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The Farm Hall Transcripts: The German Scientists and the Bomb

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One of the great puzzles of the Second World War is that the Germans failed to make the atomic bomb. While much has been written about this there has always been a missing piece: the explanation of the Germans themselves. Such German testimony that we have had was written well after the fact and could have been self-serving. But it has been known for nearly fifty years that ten of the leading German nuclear scientists were interned in England in the summer and fall of 1945 and their conversations were recorded. The transcripts of these recordings were classified by the British government as "TOP SECRET" and were not available to the public until January of this year. They make up an extremely dramatic and revealing historical document. What follows is an edited version of part of the transcripts, which deals with the reaction of the Germans when they learned about Hiroshima, to which I have added my own commentary. To make the significance of the transcripts clear, some historical introduction is needed.

1.

In the autumn of 1943 an intelligence gathering unit named the Alsos Mission was created by General Leslie Groves, who was in charge of the American atomic bomb project. With the Allied forces advancing in Europe, he decided that a small group, partly scientific and partly military, would follow just behind the armies and try to find out in detail the real status of the German atomic bomb project of which we had only hints, many of them disquieting. It was known, for example, that the Germans were accumulating heavy water—water in which ordinary hydrogen is replaced by heavy hydrogen, which has an additional neutron. The only use anyone could think of for this material was to cause a uranium chain reaction.

Groves appointed Colonel Boris Pash as the mission's military and administrative leader and the physicist Samuel Goudsmit as its senior scientist.[1] Goudsmit was an excellent choice. He had been born in Holland, knew many of the German scientists personally, and spoke several European languages. (His parents had been killed in a German concentration camp and he learned the details of how they died while traveling with the Allied intelligence unit.) Furthermore, he was not a nuclear physicist and did not have any firsthand knowledge of the US program. Before the mission he had been

given a limited briefing, making it possible for him to ask the captured Germans questions without giving anything away. He was ordered not to tell the Germans anything about the US atom bomb project.

The Allied scientists had good reasons—apart from the evidence about heavy water—to worry that the German nuclear bomb program was ahead of ours. Nuclear fission had been discovered as a result of experiments by Otto Hahn and Fritz Strassmann in Germany in December of 1938. They had been bombarding natural uranium with slow neutrons. They expected to see some nuclear transmutations in which the products should have been elements close in the periodic table to the uranium itself—radium, for example—because the bombardment, they assumed, would chip away only a few particles, leaving an element that was close to uranium in atomic weight. Such transmutations involving the modest rearrangement of a couple of nuclear particles had been studied for several years, especially by Enrico Fermi's group in Rome. But the new transmutations observed by Hahn and Strassmann produced whole nuclear chunks —nuclei whose atomic weight was much lighter than that of uranium and remote from it in the periodic table. The nucleus had been split into pieces by the bombardment of slow neutrons. One of the products of the reaction Hahn observed was an atom that appeared to behave chemically like barium. Barium is in the middle of the periodic table while uranium is near the end of it.

Puzzled, Hahn wrote to his former collaborator Lise Meitner, who had fled to Sweden to escape the Nazis. She replied:

> Your radium results [Hahn thought his bombardment would produce radium] are really very disconcerting: a process using slow neutrons that yields barium?!…At present it seems to me very difficult to accept such a drastic breaking-up [of the uranium nucleus], but we have experienced so many surprises in nuclear physics that one cannot dismiss this by saying simply: "It's not possible!"[2]

She and her nephew, the physicist Otto Frisch, then proceeded to show that what had taken place was a process—for which Frisch coined the term fission—that could be accounted for with a model of the nucleus as a kind of liquid drop which splits into two smaller droplets when it is struck by a neutron—a model that had been invented by George Gamow and developed by Niels Bohr. Any nuclear physicist who read the work of Hahn, Meitner, and Frisch could see that, theoretically at least, the fission of heavy nuclei such as uranium could release a huge explosive force.

By the end of April 1939 German scientists including the physical chemist Paul Harteck were alerting the German Army to the possibility of using uranium fission as a new kind of super explosive. By August, German Army Ordnance had created a research program to examine the prospects for nuclear power, explosive and otherwise. It was put under the direction of the physicist Kurt Diebner—a member of the Nazi Party—who was an expert on chemical explosives. By October of that year Diebner

had requisitioned the celebrated Kaiser Wilhelm Institute for Physics in Berlin, offering its Dutch-born director Peter Debye the choice of doing war work for the Germans or leaving the country. Debye chose to leave.

By September, the month the war broke out, the "Uranium Club" as it became known, had added Werner Heisenberg, who had been a professor at the Kaiser Wilhelm Institute; Carl Friedrich von Weizsäcker and Hahn himself were also recruited. The Berlin group was only one of several that began working on the nuclear program.[3] A program was set up at Hamburg under Harteck, who turned out to be the most competent and dedicated scientist in the entire enterprise. There were also programs in Munich, in Heidelberg—under the direction of the noted experimental physicist Walther Bothe—in Kiel, and in Vienna. About one hundred scientists became involved.

When it suited them, the Germans also used large numbers of slave laborers to carry out the atomic project.[4] For example, the Auer Company, which supplied most of the uranium plates used in the attempts to make a reactor, used some two thousand women prisoners from the concentration camp at Sachsenhausen, under conditions of safety that may only be imagined.

Very early in their nuclear project, the Germans encountered many of the central problems involving fission. In 1939, not long after he arrived in the United States from Copenhagen bringing the news of the discovery of fission, Niels Bohr, in collaboration with the American physicist John Wheeler, figured out how it worked. Natural uranium, the kind that is routinely mined, is a mixture of isotopes—nuclei with the same number of protons but different numbers of neutrons. Most of natural uranium consists of the isotope U238, and only about 0.7 percent consists of the isotope U235, which has three fewer neutrons. From his knowledge of nuclear reactions in general Bohr made the inspired guess that the fission Hahn and Strassmann had observed had been produced almost entirely from the fissioning of U235, which was more susceptible to drastic breakup than U238. In fact, U238 "poisons" the fission reaction since it absorbs neutrons which are then no longer available to produce fission. To keep this from happening the neutrons that are produced when a nucleus undergoes fission must be slowed down.[5] These slow neutrons can then cause both U238 and U235 to fission, while U235 will undergo fission when struck by both slow and fast neutrons.

Both the Allies and the Germans believed that the first step toward making a bomb would be to make a reactor, a device for producing the controlled release of nuclear energy through fission. After all, the entire field of nuclear energy was new and involved a great many assumptions that had to be tested in a controlled environment before the scientists could go on to make an explosive device. The only uranium available in quantity in the early 1940s was natural uranium, and to make use of it in a reactor it first had to be embedded in a material called a moderator, in order to slow down the neutrons.

Both carbon and heavy water can be used as moderators, but using them effectively turned out to be a delicate process. The first reactor to be built, which was designed by Fermi at the University of Chicago, used a carbon moderator. On December 2, 1942, it produced a self-sustaining chain reaction, in which the neutrons produced went on to split other nuclei. Its success convinced those who knew about it that the way to make an atomic bomb had now been opened. The Germans tried to create a working reactor but never succeeded in doing so. In their original experiment, Hahn and Strassmann had used natural uranium without a moderator, and only the U235 fissioned. (The Hiroshima bomb used U235, so that no moderator was necessary. The complex process of increasing the U235 content of a sample of uranium by separating the U235 isotopes is referred to as "enrichment" of the uranium.)

Both the Americans and some of the Germans also understood that a U238 reactor would have other uses. In June of 1940, von Weizsäcker realized that if one bombarded a U238 nucleus with a neutron it might become U239, and that this element could decay into the next element in the periodic table, which the Germans called "93" and which we call neptunium. Von Weizsäcker speculated that these new, heavier elements would also be fissionable and that, because their chemical makeup was different from that of uranium, they would be less difficult to separate from other elements. It turned out, although von Weizsäcker did not realize it, that neptunium could in turn decay into "94," which we call plutonium and which was itself fissionable. (The bomb dropped on Nagasaki was made with plutonium.)

Similar ideas for producing fission with new elements heavier than uranium had occurred, a few months earlier, in 1940 to the Princeton physicist Louis Turner. Independent of Turner's theoretical speculation, the Berkeley experimental physicists Edwin M. McMillan and Philip Abelson had already produced element 93 in the circular particle accelerator called a cyclotron and were investigating its properties. The Germans also realized that 93 could be produced in a cyclotron but never were able to get one of their own to work. They had a group working at a cyclotron in Paris, but not much was learned from that quarter since its French director, Frederic Joliot-Curie, was a member of the Resistance; and the German scientist who acted as their intermediary, Wolfgang Gentner, was an anti-Nazi who protected him.

2.

The German project can be divided into three stages. Between 1939 and 1941 the Germans were convinced that nuclear power would have no part in the war since it was going to be won rapidly in any event. Nonetheless, they felt that research had to be done since nuclear power could become significant in the postwar world. They were also convinced that the Allies were working on it. Heisenberg produced a design for a nuclear reactor in which the uranium was contained in flat plates, which were embedded in a moderator. This turned out to be a mistake. Nonetheless because of his

prestige this design dominated the program during most of the war. A rival group to Heisenberg's in Berlin—headed by Karl-Heinz Höcker—conceived of a design in which cubes of uranium would be embedded in a moderator of heavy water. The cubes were superior in design to the flat plates because it was easier for neutrons to flow out of the cubes and then be slowed down by the moderator. Höcker's group made experimental machines along this line that showed promise. They might have gone on to make a full-scale reactor if Heisenberg had not insisted on commandeering most of the uranium.

In 1940 Walther Bothe, working in Heidelberg, made a second mistake, which probably set back for some years the German attempt to make a reactor. In investigating carbon as a possible moderator, he found that the graphite he was using as a source of carbon—although seemingly pure—absorbed so many neutrons that it was useless as a moderator. In the US, Leo Szilard had warned scientists on the project that graphite could, because of the methods used to manufacture it, have impurities almost undetectable except by neutron absorption.[6] Fermi's reactor at the University of Chicago used natural uranium embedded in highly purified graphite. The Germans, not reckoning that graphite of such high purity was necessary, were forced to use heavy water as a moderator. The principal source of such water was the Norwegian Hydro Company which was seized by the Germans in 1940 and subsequently taken over by IG Farben. It was bombed and sabotaged throughout the war so that the Germans never had the amount of heavy water they needed.

In February 1942 a meeting was held in Berlin to summarize the ongoing research in nuclear fission for the benefit of both military and civilian authorities. The list of papers given at the meeting, which was found by the Allies after the war, is revealing:[7]

1. Professor Doctor Schumann: "Nuclear physics as a weapon."
2. Professor Doctor Hahn: "The fission of the uranium nucleus."
3. Professor Doctor Heisenberg: "The theoretical basis for energy production from uranium fission."
4. Professor Doctor Bothe: "Results of the energy-producing designs examined up until this time."
5. Professor Doctor Geiger [the inventor of the counter]: "The necessity of general basic research."
6. Professor Doctor Clusius: "Enrichment of uranium isotopes."
7. Professor Doctor Harteck: "The production of heavy water."
8. Professor Doctor Esau: "The extension of the research group 'nuclear physics' through cooperation with other Reich departments and industry."

(In his lecture Heisenberg pointed out that if enough U235 could be accumulated, an explosion of "utterly unimaginable effect" could take place.) pineapple?

By 1942, when it became clear that the war was not going to be won rapidly, German Army Ordnance decided to turn over control of the nuclear project to the Reich Research Council located in the Kaiser Wilhelm Institute in Berlin. Its director, Abraham Esau, had to deal with the various rival programs that had emerged, but to do so he never had power comparable to General Groves's or prestige comparable to Robert Oppenheimer's. In 1942 Albert Speer was named Minister of Armaments and Munitions. He did not believe that nuclear energy would have an effect on the war, but he encouraged the scientists to continue working on it because of its long-range implications.

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p class="initial">This brings us to the final stage of the program. Allied bombing had devastated the German cities and most of the research facilities. Heisenberg, for example, moved his activities to a bunker laboratory in Berlin. Some of the German scientists such as Heisenberg and Harteck began what seems to have been a frantic attempt, under impossible conditions, to construct a reactor. Heisenberg, according to Goudsmit's account, did not believe at this stage that Germany could win the war, but he seemed to think that constructing a reactor would give him and the other German scientists a strong bargaining chip after the war since the Allies would need his expertise. Harteck's group in Hamburg came up with one idea or device after another, most of them sound, for example the "ultra-centrifuge"—two very rapidly rotating centrifuges that work in tandem to separate isotopes—which is now one of the principal methods used to make U235 in third world countries. The physicist Walther Gerlach, who was very popular with his colleagues, was put in charge of the entire atomic project, with Kurt Diebner as his assistant. If the war had not ended, the Germans, in my view, would certainly have built a reactor within the next few years.

3.

When the Alsos operation began none of this was known. The team began to learn the facts when its members entered Paris with the first. Allied troops and interviewed Joliot-Curie. The Alsos team began rounding up one scientist after another as the Allies moved into Germany. By July 3, 1945, ten of the principal German nuclear scientists were assembled in Paris, including Hahn, Heisenberg, Gerlach, Harteck, Diebner, and von Weizsäcker. Also included was Max von Laue, probably more for his protection than anything else since von Laue, who was then in his late sixties and had won the Nobel Prize in 1914, was a longstanding anti-Nazi and the only German physicist to publicly oppose the Nazis' efforts to deprive Einstein of his credit for the relativity theory. The physical chemists Karl Wirtz and Horst Korsching and the young physicist Erich Bagge were also present. They did not know that they were about to be flown to England and installed in an old country estate near Cambridge named Farm Hall, which had been used by British Intelligence as a staging area for various resistance fighters, and now became available to house the scientific "guests." They were, indeed, treated

like guests and shown every courtesy. What they did not know was that all the bedrooms and living rooms had been bugged. Indeed one of the first conversations recorded was between Kurt Diebner and Heisenberg.

> *Diebner*: I wonder whether there are microphones installed here?
>
> *Heisenberg*: Microphones installed? (laughing) Oh no, they're not as cute as all that. I don't think they know the real Gestapo methods; they're a bit old fashioned in that respect.

For six months the British recorded the Germans morning, noon, and night. That they had done this has been well-known since the publication of Goudsmit's book, in which he quotes from the transcripts of the recorded conversations. However, until February of this year the British had classified as "TOP SECRET" the results of what was called "Operation Eclipse." They were released early this year in response to a petition signed by the presidents of the Royal Society and the British Academy, among others. I have no idea why the transcripts were kept secret for so long, but they are among the most fascinating documents about the behavior of scientists I have read.

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p class="initial">What follows is an edited version—with commentary—of the conversations on the sixth and seventh of August in 1945 when the German scientists were first told of the Allied atomic bomb, as translated by British intelligence. The British Public Records Office, the source of this document, has, I have been informed, neither the original German language transcript nor the original wire recordings. [8] Omissions from the text are indicated by dots; otherwise the material is presented as in the original. We begin with a preamble by Major T.H. Ritter, who was the officer in charge of Farm Hall.

"This report covers the first reactions of the guests to the news that an atomic bomb has been perfected and used by the allies.

"The guests were completely staggered by the news. At first they refused to believe it and felt that it was bluff on our part, to induce the Japanese to surrender. After hearing the official announcement they realized that it was a fact. Their first reaction, which I believe was genuine, was an expression of horror that we should have used this invention for destruction…."

Major Ritter then reports: "Shortly before dinner on the 6th of August I informed Professor Hahn that an announcement had been made by the BBC that an atomic bomb had been dropped. Hahn was completely shattered by the news and said he felt personally responsible for the deaths of hundreds of thousands of people, as it was his original discovery which made the bomb possible. He told me that he had originally contemplated suicide when he realized the terrible potentialities of the discovery and he felt that now these had been realized and he was to blame. With the help of ???

??? considerable alcoholic stimulant he was calmed down and we went down to dinner where he announced the news to the assembled guests."

As was to be expected, the announcement was greeted with incredulity. The following is a transcript of the conversation during dinner.

Hahn: They can only have done it if they have uranium isotope separation.

Wirtz: They have it too.

Hahn: I remember Segrè's, Muhling's and my assistant Grosse's work; they had separated a fractin of a milligram before the war, in 1939.

Laue: 235?

Hahn: Yes, 235.

Harteck: That's not absolutely necessary. If they let a uranium engine [throughout the conversations the Germans use "engine" for "reactor"] run, they separate 93 [the element neptunium-Np. What Harteck did not seem to know was that Np239 is exceedingly unstable. It decays rapidly into a long-lived isotope of plutonium Pu239. This could only have been learned by measuring the properties of these isotopes. The Germans never got to this stage of their program].

Hahn: For that they must have an engine which can make sufficient quantities of 93 to be weighed.

Gerlach: If they want to get that, they must use a whole ton [of uranium].

Hahn: An extremely complicated business, for 93 they must have an engine which will run for a long time. If the Americans have a uranium bomb then you're all second-raters. Poor old Heisenberg [Heisenberg was, in fact, in his early forties, while Hahn was von Laue's age, in his late sixties].

Laue: The innocent!

Heisenberg: Did they use the word uranium in connection with this atomic bomb?

All: No.

Heisenberg: Then it's got nothing to do with atoms, but the equivalent of 20,000 tons of high explosive is terrific….

Gerlach: Would it be possible that they have got an engine running fairly well, that they have had it long enough to separate 93?

Hahn: I don't believe it.

Heisenberg: All I can suggest is that some dilettante in America who knows very little about it has bluffed them in saying "If you drop this it has the equivalent of 20,000 tons of high explosive" and in reality it doesn't work at all.

Hahn: At any rate Heisenberg you're just second-raters and you may as well pack up.

Heisenberg: I quite agree.

Hahn: They are fifty years further advanced than we.

Heisenberg: I don't believe a word of the whole thing. They must have spent the whole of their 500,000,000 pounds in separating isotopes; and then it is possible. [The BBC broadcast the Germans heard must have given the cost of the US atomic bomb project, which was about two billion dollars.]

Weizsäcker: If it's easy and the Allies know it's easy, then they know that we will soon find out how to do it if we go on working.

Hahn: I didn't think it would be possible for another twenty years.

Weizsäcker: I don't think it has anything to do with uranium.

Hahn: It must have been a comparatively small atomic bomb—a hand one.

Heisenberg: I am willing to believe that it is a high-pressure bomb and I don't believe that it has anything to do with uranium, but that it is a chemical thing where they have enormously increased the speed of the reaction and enormously increased the whole explosion.

Gerlach: They have got 93 and have been separating it for two years, somehow stabilized it at low temperature and separated 93 continuously.

Hahn: But you need an engine for that.

Diebner: We always thought we would need two years for one bomb. [This remarkable statement should be kept in mind when one considers the question of the Germans' intent.]

Hahn: If they really have got it, they have been very clever in keeping it a secret.

Wirtz: I'm glad we didn't have it.

Weizsäcker: That's another matter…

Harteck: Who is to blame.

Voice: Hahn is to blame.

Weizsäcker: I think it is dreadful for the Americans to have done it. I think it is madness on their part.

Heisenberg: One can't say that. One could equally well say, "That's the quickest way of ending the war."

Hahn: That's what consoles me.

Heisenberg: I still don't believe a word about the bomb but I may be wrong. I consider it perfectly possible that they have about ten tons of enriched uranium, but not that they have ten tons of pure U235.

Hahn: I thought one needed only very little 235.

Heisenberg: If they only enrich it slightly, they can build an engine which will go. But with that they can't make an explosive which will.

Hahn: But if they have, let us say, 30 kilograms of pure 235, couldn't they make a bomb with it?

Heisenberg: But it still wouldn't go off…[In fact the nuclear bomb dropped on Hiroshima had about 30 kilograms of U235. I will discuss shortly Heisenberg's error.]

Hahn: But tell me why you used to say that one needed 50 kilograms of 235 in order to do anything. Now you say one needs…tons.

Heisenberg: I wouldn't like to commit myself for the moment…

Weizsäcker: I would say that, at the rate we were going, we would not have succeeded during the war.

Hahn: Yes.

Weizsäcker: It is very cold comfort to think that one is personally in a position to do what other people would be able to do one day.

Hahn: Once I wanted to suggest that all uranium should be sunk to the bottom of the ocean. I always thought that one could make a bomb of such a size that a whole province would be blown up.

Weizsäcker: Do you think it is impossible that they were able to get element 93 or 94 [plutonium] out of one or more running engines?

Wirtz: I don't think that is very likely. [Plutonium production began in the reactors at Hanford, Washington, in December 1944. By the following summer enough had been made to fuel the first atomic bomb explosion on July 16 and to fuel the second atomic bomb dropped on Japan at Nagasaki on August 9.]

Hahn: Well, I think we'll bet on Heisenberg's suggestion that it is a bluff.

Heisenberg: There is a great difference between discoveries and inventions. With discoveries one can always be skeptical and many surprises can take place. In the case

of inventions, surprises can only occur for people who have not had anything to do with it. It's a bit odd after we have been working on it for five years.

Later that evening, after this colloquy, Hahn and Heisenberg found themselves alone. Heisenberg then tried to explain to his senior colleague Hahn the workings of the bomb. Heisenberg understood a great deal, but he did not understand some of the essentials. Heisenberg began the discussion by guessing that the Americans had been able to make about thirty kilograms of pure U235 a year. He was about right. Indeed all the separated U235 that had been manufactured at Oak Ridge, Tennessee, by the summer of 1945—by then it had become a city of 75,000 people—was used for the Hiroshima bomb. The critical mass of an element such as uranium or plutonium is the amount of mass that is needed for the element to develop a self-sustaining series of fission reactions—a "chain reaction." One needs at least this much fissionable material to make a bomb. The critical mass of pure U235 is fifty-eight kilograms. So Heisenberg was neatly right when he guessed that the Allies had been able to separate about thirty kilograms of U235 a year.

Hahn asked, "Do you think they would need as much as that?" Heisenberg's response is truly remarkable: "I think so certainly, but quite honestly I have never worked it out as I never believed one could get pure 235."

This is one of the significant points at which the German and Allied projects diverged. In 1940 Otto Frisch and Rudolf Peierls made the calculation of the critical mass of U235 that Heisenberg failed to make. They came up with a critical mass of 600 grams, an estimate that was too small, but it was this estimate that led first the British and then the American scientists to believe that a bomb could be made. If the critical mass had turned out to be one measured in tons, say, there would have been no attempt to build the bomb.

The Farm Hall transcripts reveal that Heisenberg never made a serious attempt to estimate the critical mass. Someone else in the German atomic bomb project must have made this calculation, since German Army Ordnance was using a working number of about a hundred kilograms. The fact that Heisenberg did not seem to be aware of this number illustrates the lack of central organization in the German program, which seemed to have been run like a collection of competing academic physics departments.

??? someone else??

The transcripts, as the next extract shows, make it clear that Heisenberg did understand the essential difference between an atomic bomb and a reactor. In an atomic bomb one wants the successive fissions to take place as rapidly as possible. Otherwise the material will blow apart before all of it can be fissioned. The bomb makes use of "fast" neutrons—neutrons that are produced in fission and move with speeds of about a thirtieth the speed of light—about ten million meters a second. A reactor makes use of "slow" neutrons—neutrons that have been slowed down to speeds of only about 2,200 meters a second.

Heisenberg: "I always knew that it could be done with 235 fast neutrons. That's why 235 only can be used as an explosive. One can never make an explosive with slow neutrons, not even with the heavy water machine [a reactor whose moderator is heavy water] as then the neutrons only go with thermal speed [the 2,200 meters a second discussed earlier], with the result that the reaction is so slow that the thing explodes sooner, before the reaction is complete…"

Hahn then asks, "How does the bomb explode?" Heisenberg replies, "In the case of the bomb it can only be done with very fast neutrons. The fast neutrons in 235 immediately produce other neutrons so that the very fast neutrons which have a speed of—say—one thirtieth that of light make the whole reaction. Then of course the reaction takes place much quicker so that in practice one can release these great energies. In ordinary uranium [U238] a fast neutron nearly always hits 238 and then gives no fission."

At this point in his colloquy with Hahn, Heisenberg made a "back of the envelope" estimate of the probable size of a bomb made entirely of U235. He proceeded to get entirely the wrong answer. It is not a matter of arithmetic. He reveals that, at this point, he has not yet understood what is meant by the "critical mass" of U235—an indispensable concept. In making his calculation for Hahn, Heisenberg correctly reasons that it takes some eighty successive generations of fissions to produce enough energy to make a large explosion. He estimates the distance that these fission neutrons travel and from that, the size of the uranium sphere. Knowing how dense uranium is—about nineteen times as dense as water—he concludes that such a bomb would weigh "about a ton"—forty times more than the actual bomb weighed.

What he really needed to compute was the critical mass, that is, the mass of uranium at which the chain reaction is self-sustaining and keeps on going until all the material has been fissioned. To compute this, one must balance the loss of neutrons—for example, those that escape from the sphere of uranium—with those that are created in the fission—about two per fission. The mass at which the losses and gains are in balance and the fission will continue is, by definition, the critical mass that Peierls and Frisch had been able to calculate. On the fourteenth of August, a week later, Heisenberg gave a lecture to his colleagues at Farm Hall in which he presented the correct calculation of the critical mass for a bomb made of U235. He had worked it out during the interval. This time he arrived at a figure of sixteen kilograms—reasonably close to the correct answer.

Heisenberg and Hahn then began to discuss more general matters. The British eavesdroppers summarize the beginning of the conversation and then reproduce the detailed dialogue. The summary begins with a curious statement:

> Heisenberg went on to complain bitterly that Goudsmit had lied to him very cleverly and thinks he might have at least told him that their experiments in America were further advanced.

That Heisenberg thinks Goudsmit was obliged, under the circumstances, to tell him anything seems astonishing. The summary continues, "They agreed that the secret was kept very well. Hahn remarked on the fact that there had been no publication of work on uranium fission in British or American scientific journals since January, 1940…" Louis Turner's article on nuclear fission appeared in the *Reviews of Modern Physics* in 1940. The idea of stopping publication in the open literature was largely Leo Szilard's. It is clear from Hahn's remark that silence about fission served to tip the Germans off that research was going on. The conversation between Heisenberg and Hahn concludes:

Heisenberg: Perhaps they have done nothing more than produce 235 and make a bomb with it. Then there must be any number of scientific matters which it would be interesting to work on.

Hahn: Yes, but they must prevent the Russians from doing it.

Heisenberg: I would like to know what Stalin is thinking this evening. Of course they have got good men…and these people can do it too. There is not much to it if you know the fission. [In fact, it took hundreds of the best scientists in the Western world three years, from 1942 to 1945, to do it and they certainly "knew the fission."] The whole thing is the method of separating isotopes.

Hahn: No, in that respect the Americans and in fact all the Anglo-Saxons are vastly superior to them. [The first explosion of a Soviet atomic bomb—Joe I—was announced on September 23, 1949.] I have a feeling that the Japanese war will end in the next few days and then we will probably be sent home fairly soon and everything will be much easier than it was before. Who knows that it may not be a blessing after all?

At 9 PM the German scientists, having been told by Major Ritter a few hours before that an atomic bomb had been dropped, heard the official announcement of Hiroshima on the BBC. The transcript notes laconically, "They were completely stunned when they realized that the news was genuine. They were left alone on the assumption that they would discuss the position…"

Korshing: That shows at any rate that the Americans are capable of real cooperation on a tremendous scale. That would have been impossible in Germany. Each one said that the other was unimportant.

Gerlach: You really can't say that as far as the uranium group is concerned. You can't imagine any greater cooperation and trust than there was in that group. You can't say that any one of them said that the other was unimportant.

Korshing: Not officially of course.

Gerlach (shouting): Not unofficially either. Don't contradict me. There are far too many people here who know.

Hahn: Of course we were unable to work on that scale.

Heisenberg: One can say that the first time large funds were made available in Germany was in the spring of 1942 after that meeting with Rust when we convinced him that we had absolute proof that it could be done. [Bernhard Rust, an ardent Nazi, was Minister of Education. The meeting referred to is the one whose list of speakers is reproduced in the introduction.]

Bagge: It wasn't much earlier here either.

Harteck: We really knew earlier that it could be done if we could get enough material. Take the heavy water. There were three methods, the most expensive of which cost 2 marks per gramme and the cheapest perhaps 50 pfennigs. And then they kept on arguing as to what to do because no one was prepared to spend ten millions if it could be done for three millions.

Heisenberg: On the other hand, the whole heavy water business which I did everything to further cannot produce an explosive.

Weizsäcker: How many people were working on V1 and V2 [the rockets]?

Diebner: Thousands worked on that [mostly slave labor].

Heisenberg: We wouldn't have had the moral courage to recommend to the Government in the spring of 1942 that they should employ 120,000 men just for building the thing up.

Weizsäcker: I believe the reason we didn't do it was because all the physicists didn't want to do it on principle. If we had all wanted Germany to win the war we would have succeeded.

Hahn: I don't believe that but I am thankful we didn't succeed….

Heisenberg: It is possible that the war will be over tomorrow.

Harteck: The following day we will go home.

Korshing: We will never go home again.

Harteck: If we had worked on an even larger scale we would have been killed by the "Secret Service." Let's be glad we are still alive. Let us celebrate this evening in that spirit.

Diebner: Professor Gerlach would be an Obergruppenführer and would be sitting in Luxembourg as a war criminal.

Korshing: If one hasn't the courage, it is better to give up straightaway.

Gerlach: Don't always make such aggressive remarks.

Korshing: The Americans could do it better than we could, that's clear.

(Gerlach leaves the room.)

Heisenberg: The point is that the whole structure of the relationship between the scientist and the state in Germany was such that although we were not 100 percent anxious to do it, on the other hand we were so little trusted by the state that even if we had wanted to do it it would not have been easy to get it through.

Diebner: Because the official people were only interested in immediate results. They didn't want to work on a long-term policy as America did.

Weizsäcker: Even if we had got everything that we wanted, it is by no means certain whether we would have got as far as the Americans and English have now. It is not a question that we were very nearly as far as they were but it is a fact that we were all convinced that the thing could not be completed during the war.

Heisenberg: Well that's not quite right. I would say that I was absolutely convinced of the possibility of our making a uranium engine but I never thought that we would make a bomb and at the bottom of my heart I was really glad that it was to be an engine and not a bomb. I must admit that.

Weizsäcker: If you had wanted to make a bomb we would probably have concentrated more on the separation of isotopes and less on heavy water.

(Hahn leaves the room.)

Weizsäcker: If we had started this business soon enough we could have got somewhere. If they were able to complete it in the summer of 1945, we might have had the luck to complete it in the winter of 1944–45.

Wirtz: The result would have been that we would have obliterated London but would still not have conquered the world, and then they would have dropped them on us.

Weizsäcker: I don't think we ought to make excuses now because we did not succeed, but we must admit that we didn't want to succeed. If we had put the same energy into it as the Americans and had wanted it as they did, it is quite certain that we would not have succeeded as they would have smashed up the factories.

Diebner: Of course they were watching us all the time.

Weizsäcker: One can say it might have been a much greater tragedy for the world if Germany had the uranium bomb. Just imagine, if we had destroyed London with uranium bombs it would not have ended the war, and when the war did end, it is still doubtful whether it would have been a good thing.

Wirtz: We hadn't got enough uranium.

Weizsäcker: We would have had to equip long distance aircraft with uranium engines to carry out airborne landings in the Congo or Northwest Canada. We would have had to

have held those areas by military force and produce the stuff from mines. That would have been impossible.

Heisenberg: I think we ought to avoid squabbling amongst ourselves concerning a lost cause. In addition, we must not make things too difficult for Hahn.

Harteck: We have probably considered a lot of things which the others cannot do and could use.

Weizsäcker: It is a frightful position for Hahn. He really did do it [i.e., his experiments led to the discovery of fission].

Heisenberg: Yes. (Pause) About a year ago I heard from…the Foreign Office that the Americans had threatened to drop a uranium bomb on Dresden if we didn't surrender. At that time I was asked whether I thought it was possible, and, with complete conviction, I replied: "No."

Wirtz: I think it is characteristic that the Germans made the discovery and didn't use it. Whereas the Americans have used it. I must say I didn't think the Americans would dare to use it.

At this point in the transcript the dialogue stops briefly and is replaced by the following narrative:

> ….When Gerlach left the room he went straight to his bedroom where he was heard sobbing. Von Laue and Harteck went up to see him and tried to comfort him. He appeared to consider himself in the position of a defeated General, the only alternative open to whom is to shoot himself. Fortunately he had no weapon and he was eventually sufficiently calmed by his colleagues. In the course of conversation with Von Laue and Harteck, he made the following remarks:
>
> *Gerlach*: When I took this thing over, I talked it over with Heisenberg and Hahn, and I said to my wife: "The war is lost and the result will be that as soon as the enemy enter the country I shall be arrested and taken away." I only did it because I said to myself, this is a German affair and we must see that German physics are preserved. I never for a moment thought of a bomb but I said to myself: "If Hahn had made this discovery, let us at least be the first to make use of it." When we get back to Germany we will have a dreadful time. We will be looked upon as the ones who have sabotaged everything. We won't remain alive long there. You can be certain that there are many people in Germany who say that it is our fault. Please leave me alone.

Next it was Hahn's turn to try to comfort Gerlach:

Hahn: Are you upset because we did not make the uranium bomb? I thank God on my bended knees that we did not make a uranium bomb. Or are you depressed because the

Americans could do it better than we could.

Gerlach: Yes. [There is, of course a considerable irony in this. The "Americans" who made the bomb included Enrico Fermi, Eugene Wigner, Hans Bethe, Rudolf Peierls, Niels Bohr, Edward Teller, along with a small army of lesser known refugees from Hitler's Europe. This fact never seems to occur to any of the Germans.]

Hahn: Surely you are not in favor of such an inhuman weapon as the uranium bomb?

Gerlach: No. We never worked on the bomb. I didn't believe it would go so quickly. But I did think that we should do everything to make the sources of energy and exploit the possibilities for the future….

Hahn: I am thankful that we were not the first to drop the uranium bomb.

Gerlach: You cannot prevent its development. I was afraid to think of the bomb, but I did think of it as a thing of the future, and that the man who could threaten the use of the bomb would be able to achieve anything…. We must not say in front of those two Englishmen that we ought to have done more about the thing. Wirtz said that we ought to have worked more on the separation of isotopes. It's another matter to say that we did not have sufficient means but one cannot say in front of an Englishman that we didn't try hard enough. They were our enemies, although we sabotaged the war. There are some things that one knows and one can discuss together but that one cannot discuss in the presence of Englishmen.

Hahn: I must honestly say that I would have sabotaged the war if I had been in a position to do so.

Now Hahn and Heisenberg find themselves alone. The British eaves-droppers summarize the beginning of their conversation, the one that led to Heisenberg's faulty explanation to Hahn of the workings of the bomb. They write:

> Hahn explained to Heisenberg that he was himself very much upset about the whole thing. He said he could not really understand why Gerlach had taken it so badly. Heisenberg said he could understand it because Gerlach was the only one of them who had really wanted a German victory, because although he realized the crimes of the Nazis and disapproved of them, he could not get away from the fact that he was working for Germany. Hahn replied that he too loved his country and that, strange as it might appear, it was for this reason that he had hoped for her defeat….
>
> Heisenberg stated that the people in Germany might say that they should have forced the authorities to release 100,000 men in order to make the bomb and he feels himself that had they been in the same moral position as the Americans and said to themselves that nothing mattered except that Hitler should win the war, they might have succeeded, whereas in fact they did not want him to win. Hahn

> admitted however that he had never thought that a German defeat would produce such a terrible tragedy for his country….

It was now getting toward midnight. Weizsäcker, Bagge, Wirtz, and Harteck have stayed up to play cards. They had the following conversation:

Bagge: We must take our hats off to these people for having the courage to risk so many millions.

Harteck: We might have succeded if the highest authorities had said, "We are prepared to sacrifice everything."

Weizsäcker: In our case even the scientists said it couldn't be done.

Bagge: That's not true. You were there yourself at that conference in Berlin. I think it was on 8 September that everyone was asked—Geiger, Bothe, and you Harteck were there too and everyone said that it must be done at once. Someone said, "Of course it is an open question whether one ought to do a thing like that." Thereupon Bothe got up and said, "Gentlemen, it must be done." Then Geiger got up and said, "If there is the slightest chance that it is possible—it must be done." That was on 8 September'39….

In the meanwhile Heisenberg and Gerlach had a discussion in Gerlach's room which lasted "half the night."

Gerlach: I never thought of the bomb, all I wanted was that we should do everything possible to develop Hahn's discovery for our country.

> The transcript continues:
>
> Heisenberg went on to stress the fact that they had concentrated on the development of the engine and stated that although the Allies appeared to have concentrated on the bomb they could presumably also make the engine now…. He blamed Hitler for the fact that "Hahn's invention has now been taken away from Germany."

Heisenberg: I am still convinced that our objective was really the right one and that the fact that we concentrated on uranium may give us a chance of collaboration. I believe this uranium business will give the Anglo-Saxons such tremendous power that Europe will become a bloc under Anglo-Saxon domination. If that is the case it will be a very good thing. I wonder if Stalin will be able to stand up to the others as he has done in the past….

Gerlach: If Germany had had a weapon which would have won the war, then Germany would have been in the right and the others in the wrong, and whether conditions in Germany are better now than they would have been after a Hitler victory…. I went to

my downfall with open eyes, but I thought I would try to save German physics and German physicists, and in that I succeeded….

Heisenberg then joined his colleagues Wirtz and Weizsäcker. The discussion turns to their futures.

Weizsäcker: Our strength is now in the fact that we are "un-Nazi."

Heisenberg: Yes, and in addition, uranium was discovered by Hahn and not by the Americans.

Weizsäcker: I admit after this business I am more ready to go back to Germany, in spite of the Russian advance.

Wirtz: My worst fears have been realized with regard to the complications which will now arise about us.

Heisenberg: I believe that we are now far more bound up with the Anglo-Saxons than we were before as we have no possibility of switching over to the Russians even if we wanted it.

Weizsäcker: If I ask myself for which side I would prefer to work I would say for neither of them.

Just before going to bed Diebner and Bagge discuss who is to blame for the German failure:

Bagge: Gerlach is not responsible, he took the thing over too late. On the other hand it is quite obvious that Weizsäcker was not the right man for it. The tragedy is that Korshing is right in the remarks he made to Gerlach. I think it is absurd for Weizsäcker to say he did not want the thing to succeed. That may be so in his case, but not for all of us. Weizsäcker was not the right man to have done it. Heisenberg could not convince anyone that the whole thing depended on the separation of isotopes….

Diebner: Now the others are going to try and make up to the Major and sell themselves. Of course they can do what they like with us now, they don't need us at all….

Bagge: You can't blame Speer as none of the scientists here forced the thing through…

Diebner: They all failed…

The British listeners comment, "Although the guests retired to bed about 1:30, most of them appear to have spent a somewhat disturbed night judging by the deep sighs and occasional shouts which were heard during the night. There was also a considerable amount of coming and going along the corridors." The next day the "guests" spent the morning avidly reading the newspaper. This provoked the following comments from Weizsäcker and Heisenberg:

Weizsäcker: History will record that the Americans and the English made a bomb, and that at the same time the Germans under the Hitler regime produced a workable engine. In other words, the peaceful development of the uranium engine was made in Germany under the Hitler regime, whereas the Americans and English developed this ghastly weapon of war.

(History will, of course, record that the Germans never succeeded in making a reactor during the war.)

Heisenberg: If the Americans had not got so far with the engine as we did—that's what it looks like…then we are in luck. There is a possibility of making money.

The transcript ends on December 31, 1945, the day before the Germans left for home. On Friday November 16 the *Daily Telegraph* announced that Hahn had been awarded the Nobel Prize for Physics for the year 1944 for his discovery of fission. The next day, the transcript notes,

> The award was duly celebrated with songs, speeches, baked meats and some alcohol. Proceedings started very badly with an unfortunate speech by von Laue at the end of which, both he and Hahn were in tears to everybody's great discomfort, particularly mine [i.e., Major Ritter], as I was sitting between them. However, the united efforts of the rest of the party restored our normal good spirits.

The final word in the transcript is that of Wirtz.

> *Wirtz*: There is a lot to be said for the commander [i.e., the commanding officer of Farm Hall] after all, no matter how much we may have cursed him. In any case, it may be wise to be in his good books. We never know when we may have another use for him.

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1 The interested reader should consult *Alsos* by Samuel Goudsmit (Tomash, 1983). This is the most recent edition and contains an invaluable introduction by the ex–British intelligence officer R. V. Jones. The role of the missions is put in context by Mark Walker in his *German National Socialism and the Quest for Nuclear Power 1939–1949* (Cambridge University Press, 1989). Walker's book is the best reference I know for the German nuclear program. ↩

2 This quotation and a brief description of the early uranium work can be found in my *Prophet of Energy* (Dutton, 1980). It is treated in great detail in Richard Rhodes, *The Making of the Atomic Bomb* (Simon and Schuster, 1986). ↩

3 Walker, *German National Socialism*, p. 53. ↩

4 Walker, *German National Socialism*, p. 133. ↩

5 The probability that a fission or capture reaction takes place is a rapidly varying function of the energy. Some energies favor one reaction and some energies another. To avoid the capture one must reduce the neutrons energy below the energy favorable for capture. ↩

6 I am indebted to Hans Bethe for discussions of this and many other matters connected to this history. I am also grateful to my colleagues Lowell Brown, Gerald Feinberg, Paul Fishbane, and John Wheeler for their substantial help, and to Harold Furth for material in connection with his uncle Paul Harteck. ↩

7 Walker, *German National Socialism*, p. 55. ↩

8 See the *Independent*, February 23, 1992, for an account of the petition to release the documents. I am indebted to Gerald Holton for information about the statements of the British Public Records Office and other matters. The complete transcripts will be published in 1993 by IOP Publishing in the United Kingdom. ↩