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# Nuclear Weapons and Reactor Research at the Kaiser Wilhelm Institute for Physics

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## BACKGROUND

The story of the Kaiser Wilhelm Institute for Physics (*KWI für Physik*, KWIP)[1] begins with Albert Einstein. In 1914, Max Planck lured his young colleague to Berlin with an attractive package of positions and benefits that allowed Einstein to work without any teaching obligations.[2] Two years later, Einstein published his work on general relativity and quickly became famous. In 1917, Einstein was given a "paper" Kaiser Wilhelm Institute

[1] In 2004, copies of documents from the Kaiser Wilhelm Institute for Physics were returned to the Max Planck Society (*Max-Planck-Gesellschaft*) from the Atomic Archives of the Russian Federation. These documents had been seized by Soviet forces at the very end of the war and transferred to the Soviet Union, where they were evaluated in the context of the Soviet atomic bomb project. Together with the Heisenberg Papers at the Max Planck Institute for Physics and Astrophysics in Munich – which were evacuated from Berlin along with the institute in the last years of the war to Hechingen and Haigerloch in southwestern Germany – these papers provide a fairly complete documentation of the research of this institute during the Second World War and significantly change our historical understanding of the work done at the KWIP on nuclear reactors and nuclear weapons during the Second World War. The most sensational and hitherto unavailable documents include (1) a patent application by Carl Friedrich von Weizsäcker in 1941 on a nuclear reactor and how the transuranic elements it produces could be used as a nuclear explosive, and (2) a popular lecture on nuclear fission and its applications by Werner Heisenberg before Armaments Minister Albert Speer and others in June of 1942. Many duplicates of the so-called G-Reports (German-Reports on Atomic Energy) now located at the Deutsches Museum in Munich are included, but there are also some technical reports and scientific papers that have not been available previously. There is also a wealth of information on the day-to-day operation of the institute, which sheds light on the atmosphere and environment in which these scientists were working.

[2] See Horst Kant, "Albert Einstein, Max von Laue, Peter Debye und das Kaiser-Wilhelm-Institut für Physik in Berlin (1917–1939)," in Bernhard vom Brocke and Hubert Laitko (eds.), *Die Kaiser-Wilhelm-/Max-Planck-Gesellschaft und ihre Institute; Studien zu ihrer Geschichte: Das Harnack-Prinzip* (Berlin: De Gruyter, 1996), 227–243.

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(KWI) including a salary, an office, and grant money he could dispense. Four years later, Einstein received the Nobel Prize. Max von Laue, also a Nobel laureate, became the second director of the institute and handled most of the administration. Einstein was one of the few German scientists who had real political significance in Germany because of his fame, outspoken internationalism during the First World War and Weimar Republic, public advocacy of Zionism, and public criticism of anti-Semitism.[3] When the National Socialists came to power in Germany in 1933, Einstein was in the United States, where he stayed.

Max Planck, another Nobel laureate for physics who became president of the Kaiser Wilhelm Society (*Kaiser-Wilhelm Gesellschaft*, KWS) in 1930, wanted very much to establish a "real" KWIP.[4] He managed to do this with money from the American Rockefeller Foundation, despite the Foundation's misgivings about the policies of the National Socialist (NS) government. After all, this came after the purge of the German civil service in 1933 and passage of the infamous Nuremberg Race Laws in 1935.

Although Rockefeller was concerned about what the NS regime might subsequently do with the institute, in the end it was unwilling to renege on past promises and reluctant to recognize that its support had been or indeed could be politicized. The new KWIP opened in 1936 with the respected Dutch physicist and Nobel laureate Peter Debye as its director. Debye built a world-class laboratory for investigating low-temperature physics. The KWIP staff included Laue and two young physicists who would play an important role in the German "uranium project," Carl Friedrich von Weizsäcker and Karl Wirtz.[5]

During 1939, the KWIP was rocked by two different shocks: (1) publication of the discovery of nuclear fission, the result of a collaboration between the experimental chemists Otto Hahn and Fritz Strassmann at the KWI for Chemistry (KWIC) and their former colleague and theoretical physicist Lise Meitner;[6] and (2) the start of the Second World War. Just two weeks

[3] See David Rowe and Robert Schulman (eds.), *Einstein on Politics: His Private Thoughts and Public Stands on Nationalism, Zionism, War, Peace, and the Bomb* (Princeton: Princeton University Press, 2007).

[4] John Heilbron, *The Dilemmas of an Upright Man: Max Planck as Spokesman for German Science* (Berkeley: University of California Press, 1986), 175–179; Kristie Macrakis, "Wissenschaftsförderung durch die Rockefeller Stiftung im 'Dritten Reich.' Die Entscheidung, das Kaiser-Wilhelm-Institut für Physik finanziell zu unterstützen, 1934–1939," *Geschichte und Gesellschaft*, 12 (1986), 348–379.

[5] For Debye and the KWIP, see Horst Kant, "Peter Debye und das Kaiser-Wilhelm-Institut für Physik in Berlin," in Helmut Albrecht (ed.), *Naturwissenschaft und Technik in der Geschichte (25 Jahre Lehrstuhl für Geschichte der Naturwissenschaft und Technik am Historischen Institut der Universität Stuttgart)* (Stuttgart: GNT-Verlag, 1993), 161–177.

[6] For fission and the relationship between Hahn and Meitner, see Ruth Lewin Sime, *Lise Meitner: A Life in Physics* (Berkeley: University of California Press, 1996); also see Elisabeth Crawford, Ruth Lewin Sime, and Mark Walker, "A Nobel Tale of Wartime Injustice," *Nature*,

after war broke out, KWS Secretary General Ernst Telschow informed the KWIP:[7]

In the short term the main emphasis of the research should be on work important for military technology and the war economy … [including] cooperation with firms that are working on war contracts or other tasks important for the war.

## LIGHTNING WAR

German Army Ordnance (*Heereswaffenamt*, HWA) had been contacted about the potential use of nuclear fission as a weapon before the invasion of Poland, and immediately after the outbreak of war it moved quickly to secure a monopoly on this research.[8] One of the most important steps the HWA made was to take over the KWIP to devote it to military research. Debye could have stayed as director but would have had to become a German citizen. Instead, he accepted an offer of a visiting professorship in the United States and never returned.[9] Kurt Diebner, a physicist in the research section of HWA, moved into the KWIP as the acting director. This angered the KWS administration, not because the KWIP would now be involved with military research but rather because the KWS was forced to accept a scientist who did not measure up to their standards for KWI directors. The same thing had

382 (1996), 393–95, and Elisabeth Crawford, Ruth Lewin Sime, and Mark Walker, "A Nobel Tale of Postwar Injustice," *Physics Today*, 50, no. 9 (September 1997), 26–32.

[7] Telschow to Debye (16 September 1939), Archives of the Max Planck Society, Berlin (*Archiv zur Geschichte der Max-Planck-Gesellschaft*, MPG-Archiv), KWIP 9 45–48.

[8] I have written two books on this subject, *German National Socialism and the Quest for Nuclear Power, 1939–1949* (Cambridge: Cambridge University Press, 1989), and after the publication of the Farm Hall transcripts (see below) *Nazi Science: Myth, Truth, and the German Atom Bomb* (New York: Perseus, 1995), which includes a chapter on Farm Hall and an updated chapter on the German nuclear weapons work. The first serious history of the German atomic bomb, although one without a scholarly apparatus, was David Irving, *The German Atomic Bomb: The History of Nuclear Research in Nazi Germany* (New York: Simon and Schuster, 1968). After my first book was published, two alternative histories were published: Thomas Powers, *Heisenberg's War* (New York: Knopf, 1993), which argues that Heisenberg resisted Hitler by trying to deny him nuclear weapons, and Paul Lawrence Rose, *Heisenberg and the Nazi Atomic Bomb Project, 1939–1945: A Study in German Culture* (Berkeley: University of California Press, 1998), which argues that Heisenberg was a Nazi sympathizer and failed to make more progress on nuclear weapons because of scientific incompetence. Recently John Cornwell has written a synthesis of our knowledge of science under National Socialism in general and of uranium research in particular; see John Cornwell, *Hitler's Scientists: Science, War and the Devil's Pact* (New York: Viking, 2003). A recent book, Rainer Karlsch, *Hitlers Bombe. Die geheime Geschichte der deutschen Kernwaffenversuche* (Munich: DVA, 2005), reveals new information about nuclear reactor experiments and tests of a nuclear device carried out in the last year of the war.

[9] See Dieter Hoffmann, "Peter Debye (1884–1966): Ein Dossier," *Max Planck Institut für Wissenschaftsgeschichte*, *Preprint 314* (Berlin: MPIfWG, 2006) [http://www.mpiwg-berlin.mpg.de/Preprints/P314.PDF].

happened at the start of the Third Reich; when KWI for Physical Chemistry director Fritz Haber resigned in protest, the HWA quickly installed a director and turned the institute toward weapons research. The KWS was mollified when the temporary director was replaced by a scientist it could recognize as director material, Peter Adolf Thiessen, who continued to emphasize military research. The KWS administration's attitude toward the KWIP in 1939 was similar: it wanted to be rid of Diebner but had no problem with turning the physics institute toward research into nuclear energy and nuclear weapons.

The German uranium project was much more than the KWIP and should not be equated with it, but the physics institute did play a central role. Along with the existing KWIP staff, Diebner turned to a young nuclear physicist he knew, Erich Bagge, for recommendations. Bagge suggested his mentor, Werner Heisenberg, Nobel laureate, co-founder of quantum mechanics, professor at the University of Leipzig, and perhaps the best theoretical physicist left in Germany.[10] Heisenberg eventually became one of the most important individuals in the uranium project but nevertheless remained only one of several such scientists. In other words, he was not the German equivalent of Robert Oppenheimer, director of the Los Alamos Weapons Laboratory. Although eventually Diebner and Heisenberg became antagonistic rivals in nuclear reactor experiments, Diebner was concerned foremost with developing nuclear fission into a weapon that Germany could use in the war effort and was grateful that a physicist with Heisenberg's ability and stature had joined his project.[11]

Heisenberg began commuting between Leipzig and Berlin, overseeing nuclear reactor experiments in Leipzig carried out by Robert Döpel, and in Berlin directed by Wirtz. In the winter of 1939–1940, Heisenberg worked out the theory of nuclear fission chain reactions in uranium. His two secret reports[12] provided the foundation for all subsequent German work on nuclear reactors, neutron moderators, and isotope separation. Like all subsequent uranium project reports, these were first submitted to Diebner at

[10] For Heisenberg, see David Cassidy, *Uncertainty: The Life and Science of Werner Heisenberg* (New York: Freeman, 1991); a revised and updated edition of this book is forthcoming, *Beyond Uncertainty: Heisenberg, Quantum Physics, and The Bomb* (New York: Bellevue Literary Press, 2009).

[11] For Heisenberg and the KWIP, see Horst Kant, "Werner Heisenberg und das Kaiser-Wilhelm-Institut für Physik in Berlin," in Bodo Geyer, Helge Herwig, and Helmut Rechenberg (eds.), *Werner Heisenberg – Physiker und Philosoph* (Heidelberg: Spektrum Akademischer Verlag, 1993), 152–158, and Horst Kant, "Werner Heisenberg and the German Uranium Project," *Max-Planck-Insitut für Wissenschaftsgeschichte, Preprint 203* (Berlin: MPIfWG, 2002).

[12] Werner Heisenberg, "Die Möglichkeit der technischen Energiegewinnung aus der Uranspaltung" (6 December 1939), G-39, Archives of the German Museum, Munich (*Archiv des Deutschen Museums*, ADM); Werner Heisenberg, "Bericht über die Möglichkeit technischer Energiegewinnung aus der Uranspaltung (II)," G-40 (29 February 1940), ADM.

HWA, who would then distribute copies on a need-to-know basis. A great deal of relevant information had already been published in the year following the discovery of nuclear fission. Although no scientists wrote openly of nuclear weapons in their publications, if one read between the lines this possibility was clear, and many scientists inside and outside of Germany did so.

In his two-part report, Heisenberg drew in particular on the experimental work on fission published by a group of French and another group of American and émigré researchers, as well as the theoretical analysis provided by his Danish colleague and mentor Niels Bohr, both alone and in collaboration with the American John Wheeler. Heisenberg concluded that a nuclear reactor – what the Germans first called a uranium machine then later a uranium burner – could be built that combined uranium and a moderating substance to control the nuclear fission chain reaction and produce energy in the form of heat. The Austrian physical chemist Paul Harteck had suggested that such a reactor would work better if the uranium and moderator were spatially separated. Heisenberg incorporated this in his analysis and concluded that either heavy water (oxygen combined with deuterium, the rare heavy isotope of hydrogen) or carbon in the form of very pure graphite would be an effective moderator. Ordinary water would not suffice unless the percentage of the very rare lighter isotope of uranium – nuclear weight 235 instead of 238 – were enriched in a given amount of uranium via isotope separation. Moreover, Heisenberg continued, if pure or almost pure uranium 235 could be produced, it would be possible to[13] "manufacture an explosive more than ten times as powerful as existing explosives."

Weizsäcker took the next important step according to a July 1940 report.[14] Once again, building on the information available in scientific publications, he concluded that the resonance absorption of neutrons by the common isotope uranium 238 – whereby neutrons traveling at particular velocities were absorbed – would slow down the nuclear fission chain reaction in a nuclear reactor but had a subsequent benefit. The uranium 238 nuclei that absorbed a neutron would transmute in stages to a stable, man-made transuranic element 94, today called plutonium. This new element could be separated out from the uranium relatively easily because its chemistry would be different. Weizsäcker also noted that plutonium, just like uranium 235, would be a powerful new nuclear explosive.

Although Heisenberg remained very interested in and devoted to the uranium project both as a researcher and administrator, once he had finished his two-part report he clearly no longer found the theoretical problem

[13] This quotation is from the first report, G-39 ADM.

[14] Carl Friedrich von Weizsäcker, "Die Möglichkeit der Energiegewinnung aus $^{238}$ U" (17 July 1940), MPG-Archiv, KWIP 7H Pu 1–5.

very interesting. His younger colleague Weizsäcker similarly turned to other theoretical problems once he had discovered the significance of plutonium. Subsequently, most of the continuing theoretical work was done by two of Weizsäcker's students: Paul Müller and Karl-Heinz Höcker. Both were drafted in 1941 – in Höcker's case at least, against his will. Müller died in Russia; Höcker luckily was able to return to Berlin and scientific work. For the rest of the war, Höcker was responsible for analyzing the nuclear reactor experiments, with both Weizsäcker and Heisenberg looking over his shoulder at his work. In the end, Höcker became one of the most important members of the research project.

The first model nuclear reactors – designs that were not expected to sustain a chain reaction but rather to provide experimental data on nuclear constants and the effectiveness of different designs – were located at two separate locations. In Leipzig, Döpel built designs with alternating spherical layers of uranium and moderator; in Berlin, Wirtz worked with horizontal layers.[15] Heisenberg made sure that the model experiments remained under his control. When his colleagues Walther Bothe at the Physics Division of the Kaiser Wilhelm Institute for Medical Research in Heidelberg, and Harteck, respectively, suggested their own model reactor experiments, Heisenberg used his prestige and institutional connections to forestall them.

The Berlin tests were carried out in an external lab dubbed the "Virus House" to discourage curiosity. By design, the geometric symmetry of the Leipzig reactors simplified the calculations while the horizontal design of the Berlin reactors could be more easily varied. Both models were nevertheless difficult to build and manage, and as these scientists were well aware, they were far from the practical design an operating nuclear reactor would need. At the end of the B-I and B-II tests, the KWIP group concluded that water would not work as a moderator, but heavy water was promising.[16]

The HWA had to decide which moderator it would use, heavy water or graphite. After the war, a myth arose in this regard: Bothe supposedly made a "mistake" and judged carbon unsuitable, with the disastrous result that the Germans came to rely on heavy water. In fact, the story is more complicated. Bothe did test graphite and concluded that it would absorb too many neutrons. However, another physicist, Wilhelm Hanle, was not convinced. He carried out his own tests and demonstrated that Bothe had not sufficiently considered the neutron-absorbing effect

[15] Werner Heisenberg, "Bericht über die ersten Versuche an der im Kaiser Wilhelm-Insitut f. Physik aufgebauten Apparatur" (21 December 1940), MPG-Archiv, KWIP 7H E 3.

[16] Werner Heisenberg, "Bericht über Versuche mit Schichtenanordnungen von Präparat 38 und Paraffin am Kaiser Wilhelm-Institut f. Physik in Bln-Dahlem" (March, 1941), MPG-Archiv, KWIP 1H 170–211.

of impurities in the graphite sample. Hanle sent his results directly to HWA. Scientists there concluded that Hanle was probably right: very pure graphite would work, but the purification process required would be prohibitively expensive.[17]

Heavy water, on the other hand, appeared to be relatively inexpensive. The German chemical giant I.G. Farben had taken over the Norwegian Hydro plant, the only producer of heavy water before the war. The heavy water production plant was expanded with the help of German scientists. In the winter of 1939–1940, Heisenberg had calculated that a uranium heavy water reactor would need around five metric tons of heavy water to operate, and at least in theory, the Norwegian Hydro promised to be able to produce more than enough for this first reactor at a modest cost. It was clear to all concerned that once an operating reactor design was found, additional large-scale heavy water production would have to be started in Germany using other methods. In any case, for the early development phase, HWA decided to go with the apparently cheap heavy water instead of the definitely expensive graphite.

The model reactors made steady progress, although the supply of the two most important materials, purified uranium and heavy water, remained frustratingly low. The "B" series at the KWIP had to use uranium oxide and paraffin, rich in hydrogen, as a moderator. The "L" series in Leipzig first used uranium oxide and ordinary water, then switched to heavy water. The scientists knew that pure uranium and heavy water would be much more effective, but they were not available in sufficient amounts. Nevertheless, the results of the L series in particular offered hope that a nuclear reactor could be built that would sustain a chain reaction.

Other uranium research offered mixed results. On one hand, Paul Harteck and Wilhelm Groth, before giving up in the spring of 1941, had spent a year and a half struggling to get the Clusius-Dickel thermo-diffusion isotope separation tube to work with the compound uranium hexafluoride. They now began work with centrifuges. At the KWIP, Erich Bagge began work on a novel separation method for uranium, an "isotope sluice,"[18] while Horst Korsching investigated producing purified metal uranium through both electrolysis and isotope separation by means of thermo-diffusion.[19] Kurt Starke, a physical chemist working at Hahn's KWIC, succeeded in manufacturing and studying very small amounts of element

[17] "Energiegewinnung aus Uran" (February 1942), 87–88, ADM.

[18] Erich Bagge, "Über die Möglichkeit einer Anreicherung der leichten Uranisotope mit der Isotopenschleuse," G-124 (16 March 1942), ADM.

[19] Horst Korsching, "Über die Herstellung von metallischem Uran durch Elektrolyse" (29 September 1941), MPG-Archiv, KWIP 1H 44–46; Horst Korsching, "Trennung von schwerem und leichtem Benzol durch Thermo-Diffusion in flüssiger Phase," G-102 (5 September 1942), ADM.

93, now called neptunium.[20] This element had a 2.3 day half-life, and as American researchers had argued in a 1940 publication, probably decayed into plutonium.

## THE END OF INNOCENCE

In an interview published in 1993, Carl Friedrich von Weizsäcker described his motivation for participating in the German uranium project as follows:[21]

> Actually I was not at all interested in the bomb in a technical sense, nor the reactor. ... That was work I had to do. My interests were purely political. It was the dreamy wish, that if I was one of the few people who understand how to make a bomb, then the highest authorities would have to speak with me, including Adolf Hitler.

In a different interview published in 1991, he admitted that he had been naive to think that he could have influenced Hitler's policies: "I admit it, I was crazy."[22]

Sometime between the summer of 1940 and the summer of 1941, Weizsäcker took two important steps. First, he submitted a patent application[23] that emphasized the military applications of nuclear reactors and plutonium. Element 94 could be produced in a "uranium machine," whereby the new transuranic element could be separated "chemically" from the uranium. The "explosive production of energy and neutrons" could be used "in a bomb."

Next, he discussed the military applications of the uranium research with Diebner.[24] Uranium could be used to produce energy in two ways: (1) in its natural form; and (2) in a "highly concentrated effective" form, either pure uranium 235 or a transuranic element. In principle, uranium could be used to "power a rocket"; but at the moment there were still practical difficulties, and this remained a "matter for future development." Much more important were two other applications: as (1) "a heat machine," and (2) as an "explosive."

During the spring, summer, and early fall of 1941, Weizsäcker also enthusiastically participated in German cultural propaganda in occupied Europe.

[20] Kurt Starke, "Über die Trennung des künstlich radioaktiven Urans und seines Folgeprodukts (Element 93) vom Uran" (20 May 1941), MPG-Archiv, KWIP 1H 52–70.

[21] Dieter Hoffmann (ed.), *Operation Epsilon. Die Farm-Hall-Protokolle oder Die Angst der Alliierten vor der deutschen Atombombe* (Berlin: Rowohlt Berlin, 1993), 337–338.

[22] Carl Friedrich von Weizsäcker, "Ich gebe zu, ich war verrückt," *Der Spiegel*, 17 (1991).

[23] Carl Friedrich von Weizsäcker, "Energieerzeugung aus dem Uranisotop der Masse 238 und anderen schweren Elementen (Herstellung und Verwendung des Elements 94)," MPG-Archiv, KWIP 7H Pu 6–11; it is not clear what happened once this patent was submitted.

[24] Carl Friedrich von Weizsäcker, "Kurzer Bericht über die eventuelle praktische Auswirkung der Uranuntersuchungen auf Grund einer Rücksprache mit Dr. Diebner," MPG-Archiv, KWIP 56 170–172.

This included scientific intelligence gathering. In March, Weizsäcker submitted a report on a trip to occupied Copenhagen.[25] He had been in Denmark to give talks at the Danish Physical and Astronomical Society, at Bohr's Institute for Theoretical Physics and, with the assistance of the German ambassador, at the "German-Danish Society."

I was able to study the experimental and theoretical work at Bohr's institute, investigations of uranium and thorium fission by fast neutrons and deuterons. I have brought back copies and manuscripts of the work that is of great interest for our current investigations.

The technical production of energy from uranium fission is not being worked on in Copenhagen. They know that such investigations are being done in America, especially from Fermi. However, since the beginning of the war, no clear news has come from America. Bohr clearly did not know that we are working on these questions. Of course I encouraged this belief. Bohr himself brought the conversation to this point. …

The American journal *Physical Review* was available in Copenhagen up until the issue from January 15, 1941. I have made photocopies of the most important publications. Arrangements have been made for the German Embassy to photocopy the journal for us as it arrives.

In early September, before his trip to Copenhagen with Heisenberg, Weizsäcker also passed on to the German Army information from a Swedish newspaper regarding an Allied atomic bomb project and sent a report to the Reich Ministry of Education and Science (*Reichserziehungsministerium*, REM) on the American advantage over Germany in nuclear physics.[26]

The Plenipotentiary of the German Reich in Denmark reported that Weizsäcker's performance had been impressive:[27]

The large audience followed the talk delivered in Danish before the Physical and Astronomical Society, "Is the World Infinite in Time and Space," with great, approving interest.

For his second public lecture at the Danish-German Society Dr. Weizsäcker spoke on the same subject before a selected group of Danes and Germans. He was able to make this difficult subject so interesting that most of the audience, including the commander of the German troops in Denmark, could easily follow him. At the end the speaker was rewarded with generous applause for his calm and scholarly remarks.

Finally the Institute for Theoretical Physics invited Dr. von Weizsäcker to give a talk before an exclusively scientific audience on the subject: "The Relationship of

[25] Carl Friedrich von Weizsäcker, "Bericht über die Vortragsreise nach Kopenhagen vom 19.-24.3.41" (26 March 1941), MPG-Archiv, KWIP 5–1 352–353.

[26] Only English translations are available for these two documents; Weizsäcker to Oberkommando der Wehrmacht (4 September 1941), National Archives and Records Services, Washington, DC (NAARS), and Weizsäcker to REM (5 September 1941), NAARS.

[27] Der Bevollmächtige des Deutschen Reiches an das Auswärtige Amt in Berlin (27 March 1941), Federal German Archives (*Bundesarchiv*, BArch), REM 2943, 524–525.

Quantum Mechanics to Kantian Philosophy." The lecture was followed by a lively discussion among the scientists present. …

In summary, the lectures from Dr. von Weizsäcker were exceptionally effective, both for lay audiences as well as scientific Danish circles. For this reason we are considering inviting Dr. von Weizsäcker, along with Professor Dr. Heisenberg, Leipzig, to a workshop for mathematics, astronomy, and theoretical physics at the newly founded German Cultural Institute this coming fall.

It was possible for an intelligent and politically astute individual like Weizsäcker to appear "crazy" because of the contexts of the uranium work and the war. The scientists had worked out a clear path to nuclear energy and nuclear weapons and had made good progress – enough progress to make their goals appear promising, if still far-off. At this time, the war was going very well for Germany. Most of Europe was conquered, the Third Reich had signed a nonaggression pact with the Soviet Union, Britain was under siege, and the United States was staying out of the war.

Very few members of the German uranium project were enthusiastic National Socialists; rather, many more were opportunistic National Socialists or fellow travelers. Typically, the senior scientists were not members of a National Socialist organization whereas with few exceptions the younger scientists were either members of the NSDAP or one of its ancillary organizations. Whether or not these scientists liked Hitler, at this point he had apparently done what the German Empire had failed to do in the First World War: conquer Europe for Germany. The scientists working on uranium at the KWIP were able to serve their country as scientists instead of frontline soldiers but had no reason to expect that their work would be relevant for the war Germany was fighting.

In contrast to his friend, former student, and colleague Weizsäcker, Heisenberg appears to have been more ambivalent about the consequences of the model nuclear reactors and isotope separation methods he and his colleagues were working on. Here it is worthwhile to remember the definition of ambivalence: contradictory emotional or psychological attitudes toward a particular person or object, often with one attitude inhibiting the expression of another.[28]

In April of 1941, when Germany was expanding the war by invading Yugoslavia and Greece, in America the émigré physicist Rudolf Ladenburg passed on a striking message to his colleague Lyman Briggs:[29]

28 Online version of *Webster's Third New International Dictionary, Unabridged*, accessed 15 August 2005.

29 Rudolf Ladenburg to Lyman Briggs (14 April 1941), National Archives, Washington, DC (NA), Record Group 227, S-I Briggs, Box 5, Ladenburg Folder; this document, along with other sources, is used by Powers to argue that Heisenberg deliberately resisted Hitler by denying him nuclear weapons.

> It may interest you that a colleague of mine who arrived from Berlin via Lisbon a few days ago, brought the following message: a reliable colleague who is working at a technical research laboratory asked him to let us know that a large number of German physicists are working intensively on the problem of the uranium bomb under the direction of Heisenberg, that Heisenberg himself tries to delay the work as much as possible; fearing the catastrophic results of a success. But he cannot help fulfilling the orders given to him, and if the problem can be solved, it will be solved probably in the near future. So he gave the advice to us to hurry up if the U.S.A. will not come too late.

Two weeks later, another émigré physicist, Leo Szilard, wrote to Isidor Rabi, the 1944 Nobel laureate and one of the leading scientists in the wartime American RADAR project:[30] "Ladenburg says he is pretty sure that a large number of German physicists are working intensively on the problem of the uranium bomb under the direction of Heisenberg."

In the spring of 1941, Heisenberg may have feared the consequences of success for the German uranium project (given the historical sources available, there is no way to know for sure), but that begs the question of what "success" would have meant at this time. From the perspective of most Germans, Germany had won the war in Europe; it was only a matter of time before its enemies would cease their resistance. At this time, Germany's armed forces and the National Socialist leadership did not need nuclear weapons. At best, such weapons would have appeared to be of future importance.

The problematic part of this quotation is the claim that "Heisenberg himself tries to delay the work as much as possible." His work in the uranium project is well documented, including what he did and said, who received this information, and how they responded to it. This all makes clear that Heisenberg had not been delaying the uranium work from September 1939 to April 1941, and he also did not delay it from April 1941 to the end of the war. As will be shown below, however, he did not push the development of nuclear weapons as hard as he could have.

Whatever innocence the KWIP scientists might have had probably began to evaporate in June. Tensions between Germany and the United States escalated. In August, the American and British governments announced the Atlantic Charter, formally allying the two against Germany. Hitler unleashed Operation Barbarossa, the German invasion of the Soviet Union on June 22. Although at first the "lightning war" (*Blitzkrieg*) was successful here as well, the war had now profoundly changed. Germany was fighting an enemy with vast territory and resources.

[30] Szilard to Rabi (28 April 1941), Library of Congress, Washington, DC, Box 7, Folder 16 Rabi Papers.

Moreover, this was a different quality of warfare, an ideologically driven war of subjugation and extermination.[31] Heisenberg, like many Germans, was clearly affected by the ideological nature of the war with the Soviet Union; when Heisenberg visited occupied Holland in 1943, in a private conversation he told a colleague:[32]

Only a nation which rules ruthlessly can maintain itself. Democracy cannot develop sufficient energy to rule Europe. There are, therefore, only two possibilities: Germany and Russia. And then perhaps a Europe led by Germany would be the lesser evil.

There is evidence that the KWIP researchers had become ambivalent about their uranium work just before Heisenberg's and Weizsäcker's September trip to Copenhagen. On August 28, Wirtz submitted a patent for a nuclear reactor, including the names of all the KWIP scientists, and, in contrast to Weizsäcker's earlier patent application, with no references to nuclear explosives.[33] Of course, the patent office still had Weizsäcker's submission and would not have forgotten that it had mentioned the possibility of plutonium bombs, and an operating nuclear reactor was still the precondition for further research on nuclear weapons; but the KWIP patent application does suggest that these scientists no longer wanted to emphasize nuclear explosives.

The visit of the two German physicists to Denmark in September 1941 has inspired both historians and playwrights.[34] When they traveled to Copenhagen, German troops were laying siege to Leningrad and in Germany the remaining Jews had just been forced to wear the star of David on the outside of their clothes. After the war, Heisenberg and Weizsäcker themselves insisted that they had gone to Copenhagen to help Bohr and to enlist his assistance in forestalling the creation of all nuclear weapons. For his part, after the war Bohr and other Danish colleagues recalled that his German colleagues had urged him to collaborate with the German occupation authorities and that Heisenberg had expressed pleasure at the German victories in the East. In particular, while Bohr did remember Heisenberg bringing up the

[31] See, for example, Omer Bartov, *Hitler's Army: Soldiers, Nazis, and War in the Third Reich* (New York: Oxford University Press, 1941).

[32] Gerard Kuiper to Major Fischer (30 June 1945), University of Arizona, Tucson, Gerard Kuiper Papers.

[33] "Patentanmeldung. Technische Energiegewinnung, Neutronenerzeugung und Herstellung neuer Elemente durch Spaltung von Uran oder verwandten schweren Elementen" (28 August 1941), MPG-Archiv, KWIP 7H 24, 25–1 to 25–14.

[34] Michael Frayn, *Copenhagen* (New York: Anchor Books, 1998). For commentaries on the Bohr letters, along with the recently published Bohr letters, see Matthias Dörries (ed.), *Michael Frayn's Copenhagen in Debate: Historical Essays and Documents on the 1941 Meeting between Niels Bohr and Werner Heisenberg* (Berkeley: Office for History of Science and Technology, University of California, 2005); for the online version of the letters, http://www.nbi.dk/NBA/papers/introduction.htm (accessed 15 August 2005).

question of nuclear weapons, he also insisted that his German colleague had not stated or implied that Germany would not make them. Perhaps the truth lies somewhere between: Heisenberg and Weizsäcker went to Bohr with ambivalent feelings about their uranium work, the war, and their National Socialist government, and returned to Germany more troubled than before.

In contrast to the time before Operation Barbarossa, the Danish scientists were no longer pretending that the German occupiers were welcome guests in Denmark. A letter from Heisenberg to his wife describes his visit:[35]

> The conversation quickly turned to questions of humanity and the misfortune of our time; agreement about humanity came as a matter of course; but political questions were difficult, for even a man like Bohr was unable completely to separate thought, emotion, and hate. But they probably should not be separated. …
>
> We had a few scientific discussions in Bohr's institute; the Copenhagen colleagues do not know much more than we do. Tomorrow the lectures at the German Cultural Institute begin; the first official lecture is mine, tomorrow evening. Unfortunately the members of Bohr's institute will not come for political reasons. It is strange, how the Danes, even though they can live completely undisturbed and are doing very well, can be full of so much hate or fear that an understanding in the area of culture – which earlier was self-evident – has now become almost impossible. I gave a little talk in Danish at Bohr's institute, which was naturally just like before (the people at the German Cultural Institute explicitly approved it), but they do not want to go into the German Institute as a matter of principle because at and after the opening there was a series of snappy speeches on the New Order in Europe.

All accounts agree that these discussions of the "purely human problems" were difficult and unsettling. Whatever Heisenberg said to Bohr about uranium, and whatever Bohr said in reply – no one actually knows for sure what was said in this regard – Heisenberg's and Weizsäcker's experiences in Copenhagen must have provided them considerable food for thought. Afterward, Weizsäcker was much more cautious about participating in cultural propaganda.[36] The uranium project must have looked very different once they returned. Thereafter, the mention of nuclear explosives was avoided by the KWIP scientists – with a few important exceptions described below.

## SELLING URANIUM RESEARCH

If Operation Barbarossa represented a profound change for the German uranium project, then the events of November and December 1941 transformed

[35] http://werner-heisenberg.unh.edu/kop-letter.htm (accessed 10 August 2005); also see Werner Heisenberg, *Liebe Eltern!: Briefe aus kritischer Zeit 1918 bis 1945. Mit Dokumenten aus dem Familienarchiv*, edited by Anna Maria Hirsch-Heisenberg (Munich: Langen Müller, 2003), especially 301–302 and 321.

[36] For Heisenberg's and Weizsäscker's foreign lectures during the war, see Walker, *Nazi*, 123–181.

it. First, the German lightning war ground to a halt in the Russian winter. As Adolf Hitler's generals told him, the lightning war was finished. The Japanese attack on Pearl Harbor and Hitler's subsequent decision to declare war on the United States made it a true world war. Now Germany, its allies Italy and Japan, and the territories it occupied or dominated were fighting the Soviet Union, the British Empire, and the United States. It was a war of attrition with Germany holding far fewer resources and much less manpower.

Two days before the attack on Pearl Harbor, the HWA summoned the institute directors involved in the uranium project to a meeting and for the first time asked for a timetable: when would these new weapons be ready? Would they be able to influence the outcome of the war, from either side? Just a few weeks before, Heisenberg had drafted an important status report:[37]

> At the moment, the work on producing energy in the uranium machine has reached a relatively clear stage as far as physics is concerned. There is no longer any doubt that a self-sustaining reactor can be built in principle. Undoubtedly this main goal must be reached as soon as possible. …
>
> Today the only necessary work is that which contributes immediately to reaching the goal of a self-sustaining reactor in the shortest possible time; among these, the most important are those that determine the pace of the work. …
>
> The prerequisites for the construction of a machine with heavy water and metal uranium are:
>
> (1) Acquiring 5–10 tons of heavy water
> (2) Acquiring 5–10 tons of metal uranium in suitably cast forms
> (3) Carrying-out intermediate experiments
> (4) The construction of a technical reactor
>
> A certain critical mass of capable scientists is necessary [for this work]. … Even if the work is cut back severely, the two nuclear physics institutes that have been most important for the development up until now (KWI for Medical Research, Physics Section in Heidelberg; and KWI for Physics in Berlin-Dahlem) must remain capable of work.

When Heisenberg mentioned deadlines, he was a little evasive. Since they could not expect the Norwegian Hydro to provide enough heavy water for a large-scale project, heavy water production would have to begin in Germany. However, "the production [of heavy water] on a large scale will only be possible in Germany during 1942 if the number of workers is increased considerably." The timetable Heisenberg gave for the large-scale

[37] Werner Heisenberg, "Zur Durchführung der Arbeiten an der Uranmaschine" (27 November 1941), MPG-Archiv, KWIP 56 84–91.

nuclear reactor experiment was also imprecise. "The experiment can be carried out approximately two months after the delivery of the uranium metal pieces." Perhaps most important, nowhere in this report does Heisenberg mention nuclear explosives or indeed any military application of nuclear fission.

In February 1942, Diebner and other staff scientists at the HWA prepared a long overview report on the uranium project entitled "Energy Production from Uranium."[38] This report is notable for its explicit discussion of nuclear explosives, but nevertheless with a cautious tone:[39]

> If this "chain reaction" develops slowly, the uranium represents a heat-producing machine; if it develops quickly, [then it is] an explosive of the greatest effect. …
>
> Besides the complete separation of [uranium] isotopes, which is certainly possible in principle, but is technically very difficult, today we know in theory another way to the manufacture of explosives, but one that can only be tested when a heat-producing machine is running. When neutrons are absorbed by uranium 238, a substance ("element 94") is formed that is even easier to fission than uranium 235. Since this substance is chemically different from uranium, it must be easy to separate out from a [uranium] machine that has been shut down. However, today we know neither the amount which will be produced, nor its properties exactly enough for a certain prediction. … The explosive could be detonated by bring together a sufficient amount (presumably around 10–100 kg). …
>
> The pace of materials acquisition today determines the further development of the experimental work. When the necessary amounts of metal uranium and heavy water are available, then the construction of a self-sustaining machine will be attempted.
>
> If it is successful – as one must expect after the laboratory experiments – then the further development includes three tasks:

(1) The development of the machine into a technically usable apparatus.
(2) The technical, and especially military applications of the machine [propulsion of ships; submarines; airplanes and ground vehicles; fixed energy sources; source of penetrating radiation; and the medical-biological area].
(3) The manufacture of a uranium explosive.

The HWA concluded that uranium would not decide the outcome of the war from either side and that the research project should be transferred to a civilian authority. The new priorities in the war economy had an immediate effect on the uranium project. Harteck and Weizsäcker – both by now senior scientists – were called up for regular military duty. Heisenberg and the Leipzig physical chemist Karl-Dietrich Bonhoeffer used the excellent

[38] "Energiegewinnung aus Uran" (February 1942), ADM.
[39] "Energiegewinnung aus Uran" (February 1942), 9, 12–13, 15–17, ADM.

personal connections they had with high-ranking military officers to reverse these orders. Heisenberg and his colleagues were now faced with the necessity of convincing the military authorities of the importance and relevance of their work or losing their exemptions from direct military service. As a result, over the next two years Heisenberg gave several remarkable popular lectures on nuclear energy and weapons.

Beginning in 1941 and in the shadow of the looming war between Germany and the United States, German scientists began mentioning the American competition in nuclear physics and uranium research when they lectured before and prepared memoranda for military, political, and industrial leaders. Perhaps the best example of this is the January 1942 memorandum sent by German Physical Society president and industrial physicist Carl Ramsauer to REM on the dangerous decline of theoretical physics in Germany.[40] Surprisingly, there was never any similar mention of Soviet science and engineering, even though this eventually played an important role in defeating Germany.

In February 1942, a series of popular lectures was held before the Reich Research Council (*Reichsforschungsrat*, RFR) and leading political, industrial, and military figures in the National Socialist state in order to sell the project. Heisenberg gave a provocative talk[41] carefully designed to attract interest without promising what he could not deliver and, as he put it after the war, "tailored to the level of understanding of a Reich minister of the time:"[42]

> The behavior of neutrons in uranium can be compared to the behavior of a population, whereby the fission process is analogous to marriage [with children] and the capture process analogous to death. In ordinary uranium, the number of deaths far outweighs the number of births, so that a population will die out after a short time.
>
> Obviously an improvement is only possible if (1) the number of births per marriage increases; (2) the number of marriages rises; or (3) the probability of death is reduced.
>
> Option (1) is not possible. ... An increase in the number of fissions (2) can be achieved if one enriches the uranium isotope 235, which can be fissioned at low

[40] Dieter Hoffmann, "Carl Ramsauer, die Deutsche Physikalische Gesellschaft und die Selbstmobilisierung der Physikerschaft im 'Dritten Reich,'" in Helmut Maier (ed.), *Rüstungsforschung im Nationalsozialismus. Organisation, Mobilisierung und Entgrenzung der Technikwissenschaften* (Göttingen: Wallstein, 2002), 273–304.

[41] Werner Heisenberg, "Die theoretischen Grundlagen für die Energiegewinnung aus der Uranspaltung" (26 February 1942), Samuel Goudsmit Papers, American Institute of Physics, Center for the History of Physics, College Park, Maryland (SGP); this has been published as Walter Blum, Hans-Peter Dürr, and Helmut Rechenberg (eds.), *Werner Heisenberg: Gesammelte Werke / Collected Works. Series A / Part II* (Berlin: Springer Verlag, 1989), 517–525.

[42] Heisenberg to Goudsmit (5 January 1948) SGP.

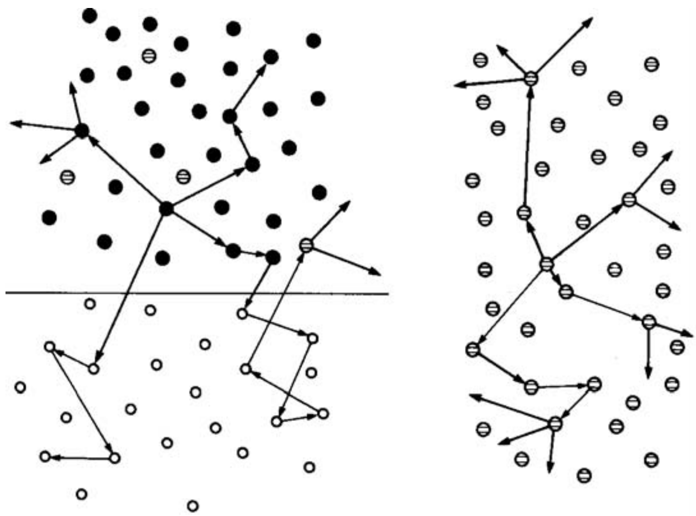

FIGURE 14.1: Chain reactions in uranium

*Source:* Originally published in Mark Walker, *German National Socialism and the Quest for Nuclear Power, 1939–1949* (Cambridge: Cambridge University Press, 1989), 56.

energies, but is rare. Indeed if it would be possible to produce pure uranium 235, then the situation on the right side of [Figure 14.1] takes place.

After one or several collisions, every neutron that had not exited through the outer layer would cause a further fission. Here the probability of death through capture is vanishingly small when compared to the probability of increase. Thus if a large enough amount of uranium 235 is piled up, then the neutron loss to the outside remains small compared to the increase inside. The number of neutrons increases enormously and the entire fission energy of 15 billion calories per ton is released in a small fraction of a second. Pure isotope uranium 235 thus undoubtedly represents an explosive of utterly unimaginable effect. However, this explosive is very difficult to produce.

A large part of the Army Ordnance research groups is working on enrichment or pure production of the isotope uranium 235. American researchers also appear to be pursuing this goal with great effort. …

A [uranium] machine … [would be] suitable for heating a steam turbine and over time can transfer all of its great energy to such a heat machine. Such machines can be practically applied in transportation vehicles, for example, in ships, which would have a huge radius of movement from the great amounts of energy in a relatively small amount of uranium. Since the machine does not burn oxygen, it would be especially advantageous in submarines.

Thanks to an idea from Weizsäcker, as soon as such a machine is in operation, the question of creating explosives takes on new meaning. When uranium is transformed in the machine a new substance (element number 94) is created, which very probably is an explosive of the same unimaginable effect as pure uranium 235. This substance can be separated much more easily out of uranium than uranium isotope 235, since it can be separated chemically. …

The results achieved up until now can be summarized in the following way: (1) creating energy from uranium fission is undoubtedly possible, if isotope uranium 235 can be enriched. The *pure production* of uranium 235 would lead to an explosive of unimaginable effect.

(2) Ordinary uranium can also be used in a layer arrangement with heavy water to create energy. A layer arrangement of these materials can transfer its great energy over time to a heat engine. Thus this is a means to store very large amounts of technically usable energy in a relatively small amount of substance. The operating machine can also be used to produce an enormously strong explosive; it also promises many other scientifically and technically important applications.

By summer 1942, the uranium project was once again on firm footing. The RFR had taken over the project, which ensured continuing financial support. Both Kaiser Wilhelm president and industrialist Albert Vögler and Reich Armaments Minister Albert Speer took a keen interest in the work. In June of that year, Heisenberg gave a second talk before Speer and another group of dignitaries.[43] This lecture is notable for how it differed from the February talk. The analogy to deaths and births was not used, but there was even more emphasis on the American threat:

The interest in these newest developments [nuclear fission] was exceptionally great in America. A few days after the discovery American radio broadcast extensive reports and within half a year a large number of scientific publications on this subject had appeared in America.

The German uranium project had just recently had promising experimental results:

After a series of important preliminary work … we have finally succeeded in building a small experimental device, with around 150 liters heavy water and 600 kilograms metal uranium that actually increased the number of neutrons inserted into it and produced energy. According to the results we have now, an expansion of the diameter of this device … by three-to-six times would lead to a uranium burner, that is, a device that can spontaneously deliver large amounts of energy without external neutrons being added.

When Heisenberg mentioned nuclear explosives, he did so in a diffident way:

After the uranium burner has been built, it does not appear impossible that one day the path shown by Weizsäcker could be taken to an explosive substance more than a million times more powerful than those available today.

[43] Werner Heisenberg, "Die Arbeiten am Uranproblem" (4 June 1942), MPG-Archiv, KWIP 56 174–178.

Heisenberg closed his talk cautiously:

At the moment, the time needed for the technical development of such a burner is being determined by the availability of materials, especially the production of heavy water. But even aside from the question of materials, a great deal of scientific developmental work has to be done.

Even when one takes into account the difficulty of such developmental work, one has to recognize that in the next few years new land of the greatest significance for technology can be discovered. Since we know that many of the best laboratories in America are working on this problem, we can hardly afford not to pursue these questions in Germany. Even if one considers that such developments usually take a long time, one has to reckon with the possibility that if the war with America lasts several years more, then the technical exploitation of nuclear energy can one day suddenly play a decisive role.

Finally, in 1943, after Speer's support and goodwill had been secured, Heisenberg gave a final popular talk before the Reich Aviation Academy,[44] which was very interested in weapons development. Indeed, this was the part of the war when the search for "wonder weapons" that could help Germany turn the tide had begun in earnest. Here he did not mention nuclear explosives at all – although some people in his audience probably could remember that he had in the past. Indeed, Heisenberg told his audience that scientists were working to produce pure uranium 235 but never said what it would be good for. His conclusion was much milder than in his previous two talks:

If such a [uranium] burner can be built, then it could be used to power steam engines and in ships and other forms of transportation for which it is important to store the largest possible amount of energy in a small space. It goes without saying that before this goal is achieved, many other purely technical problems need to be solved with regard to the transfer of heat, the corrosion of the metals used, and so on.

In summary, the first step toward a very important technical development has been taken and, according to the experimental results available today, there is no doubt that nuclear energy can be liberated for technical goals on a large scale. On the other hand, the practical continuation of this development will naturally encounter great difficulties because of the strained war economy.

Heisenberg has gone from graphic portrayals, where he dangled the possibility of powerful new weapons before leading soldiers, industrialists, and National Socialist leaders, to an apparent desire to downplay bombs in favor of nuclear energy for the war effort, something that also impressed and interested political, industrial, and military leaders. Of course, the cat was already out of the bag. The KWIP scientists could not make people forget about nuclear explosives. But they clearly had become more and more

[44] Werner Heisenberg, "Die Energiegewinnung aus der Atomkernspaltung," G-217 (6 May 1943), ADM; this has been published as Blum, Dürr, and Rechenberg, 570–575.

ambivalent about the military consequences of their work and did not push as hard as they could have to make atomic bombs.

## HEISENBERG VERSUS DIEBNER

Now that the HWA was giving up control of the uranium project, the KWS moved quickly to push Diebner out and replace Debye with a new director. Although Heisenberg was perhaps the obvious choice because he had been attached to the KWIP as an advisor, Bothe, who arguably would have been more qualified to oversee experimental work, was also considered. However, Harteck insisted that Heisenberg was the best choice while Hahn and Laue explained that Bothe was not appropriate "because of the difficulty of working with [him]."[45]

Heisenberg's recent political rehabilitation also played an important role. In 1937, Heisenberg had been attacked in the SS weekly *Das Schwarze Korps*[46] as a "White Jew" and "The Ossietzky of Physics." Indeed, according to this article, "Heisenberg is only one example among others. Together they are the place holders of Judaism in German spiritual life, who must disappear just like the Jews themselves." Heisenberg appealed directly to SS Reichsführer Heinrich Himmler.

A year later, after an "especially correct and especially tough" investigation, Himmler replied to Heisenberg:[47]

> I am pleased to be able to inform you that I do not support the attack in *Das Schwarze Korps* through his [Johannes Stark's] article and that I have forbidden any further attack against you. …
>
> P.S. However, I do consider it right that, in the future you clearly separate for your audience the recognition of scientific research results from the human and political conduct of the researchers.

Heisenberg had already heard this advice from Ludwig Prandtl, the aeronautical researcher who had spoken with Himmler. In a letter to Prandtl,[48] Heisenberg reassured his colleague:

> Actually I have always followed Himmler's advice in private conversations … even before he gave it to me, because I never was sympathetic toward Einstein's public conduct. However, in lectures I have always spoken on purely scientific topics and therefore have had no opportunity to say something about Einstein the person (or Stark). But I will gladly follow Himmler's advice and, when I speak about the theory of relativity, simultaneously emphasize that I do not share Einstein's politics and

[45] Aktennotiz (22 January 1942), MPG-Archiv.
[46] "'Weisse Juden' in der Wissenschaft," *Das Schwarze Korps* (15 July 1937), 6.
[47] Himmler to Heisenberg (21 July 1938), SGP.
[48] Heisenberg to Prandtl (8 March 1938), MPG-Archiv, IX 4 1935–1939.

worldview – which by the way Mr. Himmler can see from the fact that I did not and do not have the intention of leaving Germany.

The SS report was positive, although the last sentence (see below) does not ring true:[49]

Heisenberg is a man of exceptional scientific reputation. His strength lies in the good school of physicists he has trained, including von Weizsäcker, Flügge, and others.

Heisenberg's character and conduct are decent. Heisenberg is the apolitical scholar type. If he is also ready at any time to stand up for Germany, that is because he believes that one is either "born a good German, or not."

... Over the course of the years Heisenberg has become more and more convinced by the successes of National Socialism and today is positive toward it. However, he believes that, aside from the occasional participation in a [political indoctrination] camp and similar things, an active political role is not appropriate for a university teacher. Today Heisenberg also fundamentally rejects the alienation[50] of German living space by Jews.

Heisenberg clearly deserved this appointment, but merit was not the only reason he got it. For his part, Heisenberg knew very well whom he had to thank for the KWIP post. In a 1943 letter to Himmler,[51] Heisenberg wrote:

A few years ago you let me ... know through your staff that you desired ... a public rehabilitation of my honor. ... In May of last year I was appointed director of the Kaiser Wilhelm Institute for Physics in Berlin-Dahlem, and I thank you for the rehabilitation of my honor connected to this appointment.

Heisenberg also followed Himmler's advice. In an article entitled "The Assessment of 'Modern Theoretical Physics,'" published in the *Journal for the Entire Science*,[52] the house journal for the "Aryan Physics"[53] movement, Heisenberg said this about Einstein and relativity:

America would have been discovered if Columbus had never lived; the theory of electric phenomena would also have been found without Maxwell, electric waves without Herz; for the discoverers cannot change the facts. In the same way the theory of relativity would undoubtedly have been created without Einstein. ... As far as the *correctness* of a theory is concerned, it is best to completely ignore the history of the discovery.

Heisenberg's increased prestige and influence at the KWIP inevitably meant a loss of the same for Diebner, who responded to his exile by gathering together a group of younger scientists and whatever materials were

[49] Himmler to Mentzel (REM) (26 May 1939), BArch REM 2943, 370–372.
[50] *Überfremdung*.
[51] Heisenberg to Himmler (4 February 1943), SGP.
[52] *Zeitschrift für die gesamte Naturwissenschaft*.
[53] *Deutsche Physik*.

available at the HWA experimental center in Gottow in order to carry out his own model nuclear reactor experiments. Essentially, there was now a division of labor in the uranium project, whereby Diebner's group tried to achieve the greatest neutron multiplication while Heisenberg's group was working to refine and correct the theory.[54]

Diebner challenged the KWIP layer design by using a three-dimensional lattice of cubes. Although his group was also hampered by a shortage of materials, they improvised: model experiment G-I used paraffin disks with cube-shaped holes into which uranium oxide powder was added, spoonful by spoonful;[55] G-II used metal uranium cubes made out of plates frozen in heavy ice;[56] G-III used cast uranium cubes – with some made out of plates as well – suspended in heavy water.[57]

The experimental outcome in Gottow was clearly better than anything the experiments in Leipzig or Berlin-Dahlem had achieved. Höcker was asked to interpret the Gottow experiments and concluded that the lattice design was inherently superior to layers. But Höcker went on to argue that cylinders represented a much more effective solution than the impractical cube lattice.[58] Abraham Esau, the Plenipotentiary for Nuclear Physics in RFR, accepted this argument.[59] Höcker also cautiously suggested to Heisenberg that a design using cylinders would be best.[60]

The Leipzig model reactor experiments stopped when Heisenberg became director of the KWIP. The B-series of horizontal layer designs were slowed down by the steadily deteriorating war. The Norwegian production of heavy water never reached the levels the Germans expected. Heavy water was not the highest priority for the Norwegian Hydro, which had to produce synthetic nitrogen for both fertilizer and explosives manufacture. Allied sabotage and bombings also interrupted heavy water production. The large metal uranium plates Heisenberg had ordered for the KWIP experiments were difficult for the Auergesellschaft to produce. As a result, while Diebner's group was enjoying one success after another with improvised experiments using the materials at hand, the reactor

54 I want to thank Cathryn Carson for this point.

55 Friedrich Berkei, Kurt Diebner, et al., Bericht über einen Würfelversuch mit Uranoxyd und Paraffin, November 1942," ADM.

56 K. Diebner, G. Hartwig, W. Herrmann, H. Westmeyer, W. Czulius, F. Berkei, and K. H. Höcker, "Bericht über einen Versuch mit Würfeln aus Uran-Metall und Schwerem Eis," G-212 ADM.

57 Kurt Diebner, "Über die Neutronenvermehrung einer Anordnung aus Uranwürfeln und Schwerem Wasser (G III)," ADM

58 Karl-Heinz Höcker, "Über die Anordnung von Uran und Streusubstanz in der U-Maschine" (25 January 1943), MPG-Archiv, KWIP 1H 84–97.

59 Abraham Esau, "Bericht über den Stand der Arbeiten auf dem Gebiet der Kernphysik" (1 July 1943), MPG-Archiv, KWIP 56 63–71.

60 Höcker to Heisenberg (14 August 1943), MPG-Archiv, KWIP 7H Die Erfahrung mit den Reaktoren, 29.

experiments under Heisenberg languished because they had to wait for the large cast metal plates and sufficient amounts of heavy water.[61]

The work at the KWIP was also hampered by tensions between Heisenberg and Esau. For a while this worked to Diebner's benefit – for example, when Esau transferred the KWIP's heavy water to him – but eventually Heisenberg and KWS president Vögler were able to persuade their patron Armaments Minister Speer to force Esau out. His replacement was Walther Gerlach, professor for Experimental Physics at the University of Munich. Gerlach balanced support for both Diebner and Heisenberg. The KWIP group's goal of achieving a self-sustaining chain reaction was doomed to failure as long as they stayed with the horizontal layer design, but Heisenberg was determined to carry it out.

## TWILIGHT OF THE GODS

At the start of 1944, most of the KWIP was involved in "work important for the war."[62] The "Production of Energy from Nuclear Fission" work enjoyed the highest priority. The low temperature physics section of the institute was developing cold-resistant devices for use by frontline troops under a contract with the SS. The KWIP optical laboratory was working on a spectroscopic process needed by industry. Finally, in 1944, Wirtz was able to carry out experiments B-VI and B-VII using metal uranium plates and heavy water in the new state-of-the-art bunker laboratory at the KWIP. The results were inferior to the Gottow experiments with regard to neutron multiplication. The ever-deteriorating war now made work in Berlin almost impossible. However, Heisenberg nevertheless reported these results in positive terms to Vögler:[63]

> The results of the first large-scale experiment in the bunker laboratory are quite good. The results correspond in all essential points to expectations. The neutron increase is higher than all previous experiments. The Gottow experiments also show that changing the geometric arrangement of the metal [uranium] can increase this still further.

Vögler was a consistently strong supporter of Heisenberg and the uranium work at the KWIP[64]:

> If I can help in any way to accelerate the acquisition of the necessary material, then please give me the corresponding papers. I am also happy to meet again with

[61] Werner Heisenberg, Fritz Bopp, Erich Fischer, Carl Friedrich von Weizsäcker, and Karl Wirtz, "Messungen an Schichtenanordnungen aus 38-Metall und Paraffin" (30 October 1942), MPG-Archiv, KWIP 56 121–140.

[62] "Bericht über die laufenden kriegswichtigen Arbeiten des Kaiser Wihelm-Instituts für Physik" (6 January 1944), MPG-Archiv, KWIP 56 97.

[63] Heisenberg to Vögler (3 April 1944), MPG-Archiv, KWIP 29 357–358.

[64] Vögler to Heisenberg (31 October 1944), MPG-Archiv, KWIP 5–2 314.

Minister Speer, who as you know is exceptionally interested in these questions and asks me about it at every opportunity.

A few months earlier, in April 1944, Vögler had explicitly asked about nuclear explosives:[65] "Have the experiments brought us closer to the manufacture of so-called energy bombs?" No response to this question from Heisenberg has been found.

Thanks to the support of Speer, most KWIs were able to evacuate Berlin and seek quieter locations. The KWIP settled in Hechingen in southwest Germany, with a nuclear reactor experiment set up in neighboring Haigerloch. In fact, Heisenberg and Wirtz had embraced Höcker's suggestion and intended to bypass Diebner's effective but impractical cube lattice design and use an arrangement of cast metal uranium cylinders immersed in heavy water. Unfortunately, the ever-deteriorating war made this impossible. Instead, Wirtz was forced to copy Diebner's design and use a lattice of uranium cubes suspended in heavy water.

Gerlach had pressured the KWIP group to carry out a large-scale reactor experiment:[66]

I am very anxious to hear what you think of the suggestion, as soon as possible, to use all the cubes to make a large-scale experiment. I consider it urgently necessary that we do not wait until the cylinders are finished. Again and again the officials overseeing research and development have pressured us to do this, and I have to admit that they are right in the sense that many people have been exempted from frontline service in order to carry out such experiments. I have now begun to halt work, both in physics in general and in nuclear physics, which is less important than the main problem [uranium]. In this way physicists and technicians are being freed up for the most important work.

Neither at the time nor afterward did Heisenberg or Wirtz give Diebner the credit he deserved for developing the lattice reactor design. The final KWIP model reactor experiment urged by Gerlach had almost but not quite enough heavy water and uranium to go critical – but in the end that was fortunate. Because of their determination to achieve a self-sustaining chain reaction and constraints caused by the war, this experiment did not include much in the way of safety equipment. If it had gone critical, the scientists might have been subjected to strong radiation.

With Gerlach's support, Diebner's group continued their work. A final reactor experiment, G-IV, used a lattice of uranium cubes in the shape of a sphere.[67] Rainer Karlsch argues that this may even have gone critical for a short time and apparently ended in an accident. Evidence suggests that

[65] Vögler to Heisenberg (12 April 1944), MPG-Archiv, KWIP 56 79.
[66] Gerlach to Heisenberg (30 October 1944), MPG-Archiv, KWIP 7H P 33.
[67] Diebner to Heisenberg (10 November 1944), MPG-Archiv, KWIP 5–1 26.

some of the scientists working for Diebner took a significant further step by building and testing a nuclear weapon design in the last desperate months of the war.[68] This weapon was nothing like the atomic bombs dropped on Japan the following August; rather, it sought to use hollow-point explosive charges to provoke nuclear fission in small samples of significantly enriched uranium, and nuclear fusion in a small amount of lithium-deuteride. It is not clear that this design worked in the sense that it succeeded in provoking nuclear reactions. It is clear that a group of German scientists designed and tested what they thought would be a nuclear weapon. Diebner and Gerlach kept this weapon and its test a closely guarded secret. None of the other uranium project scientists, including Heisenberg and Weizsäcker, found out about it.

By 1944, the KWIP personnel had grown to fifty, including fifteen women. The breakdown is as follows:[69]

19 physicists (18 men, 1 woman)
9 lab technicians (1 man, 8 women)
7 mechanics (men)
3 cleaners (women)
2 pipe fitters (men)
2 secretaries (women)
1 carpenter (man)
1 chemical technician (man)
1 concierge (man)
1 electrician (man)
1 engineer (man)
1 glass blower (man)
1 helper (woman)
1 laborer (man)
also
4 (men) in military service, not counting those who were deceased

By this time, Heisenberg was looking toward the postwar period. In May of that year, he told his older colleague Laue about his plans for the KWIP:[70]

I have reminded ... a few institute members that the contracts for scientists who started during the war run out at the end of the war. I have justified this by arguing that, especially for scientists, it is easier now than it will be at the end of the war to

[68] For the G-IV experiment and the nuclear weapon test, see Rainer Karlsch, *Hitlers Bombe. Die geheime Geschichte der deutschen Kernwaffenversuche* (Munich: DVA, 2005), 115–161, 209–237; also see Rainer Karlsch and Mark Walker, "New Light on Hitler's Bomb," *Physics World* (June 2005), 15–18.
[69] "Personalliste" (20 March 1944), MPG-Archiv, KWIP 6cn 1–15.
[70] Heisenberg to Laue (5 June 1944), MPG-Archiv, KWIP 5–1 158.

find another position. Thus I have given these members the possibility of leaving the institute, of course after first consulting me. I consider this step necessary because I am convinced that the institute's work will have to be restricted after the war and because I would like to avoid the sudden appearance of great hardship. On the other hand, I did not send this letter to all members who started during the war, rather only to those whom I believe would have to leave if I am forced to shrink the institute.

Several months later, Heisenberg was more explicit:[71]

… because I feel that all such changes should wait until after the war. After the war is ended the institute will need a completely new research program, and none of us can now foresee which work the institute will be able to do, or even in which form the institute will continue.

## REHABILITATION

As the Allied armies advanced into Germany from all sides, a special scientific intelligence-gathering unit, the Alsos Mission, followed behind the American armies with the specific task of finding and neutralizing any "German atomic bomb."[72] When the scientific head of this mission, the Dutch-born and now naturalized American physicist Samuel Goudsmit came to Hechingen, the uranium, heavy water, and scientific reports were hidden. Wirtz and Weizsäcker told Goudsmit that he would have to wait and talk to Heisenberg, who had gone to Bavaria to be with his family. However, when the Alsos Mission found the buried materials and the reports hidden in a cesspool, Wirtz and Weizsäcker changed their minds and cooperated.

When Goudsmit found Heisenberg, he made an ambivalent impression by appearing both anti-Nazi and nationalistic. Ironically, Heisenberg and the rest of his colleagues believed that they were ahead of the Americans in the race to harness nuclear fission. Heisenberg told Goudsmit he would be very interested in the work they had been doing. Eventually, ten German scientists were interned in Farm Hall, a country estate in England.[73] More than half of the captive scientists – Bagge, Heisenberg, Korsching, Laue, Weizsäcker, and Wirtz – had worked at the KWIP. They enjoyed the good food and hospitality at Farm Hall until their tranquility was shattered by the news of Hiroshima.

Each of the interned scientists reacted differently to the news. The other scientists at Farm Hall had already maneuvered Diebner into the position of

[71] Heisenberg to Laue (14 November 1944), MPG-Archiv, KWIP 5–1 162.

[72] For the Alsos Mission, see Walker, *German*, 153–160.

[73] For Farm Hall, see Walker, *Nazi*, 207–241; Charles Frank (ed.), *Operation Epsilon: The Farm Hall Transcripts* (London: IOP, 1993), and Jeremy Bernstein (ed.), *Hitler's Uranium Club: The Secret Recordings at Farm Hall*, 2nd ed. (New York: Copernicus Books, 2001).

a scapegoat as the "Nazi" in the group. Gerlach acted like a defeated general and his colleagues feared that he would commit suicide – behavior that makes much more sense after the revelations that he had helped Diebner build and test a nuclear weapon. Hahn was self-righteous, insisting that he had had nothing to do with the military applications of his discovery. Heisenberg was concerned with his scientific reputation. Finally, Weizsäcker worked hard to develop arguments and explanations that would help them in the future – for example, that they had not really wanted to make atomic bombs.

When the Farm Hall scientists returned to Germany in 1946, the KWIP and the KWS were reestablished in Göttingen, within the British zone of occupation.[74] When the KWS was refounded as the Max Planck Society, the KWIP was renamed the Max Planck Institute for Physics. Its members played very important roles in the postwar development of science in West Germany.[75] Laue became the first president of the German Physical Society in the British Zone.[76] Heisenberg gained a great deal of influence as an informal advisor to West German chancellor Konrad Adenauer, although the physicist's initiatives were not always successful.[77] He helped found the

[74] See Klaus Hentschel and Gerhard Rammer, "Nachkriegsphysik an der Leine. Eine Göttinger Vogelperspektive," in Dieter Hoffmann (ed.), *Physik in Nachkriegsdeutschland* (Frankfurt am Main: Verlag Harri Deutsch, 2003), 27–56, and Mark Walker, "Otto Hahn: Responsibility and Repression," in *Physics in Perspective,* 8, no. 2 (2006), 116–163.

[75] See Michael Eckert, "Neutrons and Politics: Maier-Leibnitz and the Emergence of Pile Neutron Research in the FRG," *Historical Studies in the Physical and Biological Sciences*, 19, no. 1 (1988), 81–113; Michael Eckert, "Die Anfänge der Atompolitik in der Bundesrepublik Deutschland," *Vierteljahrshefte für Zeitgeschichte*, 37, no. 1 (1989), 115–143; Michael Eckert, "Das 'Atomei': Der erste bundesdeutsche Forschungsreaktor als Katalysator nuklearer Interessen in Wissenschaft und Politik," in Michael Eckert and Maria Osietzki (eds.), *Wissenschaft für Macht und Markt. Kernforschung und Mikroelektronik in der Bundesrepublik Deutschland* (Munich: Beck Verlag, 1989), 74–95; and Michael Eckert, "Kernenergie und Westintegration. Die Zähmung des westdeutschen Nuklearnationalismus," in Ludolf Herbst, Werner Bührer, and Hanno Sowade (eds.), *Vom Marshallplan zur EWG. Die Eingliederung der Bundesrepublik Deutschland in die westliche Welt* (Munich: R. Oldenbourg Verlag, 1990), 313–334.

[76] See Gerhard Rammer, "'Sauberkeit im Kreise der Kollegen': Die Vergangenheitspolitik der DPG," in Dieter Hoffmann and Mark Walker (eds.), *Physiker zwischen Autonomie und Anpassung. Die Deutsche Physikalische Gesellschaft im Dritten Reich* (Weinheim: VCH-Verlag Chemie, 2006).

[77] See Cathryn Carson, "New Models for Science in Politics: Heisenberg in West Germany," *Historical Studies in the Physical and Biological Sciences*, 30, no. 1 (1999), 115–171; Cathryn Carson, "A Scientist in Public: Werner Heisenberg after 1945," *Endeavour*, 23, no. 1, (1999), 31–34; Cathryn Carson, "Old Programs, New Policies? Nuclear Reactor Studies after 1945 in the Max-Planck-Institut für Physik," in Doris Kaufmann (ed.), *Geschichte der Kaiser-Wilhelm-Gesellschaft im Nationalsozialismus. Bestandsaufnahme und Perspektiven der Forschung*, 2 vols. (Göttingen: Wallstein, 2000), vol. 2, 726–749; Cathryn Carson, "Nuclear Energy Development in Postwar West Germany: Struggles over Cooperation in the Federal Republic's First Reactor Station," *History and Technology*, 18, no. 3 (2002), 233–270;

short-lived German Research Council (*Deutscher Forschungsrat*), which was eventually absorbed into the German Research Foundation (*Deutsche Forschungsgemeinschaft*), was instrumental in arranging the West German participation in CERN and other international projects, and served on the German Atomic Commission.

Weizsäcker spoke with and thereby influenced the writer Robert Jungk, whose 1956 book *Brighter than a Thousand Suns* popularized the myth that Heisenberg, Weizsäcker, and their colleagues had resisted Hitler by denying him nuclear weapons.[78] When Heisenberg failed to get the first West German nuclear reactor station to come to Munich, Wirtz became the director of the new Institute for Neutron Physics and Reactor Technology at the Karlsruhe Nuclear Research Center. Finally, all of these scientists participated in the 1957 Göttingen Manifesto, where they called for strong support of nuclear research but refused to have anything to do with West German development of nuclear weapons. This public statement was a consistent continuation of their ambivalent attitude toward nuclear reactors and their military consequences that began during the war and continued during the postwar period.

## HISTORIANS AND "HITLER'S BOMB"

Most historians who have examined the history of the German efforts during World War II to harness nuclear fission for nuclear energy and nuclear weapons have focused on Werner Heisenberg: what he did or did not do, what he wanted or intended to do. In fact, the history of the German "uranium project" is far greater than Heisenberg or even the KWIP. Heisenberg was one of the most important scientists working on nuclear fission during World War II, but he was also only one of several such scientists.

Three historians have published interpretations of Heisenberg that differ among themselves, and differ from this author's interpretation. In 1993, Thomas Powers argued that Heisenberg had resisted Hitler by leading a conspiracy to deny the German "Führer" nuclear weapons.[79] Two years later, Paul Lawrence Rose portrayed Heisenberg as a Nazi sympathizer who

Cathryn Carson, "Heisenberg and the Framework of Science Policy," *Fortschritte der Physik*, 50, nos. 5–7 (2002), 432–436; Cathryn Carson and Michael Gubser, "Science Advising and Science Policy in Post-War West Germany: The Example of the Deutscher Forschungsrat," *Minerva*, 40 (2002), 147–179; Cathryn Carson, "Objectivity and the Scientist: Heisenberg Rethinks," *Science in Context*, 16 (2003), 243–269.

[78] Robert Jungk, *Brighter than a Thousand Suns: A Personal History of the Atomic Scientists* (New York: Harcourt Brace, 1958); also see Jungk's foreword to Mark Walker, *Die Uranmaschine. Mythos und Wirklichkeit der deutschen Atombombe* (Berlin: Siedler Verlag, 1990), and his memoirs, Robert Jungk, *Trotzdem: mein Leben für die Zukunft* (Munich: Hanser, 1993).

[79] Powers.

failed to make nuclear weapons for Hitler only because of his arrogance and incompetence.[80] Cathryn Carson has published several sophisticated and subtle papers analyzing Heisenberg's postwar career as scientist, science policy maker, and intellectual, arguing that Heisenberg's statements were more differentiated after the war than many were willing or able to see: whereas after the war others – including in particular the author Robert Jungk – portrayed Heisenberg as a resistance fighter, Heisenberg himself did not.[81]

Thomas Powers was right in his 1993 book[82] to emphasize the April 1941 letter from Ladenburg as an important historical source for Heisenberg's mixed feelings about the uranium research, but he was wrong to take it as proof that Heisenberg resisted Hitler by denying him nuclear weapons. Heisenberg neither denied Hitler nuclear weapons nor resisted him. The recently returned KWIP papers, together with the "G-Reports" and the Heisenberg Papers in Munich, clearly document that Heisenberg did not slow down, divert, stop, camouflage, or hide the progress he and his colleagues were making toward nuclear reactors, nuclear explosives, and nuclear weapons. Paul Lawrence Rose was right in his 1998 book[83] to reject the postwar claims that Heisenberg and Weizsäcker had diverted, slowed down, or stopped research in order to resist Hitler, but he was wrong to follow Goudsmit's postwar analysis[84] and claim that German scientific incompetence had been the cause. Once again, now that the KWIP papers are available, we have a fairly complete documentation of what these scientists did or did not do.[85] Heisenberg's assumption that a nuclear reactor would regulate itself was dangerous but not incompetent. He and his colleagues clearly understood well how nuclear explosives could be created and how nuclear weapons in principle would work. The German scientists made some mistakes – their counterparts in the United States sometimes did as well – but these were not the reason Germany did not attempt the industrial-scale development of nuclear weapons.

Cathryn Carson was right to argue that Heisenberg's postwar statements need to be examined more carefully. It is clear that during the postwar period Heisenberg was being portrayed as a resistance fighter who led a conspiracy to deny nuclear weapons to Hitler, but Carson argues that Heisenberg was not responsible for this portrayal; rather, his sometimes suggestive and

80 Rose.

81 Cathryn Carson, "Reflections on Copenhagen," in Dörries, 7–17; Carson, "New," especially 134–135.

82 Powers.

83 Rose.

84 Samuel Goudsmit, *Alsos,* 2nd ed. (Los Angeles: Tomash, 1983).

85 The one frustrating exception is the actual calculation of critical mass that clearly was done at least once but has not yet been found.

vague statements on what he did during the war reflected his reluctance to participate in this discussion and his ambivalence about the work on uranium done during the National Socialist period. An unexpected type of continuity is now clear: a continuity of ambiguous ambivalence. During the war, Heisenberg was ambivalent about nuclear reactors and their consequences; after the war, Heisenberg was ambivalent about what he had done with nuclear reactors. During the war, Heisenberg gave evasive but suggestive answers when asked about nuclear weapons; after the war, he gave evasive but suggestive answers when asked about his wartime work on nuclear weapons. In fact, Heisenberg was quite consistent.

Finally, Rainer Karlsch was right to question whether the research carried out at the KWIP, or indeed the entire known uranium project, was the whole story of nuclear reactors and nuclear weapons under Hitler. His revelations of an additional model reactor experiment, G-IV, as well as a subsequent nuclear weapon test carried out by HWA scientists have placed the KWIP work in the proper context. Compared with Diebner, Gerlach, and the other scientists involved in the nuclear test, Heisenberg and Weizsäcker clearly did not try as hard as they could have done to create nuclear weapons for the National Socialists to use. Weizsäcker tried quite hard for a while, then fell into line with his more ambivalent senior colleague Heisenberg.

## CONCLUSION

Now we have come to a question that has often been asked: did German scientists try to make nuclear weapons for Hitler? New documents reinforce this author's original interpretation[86] of "Hitler's Bomb": the project scientists were neither resistance fighters nor incompetent; rather, they produced good scientific work that appears modest only when compared to the Manhattan Project. The administrators were neither stupid nor short-sighted; rather, they made reasonable science policy decisions even though they decided not to boost uranium research up to the industrial level and make a realistic effort to achieve nuclear weapons during the war. Paradoxically, these new sources also reveal that these scientists were both more and less enthusiastic about creating nuclear weapons for Hitler's government and military than has previously been assumed. Moreover, the key to understanding this paradox is, again as this author has previously argued, chronology – recognizing and appreciating change over time.

During the period from the September 1939 German invasion of Poland to the spring of 1941, before the invasion of the Soviet Union, Heisenberg worked out the basic theory of nuclear reactors, including the possibility of using pure or nearly pure U-235 as a nuclear explosive, and von Weizsäcker

[86] See footnote 1 above; Walker, *German*.

recognized that an operating nuclear reactor would produce a transuranic element 94 (plutonium) that would be just as good a nuclear explosive as U-235. Weizsäcker did not stop there; he submitted a patent that explicitly explained how nuclear reactors could be used to manufacture nuclear explosives and discussed with an official from Army Ordnance the possible military applications of nuclear fission. Heisenberg did not keep quiet about plutonium – as suggested in Michael Frayn's drama *Copenhagen;* rather, he told Hitler's Armaments Minister Albert Speer that the nuclear reactors they were working on could be used to make nuclear explosives for atomic bombs.

However, while the many reports and lectures do make clear that the researchers at the KWIP and other members of the uranium project were making good progress toward nuclear weapons – even though by the end of the war in Europe they had unknowingly fallen far behind their competition in the United States – these documents also demonstrate a growing ambivalence toward the future military applications of their work. Heisenberg's popular lectures before audiences of prominent political, military, and industrial leaders show this very clearly. In February 1942, Heisenberg speaks of nuclear explosives many times more powerful than any then available; in June of the same year he mentions nuclear explosives in a very reserved and diffident way; in the spring of the next year he does not mention nuclear explosives at all in a lecture on the applications of nuclear fission. Heisenberg – like the rest of his colleagues in the German uranium project – did not stop working on the nuclear reactors or isotope separation that everyone knew eventually would lead to nuclear explosives and atomic bombs, but he did stop publicizing these weapons.

When the Second World War began, German scientists at the KWIP took up research on nuclear fission, chain reactions, isotope separation, transuranic elements, and nuclear reactors with enthusiasm and with few misgivings. As long as the war was going well for Germany and its National Socialist leadership, so that nuclear weapons were not needed, these scientists retained their enthusiasm and worked hard to advance their research. When the war began to turn sour, they were confronted with the reality of both what a National Socialist victory would mean for Europe and what a defeat would mean for Germany. They did not stop working, divert, or slow down their progress, or resist National Socialism. However, as the revelations about Diebner's last reactor experiment and nuclear weapon test demonstrate, Heisenberg, von Weizsäcker, and Wirtz also clearly did not push as hard as they could to create nuclear weapons. The history of the Kaiser Wilhelm Institute for Physics during World War II demonstrates that scientists did not have to be enthusiastic about National Socialism or the war to work on weapons of mass destruction for the Third Reich.