klaus Fuchs-Kittowski. Berlin: trafo Wissenschaftsverlag 2012, pp. 183–197; See also: Kant, H.: Werner Heisenberg and the German Uranium Project. Otto Hahn and the declarations of Mainau and Göttingen. (= Preprint 203(2002) Max Planck Institute for the History of Science), esp. pp. 21–40. [https://www.mpiwg-berlin.mpg.de/sites/default/files/Preprints/P203.pdf]

[82] Cf. Hahn, O.: Mein Leben. op. cit. p. 230. In his notebook Hahn notes under 11.7.55 "In the afternoon even longer meetings with the 16 Nobel Prize winners present. Finally, Lipmann gives in." (in Hahn, D.: Otto Hahn – Begründer des Atomzeitalters. Eine Biographie in Bildern und Dokumenten. München: Paul List 1979, p. 249) (translation by the author); Cf. also Born's remark in: Max Born: My Life and My Views. New York 1968, p. 85. Of the first signatories, Compton and Yukawa were not present in Lindau (see figure of the original declaration in Hahn, D., loc. cit. p. 250; also in Gerlach, W. & D. Hahn: Otto Hahn – Ein Forscherleben unserer Zeit. (= Große Naturwissenschaftler Vol. 45). Stuttgart: Wissenschaftliche Verlagsgesellschaft 1984, p. 154 f).

[83] As *Mainauer Erklärung* [Mainau Declaration] is denoted the appeal appointed at the Lindau Conference of Nobel Laureates, which was made public during a meeting on the isle of Mainau.

[84] Hahn emphasized the latter explicitly in a letter to Karl Bechert (1901–1981) of December 12, 1957 [MPG Archive, NL Hahn, Abt. III, Rep. 14A, No. 00 208, p. 2]. Bechert was a physicist and SPD politician and dedicated himself early on to the fight against both military and civil uses of nuclear energy; later he was also a co-founder of the anti-nuclear power movement.

It is important to note that with the Mainau Declaration, and even more so with the Göttingen Declaration, leading German (natural) scientists moved from their immediate scientific sphere of activity to a broad political public for the first time. But did they really do so out of political conviction or rather for very different selfish reasons? It is certainly reasonable to doubt whether this image-boosting appearance actually warrants the responsible political intent that has increasingly been attributed to it in recent years.

Hahn repeatedly emphasized that in this matter he was not acting as president of the Max Planck Society but as an independent scientist, but on the other hand he used the opportunity to represent the intensions of the *Göttinger Achtzehn* [Göttingen Eighteen] at the 1957 annual meeting of the Society in Lübeck at the end of his presidential address.[85]

There were different views among the signatories on the further course of action.[86]

For Hahn, the next suitable opportunity to bring his concern to the public was at his much-acclaimed lecture "Atomenergie für den Frieden oder für den Krieg" [Atomic Energy for Peace or War], which he gave on November 14, 1957 in the Vienna Konzerthaus, invited by the Austrian Cultural Association.[87] In this he remained true to his conviction that he was unequivocally opposed to nuclear war, and quoted the Mainau and Göttingen Declarations at length, but nevertheless vehemently advocated for peaceful uses of nuclear technology.[88]

Even Weizsäcker, who played a significant role in preparing the Mainau and Göttingen Declarations, was still guided by this conviction at that time. This is true even for the vast majority of scientists involved in the development of atomic bombs.

"[…] the physicists have known sin; and this is a knowledge which they cannot lose," commented J. Robert Oppenheimer (1904–1967), the so-called "father of the American atomic bomb" following the deployment of the two atomic bombs against Japan and after the end of the Manhattan Project in 1947. Oppenheimer did not define this "sin," but was clearly referring to military applications, and it must be noted that most of the scientists involved must be given a high degree of responsibility. They had decided to take this step precisely because they feared that this weapon would be unscrupulously abused by others who might possess it. Given their political and social backgrounds, they could hardly have guessed in those days that the

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[85] Hahn, O.: Ansprache des Präsidenten auf der Hauptversammlung der MPG 1957 in Lübeck. In: Mitteilungen aus der Max-Planck-Gesellschaft, issue 4/1957 (August), pp. 194–201 (here p. 199 f).

[86] However, in accordance with the compromise agreed in the Federal Chancellery on April 17, 1957, the scientists were generally of the opinion that they should not go public before the federal elections in September 1957, in order not to expose themselves to the accusation of taking a party-political stand. See Kraus, E.: Von der Uranspaltung zur Göttinger Erklärung. Otto Hahn, Werner Heisenberg, Carl Friedrich von Weizsäcker und die Verantwortung des Wissenschaftlers. Würzburg: Königshausen & Neumann 2001; Rese, A.: Wirkung politischer Stellungnahmen von Wissenschaftlern am Beispiel der Göttinger Erklärung zur atomaren Bewaffnung. Frankfurt am Main: Lang 1999.

[87] Hahn accepted the invitation on 11.9.1957 [MPG Archive NL Hahn, Dept. III, Rep. 14A, No. 05 548, p. 15].

[88] Lecture manuscript in the MPG Archive NL Hahn, Dept. III, Rep. 14A, No. 06 379.

U.S. Government, which originally had to be persuaded by them to take up the development of atomic bombs, would later unscrupulously abuse this weapon itself.[89] But the peaceful use, which they advocated with varying degrees of vehemence in the 1950s and 1960s, was an undoubtedly positive option for them.[90]

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It should not be forgotten that the euphoria among scientists regarding the peaceful use of nuclear energy in the 1950s and 1960s was supported by a political euphoria (not only in Germany), which was related on the one hand to the circumstances of the Cold War and on the other hand to economic considerations, which Franz Josef Strauß (1915–1988), Federal Minister for Atomic Questions from 1955–1956, put in a nutshell:

> But we must now take the first steps, quite modestly and simply, that are necessary for us to occupy an equal place in the circle of nuclear powers […] that use this power for peaceful purposes in the foreseeable future.[91]

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[89] Cf. inter alia Kant, H.: J. Robert Oppenheimer. op. cit. p. 156; Bird, K. & Schweber, M.: American Prometheus – The Triumph and Tragedy of J. Robert Oppenheimer. New York: Alfred A. Knopf, 2005, esp. p. 388.

[90] Nevertheless, the United States' Acheson–Lilienthal Plan of 1946, a first draft for the international control of atomic weapons and the atomic energy industry, which had been drawn up with Oppenheimer's decisive involvement, had already made it clear: "The development of atomic energy for peaceful purposes and the development of atomic energy for bombs are in much of their course interchangeable and interdependent." [A Report on the International Control of Atomic Energy; Prepared for the Secretary of State's Committee on Atomic Energy. Washington, D.C. March 16, 1946, p. 10]. This basic problem could not be solved even by a clear commitment to peaceful use, as further developments showed, even though efforts were made to keep the military aspect in the background for the public.

Hahn, for example, although he had again vehemently advocated the peaceful use of nuclear energy at the General Assembly of the Max Planck Society in Hannover in 1958, also expressed initial cautious doubts about this use. "For years I have occasionally wondered whether it wouldn't be better if the entire utilization of atomic energy had never become a fact […]," but then emphasized his positive view that it is beneficial to have atomic energy available in view of the shortage of coal and oil. However, he also points out the dangers of the fission products produced in the nuclear reactor as well as their use (e.g., plutonium) for the construction of atomic bombs, and then finally refers to the emerging possibility of nuclear fusion, emphasizing among other things that the fusion reactor cannot be used for the production of hydrogen bombs, but could solve the energy problem. [Hahn, Otto: Ansprache auf der Hauptversammlung der Max-Planck-Gesellschaft 1958 in Hannover. In: Mitteilungen aus der Max-Planck-Gesellschaft zur Förderung der Wissenschaften (1958) 4, pp. 216–224 (here pp. 221 ff)]. (translation by the author)

[91] Quoted after Fischer, P.: Atomenergie und staatliches Interesse: Die Anfänge der Atompolitik in der Bundesrepublik Deutschland 1949–1955. (= Internationale Politik und Sicherheit, Vol. 30/3) Baden-Baden: Nomos 1994, p. 261. (translated by the author). Fischer further shows that Strauß was by no means only interested in peaceful use, for he was convinced that "what the Bundeswehr was in one area, nuclear energy was in another" (ibid., p. 262). And finally, this military background also had an influence on the choice of fuel (natural uranium or enriched uranium) and thus on the reactor type [cf. e.g., Radkau, J. (1983) loc. cit., p. 63: "The fact that the Federal Republic of Germany refrained from building nuclear weapons did not prevent the development of nuclear energy from being pre-structured by military technology in this case, too"].

One of the consequences of this objective was that the German Government urged the energy sector to enter into nuclear power generation and announced that it would provide the necessary capital, because it was clear that the capital expenditure requirements would be much higher than for conventional power plants. The concerns of the energy industry were therefore mainly based on financial circumstances and less on risks of technical feasibility or ecological considerations.[92] And nothing much has changed since then.

Simultaneously, scientists and politicians at that time repeatedly depicted an international race in which countries found themselves with regard to the use of nuclear energy and in which they should not be left behind. Erich Bagge (1912–1996) opposed this as early as 1960—probably rather unconsciously, because it seemed natural to him:

> The question of whether it would be appropriate at all to get involved in this particularly expensive race for the peaceful use of nuclear energy was not at any time a problem for discussion.[93]

The concept of the peaceful use of nuclear energy was not limited to the generation of energy for public power grids by nuclear power plants. There were also numerous proposals to use nuclear energy directly for propulsion technology, for example for ships.[94] However, military use was also a pioneer in ship propulsion: in 1955, the first US nuclear submarine went into operation.[95] In Germany, the Society for the Utilization of Nuclear Energy in Shipbuilding and Shipping (GKSS, *Gesellschaft*

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[92] Cf. i.a. Radkau, J.: Aufstieg und Krise der deutschen Atomwirtschaft 1945–1975. Verdrängte Alternativen in der Kerntechnik und der Ursprung der nuklearen Kontroverse. Reinbek bei Hamburg: Rowohlt 1983, p. 196 ff; Müller, W. D.: Die Geschichte der Kernenergie in der Bundesrepublik Deutschland. Vol. I: Anfänge und Weichenstellungen. Stuttgart: Schäffer-Poeschel 1990 (esp. Chapter B.6.: Wer braucht Kernenergie?). On the corresponding development in the GDR, see for example Liewers, P., Abele, J. & Barkleit, G. (Eds.): Zur Geschichte der Kernenergie in der DDR. Frankfurt am Main: Peter Lang 2000.

[93] Bagge, E.: Die friedliche Nutzung der Kernenergie für technische Zwecke. In: Atom. Wirklichkeit – Segen – Gefahr. Werbebroschüre des Innenministeriums des Landes Schleswig-Holstein, Kiel 1960, pp. 55–65 (here p. 56). Bagge as well as Kurt Diebner (1905–1964) were among the members of the *Uranverein* who were detained at Farm Hall in 1945. However, in many nuclear–physical questions they differed from the circle around Heisenberg, which had not only to do with the fact that during the war they conducted their nuclear–physical research in the research center of the *Heereswaffenamt*. Bagge, a student of Heisenberg, worked at the University of Hamburg from 1948 to 1957 and was then head of the Institute for Pure and Applied Nuclear Physics at the University of Kiel. Together with Diebner he was also one of the founders of the GKSS mentioned below.

[94] For this and other examples of use, see Margulies, R.: Atome für den Frieden. Köln/Opladen: Westdeutscher Verlag 1965. Although this book was written with enthusiasm for nuclear energy in mind, it also mentions, for example in the section "The Search for Energy Sources" (pp. 13–18), a wide variety of alternative energy sources, including wind and solar energy, which could not be reliably used in industry in those days due to the technological limitations of the time.

[95] At present, the USA, Russia, France, Great Britain, the People's Republic of China, and India operate submarine fleets powered by nuclear energy. Nuclear-powered aircraft carriers have been built in the USA since 1960; there are plans to build such carriers in Russia and China.

für Kernenergieverwertung in Schiffbau und Schiffahrt), based in Geesthacht, published a tender for a nuclear-powered merchant vessel in 1960,[96] which was launched in 1964. In 1968 the ore carrier *Otto Hahn* was commissioned.[97] The nuclear merchant fleet was therefore limited to this one ship, which was decommissioned in 1979 and scrapped in 2009.[98] Nuclear cargo ships were not able to establish themselves for various reasons (above all, they turned out to be uneconomical).

Obviously, aspects which today play a major role in the assessment of the peaceful use of nuclear energy initially played only a minor role or none at all. The main focus was on the possibility of relatively unlimited availability of energy (which was also considered "clean" compared to the limited fossil fuels) and the beneficial use of radioactive isotopes, for example in medicine and technology. Although reactor safety was an important issue from the very beginning, the problem of, for example, the long-term safe storage of so-called nuclear waste (such as fuel elements, construction waste from nuclear reactors, etc.) or the technical, financial and time expenditure for the demolition of reactors initially played a subordinate role or was regarded as relatively unproblematic to solve, probably also due to the assumption that nuclear fission energy would soon be replaced by fusion energy. However, when fusion research began at the end of the 1950s it was assumed that a fusion reactor could be realized within 20–30 years at most, whereas today it is assumed that commercially viable nuclear fusion cannot be expected before 2050 (i.e., more than 100 years after the initial research began).[99] And even when it comes to the question of whether fusion energy is so much "cleaner" or more environmentally friendly than fission energy, estimates today are not as optimistic as they were at the end of the twentieth century.

In the mid-1980s, however, Weizsäcker wrote retrospectively in the introduction to a study by Meyer-Abich and Schefold, concluding that nuclear energy—in comparison to solar energy and technically feasible energy savings—did not sufficiently meet the criteria of social compatibility or economic viability:

> According to my scientific background, I was a spontaneous supporter of nuclear energy until the early seventies. […] In the winter of 1974–75, as advisor to the Federal Minister for Research and Technology, I pointed out the inevitable coming public debate on nuclear energy. The form in which the public criticism of nuclear energy was then voiced was, of course, in my opinion, far too undifferentiated in terms of the facts.

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[96] This was preceded by the Soviet nuclear icebreaker *Lenin* (launched in 1957, commissioned in 1959) and the US merchant and passenger ship *Savannah* (planned since 1955, commissioned in 1962).

[97] Hahn participated in the launch on June 13, 1964 in Kiel and saw this project as a confirmation of his ideas on the peaceful use of nuclear energy (see Hahn, D., loc. cit. p. 324; Hoffmann, K., loc. cit. p. 246).

[98] In 1979 the nuclear reactor was replaced by a diesel engine; in 1983 the ship was also converted into a container ship and continued to sail under changing names and flags until it was scrapped as a cargo ship. The removed reactor was stored at GKSS until 2010. Cf. e.g., Neumann, H.: Vom Forschungsreaktor zum "Atomschiff" Otto Hahn: Die Entwicklung von Kernenergieantrieben für die handelsmarine in Deutschland. (= Deutsche Maritime Studien 7) Bremen: H. M. Hauschild 2009.

[99] Radkau even calls the fusion reactor the "Fata Morgana der Atomeuphorie" [mirage of atomic euphoria]. [Radkau, J. & L. Hahn: Aufstieg und Fall der deutschen Atomwirtschaft. München: oekom 2013, p. 53].

> […] I now strongly support solar energy as the main energy source, supported by technically possible energy savings, and oppose the choice of nuclear energy as the main energy source; […].[100]

Radkau commented on this change of opinion by a leading nuclear physicist of the pioneering era with the following words:

> […] Weizsäcker had become skeptical of nuclear power, and that was a deep shock for them [meaning the nuclear community – HK]—as if they had lost their demigod. A remarkable thing: nuclear power is based on the laws of physics and a huge army of experts, and yet its promotion was so dependent on the blessing of key personalities.[101]

From today's perspective, Weizsäcker's statement can be generalized to the effect that there are no serious long-term alternatives to renewable energies.[102] In this assessment, the danger of nuclear catastrophes plays a role, along with other aspects, as does the still unresolved issue of nuclear waste disposal.[103] However, if in the 1950s and 1960s—depending on one's point of view—a certain nuclear hysteria or euphoria was observed in science and politics, then today, on the other hand, in the discussions about the relatively sudden nuclear phase-out after the Fukushima catastrophe in March 2011, there is a danger of lapsing into anti-nuclear hysteria or euphoria.[104] Although a nuclear phase-out had already been in the sights for some

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[100] von Weizsäcker, C. F.: Introduction to Klaus Michael Meyer-Abich & Bertram Schefold: Die Grenzen der Atomwirtschaft. München: C. H. Beck 1986, p. 15 f. (translation by the author)

[101] Interview by Frank Uekoetter with Joachim Radkau. In: Environmental History 13(2008)4, p. 757–768 (here p. 760).

[102] Hubert Laitko summarizes Weizsäcker's reflections on these issues in this way: "When weapons are developed, their destructive effect is consciously taken into account; it is the genuine purpose of weapons to achieve precisely this effect. Ecological damage, on the other hand, is usually unintentional and even contrary to the objectives of the actions that cause such damage. Cognitively and ethically, we are dealing with a completely different situation here than in weapons development. The actual complication is that here the damage does not unintentionally occur instead of the intended benefit, but the intended benefit is achieved and in *addition* – as a secondary or consequential effect – there is also ecological damage." [Laitko, H.: Der Ambivalenzbegriff in Carl Friedrich von Weizsäckers Starnberger Institutskonzept. Max Planck Institute for the History of Science, Preprint 449, Berlin 2013, p. 16]. Basically, since the 1960s/1970s such considerations have led to the establishment of the research field of *technology assessment*.

[103] An overview of nuclear accidents is provided by Mahaffey, J.: Atomic Accidents. A History of Nuclear Meltdowns and Disasters. From the Ozark mountains to Fukushima. New York/London: Pegasus Books 2015.

[104] In the meantime, there are numerous publications on the issues and consequences of the so-called energy transition and the nuclear phase-out. In connection with what is presented here I only refer to the following books: Banse, G. et al. (Ed.): Energiewende – Produktivkraftentwicklung und Gesellschaftsvertrag. (= Abhandlungen der Leibniz-Sozietät, Vol. 31) Berlin: trafo Wissenschaftsverlag 2013; Ostheimer, J. &. Vogt, M. (Eds.): Die Moral der Energiewende. Risikowahrnehmung im Wandel am Beispiel der Atomenergie. (= Ethik im Diskurs, Vol. 10) Stuttgart: W. Kohlhammer 2014; Morris, C. & Pehnt, M. (2016): Energy Transition. The German Energiewende. Heinrich-Böll-Stiftung 2016. [https://book.energytransition.org/sites/default/files/downloads-2016/book/German-Energy-Transition_en.pdf] (Accessed: 14 February 2018); Kemfert, C.: Das fossile Imperium schlägt zurück. Warum wir die Energiewende jetzt verteidigen müssen. Hamburg: Murmann 2017.

time in the Federal Republic of Germany,[105] it was not until 2000 that the red–green government under Gerhard Schröder made a corresponding decision. In 2009, key points of this proposed phase-out were effectively rescinded by the CDU/CSU/FDP government under Angela Merkel (nuclear energy should again be regarded more strongly as a "bridging technology").[106] However, following the Fukushima reactor disaster, the same Merkel government then abruptly made an unprecedented turnaround by deciding to phase out nuclear power, which now provides for the shutdown of all German nuclear power plants by 2022. At the same time, this decision manifested publicly in the so-called *energy transition*, which means the transition from fossil fuels and nuclear energy to a "sustainable" energy supply through so-called renewable energies.[107, 108] The problems of nuclear phase-out and energy transition must be considered not least in connection with the problems associated with climate change.[109]

Internationally, however, the phasing out of nuclear energy is far from being a consensus, but is the subject of highly controversial discussions.[110] Just recently, various worldwide efforts to develop and build new generations of nuclear power

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[105] The term "nuclear phase-out" emerged as a catchword of the anti-nuclear movement in the 1970s. On the origins of the anti-nuclear movement, see Radkau/Hahn, op. cit. p. 288 ff.

[106] This was due not least to the myth of the so-called "nuclear renaissance," which was propagated for the last years of the twentieth century and the first decade of the twenty-first century (the term was probably coined by William J. Nuttall); the first nuclear reactors of the so-called third generation went into operation. For a concise overview of the time in 2011, see e.g., Joskow, P. L. & Parsons, J. E.: The Future of Nuclear Power After Fukushima. In: Economics of Energy & Environmental Policy 1(2012)2, pp. 99–113 (esp. pp. 101–105).

[107] The commonly used term "renewable energy" is actually misleading, because energy cannot renew itself (law of energy conservation!). It would be better to speak of "regenerative energy" (where "regenerative" refers to the energy source).

[108] In Germany, the debate on the energy transition began as early as in the 1970s/1980s within the environmental movement and with the entry of the Green Party into the Bundestag. (see Morris/Pehnt loc. cit., p. 55 ff). Since 2011, the word "energy transition" has increasingly been used as a synonym for nuclear phase-out, which, however, tends to conceal the connections. Although the nuclear phase-out is part of the energy transition, it is only one part of it [Kemfert loc. cit., chapter Postfakt 1].

[109] Cf. for example Edenhofer, O. & Jakob, M.: Klimapolitik. Ziele, Konflikte, Lösungen. (= C. H. Beck Wissen bw 2853) München: C. H. Beck 2017.

[110] Cf. inter alia the strategy paper PINC of the EU Commission of April 2016: [https://ec.europa.eu/transparency/regdoc/rep/1/2016/DE/1-2016-177-DE-F1-1.PDF], [https://ec.europa.eu/germany/news/kommission-veröffentlicht-bericht-zur-kernenergie-der-eu_de]. (Accessed: 25 February 2018). In Germany, the Federal Government reacted with protest to these plans by the EU Commission [http://www.spiegel.de/wirtschaft/soziales/atomkraft-strategie-der-eu-bundesregierung-reagiert-empoert-a-1092664.html]. (Accessed: 25 February 2018).

plants have become known.[111, 112] At the same time, however, it should not be underestimated that the presumably greater danger still comes from the military use of nuclear energy, not only with regard to its possible use in armed conflicts,[113] but also with regard to the disposal of both obsolete nuclear warheads and similar devices and also the corresponding infrastructure used to produce nuclear weapons.

This is not the place to discuss the pros and cons of a nuclear phase-out and energy transition, because this article was primarily concerned with scientific–historical considerations on the history of the discovery of nuclear energy in order to better understand this phenomenon and its significance for science and society. But on the other hand, scientific discovery cannot be separated from considerations of its use, as we have seen.[114]

This history of discovery also shows, however, that there is apparently always a certain euphoria at the beginning of such an application, and that risks and dangers

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[111] In the international discussion on possible new nuclear power plants, the development of generation III and IV plants plays a decisive role (in this context the first generation refers to reactors built between 1950 and 1960, which are more likely to be understood as demonstration power plants, and the second generation refers to reactors built between 1970 and 1990, most of which are still in operation today). Key objectives in the development of the fourth generation are, among other things, increased safety, sustainable use of uranium and the recycling of waste (how far this is actually realistic is another question). Cf. among others [https://de.nucleopedia.org/wiki/Generation_IV], [https://www.heise.de/tr/artikel/Neue-Heimat-Kanada-3889812.html], [http://www.ageu-die-realisten.com/archives/2423] (accessed: 25 February 2018).

[112] The countries with the largest nuclear power capacity are currently (highest first): USA, France, China, Russia, South Korea, Canada (if we count "reactors in operation" we get: USA, France, China, Russia, Japan, South Korea). The USA, France, China, Russia and India (at least) are building or planning new reactors. See the Wikipedia article "Kernenergie nach Ländern" [https://de.wikipedia.org/wiki/Kernenergie_nach_Ländern] (accessed: 31 March 2021); see also: Nuclear Power in the World Today. [http://www.world-nuclear.org/information-library/current-and-future-generation/nuclear-power-in-the-world-today.aspx] (accessed: 31 March 2021). Thirteen EU Member States currently operate nuclear power plants (so approximately a quarter of the reactors operated worldwide are on EU territory). Austria, on the other hand, has never put its only nuclear power plant at Zwentendorf (project started in 1971, decommissioned in 1978) into operation; since 1999, the Bundesverfassungsgesetz für ein atomfreies Österreich [Federal Constitutional Law for a nuclear-free Austria] has been in force there. In Vienna there is only one research reactor still in operation. (Cf. inter alia Forstner, Christian: Zur Geschichte der österreichischen Kernenergieprogramme. In: Kernforschung in Österreich. Wandlungen eines interdisziplinären Forschungsfeldes 1900–1978. Edited by S. Fengler & C. Sachse. Böhlau: Wien etc. 2012, pp. 159–180). Turkey, on the other hand, is building its first nuclear power plant with Russian help in Akkuyu on the Mediterranean coast, which is scheduled to go online in 2023. Another nuclear power plant is being built in Sinop on the Black Sea coast with Japanese support (which seems to be stalled at the moment). Both regions are prone to earthquakes! [Wikipedia article "Nuclear energy in Turkey" (accessed 31 March 2021)].

[113] Cf. e.g., von Weizsäcker, E. U. & Wijkman, A.: Wir sind dran. Club of Rome: Der große Bericht: Was wir ändern müssen, wenn wir bleiben wollen. Eine neue Aufklärung für eine volle Welt. Gütersloher Verlagshaus 2017 (Chapter 1.6.2 Atomwaffen – die verdrängte Bedrohung).

[114] In this context, reference should also be made to a discussion event organized by the Leibniz-Sozietät on April, 12 2018: Die Energiewende 2.0: Essentielle wissenschaftlich-technische, soziale und politische Herausforderungen. [https://leibnizsozietaet.de/internetzeitschrift-leibniz-online-nr-29-2017/] (Accessed 29 August 2021).

only come into view later.[115] This probably also applies to the energy transition in the broader sense—many problems of wind or solar energy plants, for example, are currently being sidelined rather than being subjected to serious consideration for the future, and therefore there is a real danger that “mistakes” similar to those made in the introduction of nuclear energy will be made again.[116]

However, the question of how far research can or should actually go remains unanswered in this context. Walther Gerlach (1889–1979) already drew attention to the following connection in the mid-1950s:

> […] It is, after all, the method of physical research that “new territory” is not discovered in nature, but is created in the artificially prepared world of the laboratory: by creating conditions that can be clearly overlooked and in which disturbing secondary conditions are eliminated as far as possible.[117]

This means, however, that the laboratory experiment always takes place under restricted, “artificial” conditions, i.e., it is actually an intervention in nature. Incalculable “unintended” consequences cannot be excluded.[118]

One aspect of this ambivalence is, among other things, the fact that in researching the transuranium elements, experiments were apparently carried out that do not occur in nature in this way, i.e., they represent an intervention in nature under laboratory conditions. But does the ambivalence mentioned here really only apply to Hahn’s and Straßmann’s experiments on transuranium elements, or does it already apply to the early 1930s with regard to the discovery of artificial radioactivity? Should the research have been stopped there already, since it was finally an intervention in nature? But is that really the case? In his 1939 contribution to *Die Naturwissenschaften,* Flügge had already raised the question: “If such a conversion of uranium is possible, […] why did nature not anticipate this experiment and carry

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[115] Other corresponding examples from the history of science and technology can be cited, for example the initially inflationary use of X-rays, the agricultural use of the insecticide DDT or the use of CFCs as propellants and refrigerants.

[116] A similar problem seems already evident in the so-called digitalization, which the German Federal Government formed in March 2018 has placed at the forefront of its socio-political objectives. When the newly appointed Minister of State for Digitalization, Ms. Dorothee Bär (CSU), picked up on an FDP slogan from the 2017 federal elections: “Digital first. Misgivings second” and shortly after taking office declared: “We also want to become digital world champion! […], but I am tired of the misgivings” (cf: Interview with Dorothee Bär on March, 2018 [https://www.bild.de/politik/inland/dorothee-baer/flugtaxis-werden-in-wenigen-jahren-fliegen-55257916.bild.html], translated (accessed 8 April 2018)), then this is strongly reminiscent of the political approach to the introduction of nuclear energy in the 1950s and 1960s (cf. e.g., the statement by F. J. Strauß quoted above), and is at least a very questionable political understanding of how to deal with new scientific and technological developments, and makes a mockery of all historical experience, which is so readily emphasized especially with regard to nuclear energy. On the socio-political dimensions of digitalization, see e.g., Santarius, T. & Lange, S.: Smarte grüne Welt. Digitalisierung zwischen Überwachung, Konsum und Nachhaltigkeit. München: oekom 2018.

[117] Gerlach, W.: Die Kosten der modernen naturwissenschaftlichen Forschung. Mitteilungen aus der Max-Planck-Gesellschaft (1956) pp. 23–32 (here p. 29). Translation by the author.

[118] Parthey also makes explicit reference to this in his contribution to this book (see Ch. 7 of this volume).

it out in the rock?[119] At that time Flügge was unable to answer the question, but expressed suspicions about the possibility. In the meantime, however, a uranium ore deposit has been discovered in the Oklo region of Gabon in Africa, for example, where a reactor-like fission reaction took place about two billion years ago—only today there is no longer any fissile uranium remaining in the necessary concentration, so the process has stopped.[120]

How far may research actually go?[121] To what extent can researchers—especially basic researchers—be aware of consequences if they cross such boundaries? And where do these boundaries lie?[122] Can this be grasped by the term *ambivalence of science*? Not least, questions of scientific ethics also play an important role in physical and chemical research. The biophysicist and geophysiologist James Lovelock (*1919) regards the Earth, on the basis of his Gaia theory, as a kind of living organism![123]

The fact that Hahn and Straßmann finally discovered something other than what they had originally been looking for is ultimately also connected with this aspect of research, which cannot be discussed further here, however. On the other hand, it is not uncommon for research to reveal something that differs from expectations or even diverges entirely from the question originally investigated.[124]

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[119] Flügge: Kann der Energiehaushalt […], op. cit., p 409.

[120] Meshik, A. P.: The Workings of an Ancient Nuclear Reactor. In: Scientific American (2005, November), pp. 83–91; Schaaf, M.: Kernspaltung im Herzen der Finsternis. Afrika und die Ursprünge des Nuklearzeitalters. In: "Radiochemie, Fleiß und Intuition – Neue Forschungen zu Otto Hahn." Ed. by Vera Keiser. Berlin, Diepholz: GNT Verlag 2018, pp. 433–476.

[121] In this context, Parthey refers to the German Embryo Protection Law in his contribution to this book (see Ch. 7 of this volume). Should something similar apply to research on non-living matter? At the very least, the validity of such a question cannot be denied, but it would require a fundamentally new understanding of physical and chemical experiments.

[122] Oppenheimer wrote in June 1946 in a kind of commentary on the Acheson-Lilienthal Plan: "The point is, "[…] that if you don't try to develop atomic energy, you can't control it—you can't say first we will control it, and then we will develop it, because the developmental functions are an essential part of the mechanism for control." [Oppenheimer, J. R.: The International Control of Atomic Energy. Bulletin of the Atomic Scientists 1(1946)12, pp. 1–5 (here p. 4)]. While this is quite understandable, it is ultimately a plea for not imposing any limits on (basic) research. Can this still be maintained nowadays?

[123] Lovelock, J.: The Revenge of Gaia. Why the Earth is Fighting Back and How We Can Still Save Humanity. Allen Lane, London 2006. (In German: Lovelock, J.: Gaias Rache. Warum die Erde sich wehrt. (= Ullstein Paperback 37210) Berlin: Ullstein 2008.)

[124] One speaks of serendipity; this term goes back to the sociologist of science Robert K. Merton (1910–2003). Often, people also talk about accidental discoveries [Zufallsentdeckungen], which on closer inspection are not so much "accidental" but instead require a precise ability to observe at the right time (often, it turns out afterwards, that others had already observed the phenomenon before the accredited discoverer, but did not interpret it correctly). As further examples we only refer to the discovery of X-rays or penicillin.