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HEISENBERG AND THE GERMAN NUCLEAR RESEARCH PROJECT

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By

Gentian Rrudho

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and

Besian Xhixho

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Advisors: Professors Joseph D. Fehribach and David B.Dollenmayer

Abstract

The role of Werner Heisenberg during World War II and his impact upon the outcome of the German nuclear project has been widely discussed by historians for more than sixty years. Our goal is to find every piece of information that may give insight into events that took place at the time, allowing us to form a complete picture from which we hope to arrive at a conclusion regarding Heisenberg's role and influence in the Nazi atomic research.

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1. Introduction

The issue of how morality affects the development of science has always been the subject of much debate. Perspectives of scientists themselves, politicians, historians, and others differ upon this matter. The wide range of opinions concerning the involvement of science in the evolution of civilization is a testimony to the great interest in further exploring the effects of science on society. Werner Heisenberg himself believed that science must be viewed as an independent field that serves humanity and should not for any reason be used to harm civilization. He regarded science as the language which can be used by people around the world to communicate the results of their work, their ideas, and thoughts. The idea stressed by Heisenberg was a result of careful consideration of that wide range of opinions concerning the status of science in modern society.

> It has often been said that science should be a bridge between peoples and should help to better international understanding. It has also repeatedly been stressed, with full justification, that science is international and that it directs man's thoughts to matters which are understood by all peoples and in whose solution scientist of the most diverse languages, races or religions can participate equally. In speaking to you about this role of science at this particular time it is important that we should not make things too easy for ourselves. We must also discuss the opposite thesis, which is still fresh in our ears, that science is national and that the ideas of the various races are fundamentally different. It was held that science had to serve one's own people in the first instance and help to secure one's own political power: that science forms the basis of all technical developments, and hence of all progress, as well as of all military power. It was also held that the task of the pure sciences as well as of philosophy was to support our Weltanschauung and our beliefs. These in turn were regarded as the foundation of political power among our own people. I should like to discuss which of these two views is correct and what are the relative merits of the arguments that can be produced in their favour.[1]

On the other hand, individuals of great power including politicians and military leaders have tended to use science as a means for achieving their ambitious goals. The exploration of

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[1] Werner Heisenberg, *Science as a Means of International Understanding,* <http://werner-heisenberg.physics.unh.edu/index.htm#documents>

Nazi Germany's effort to use science and technology for the purpose of war might provide further insight in Heisenberg's actions as the lead scientist in the German atomic research.

Over the years a great deal of attention has been devoted to the outcome of the German government's initiative in building an atomic weapon. Many believe that it was the contribution of Heisenberg that led to the failure of the German effort. Some of the supporters of this view consider it very fortunate that he was the leader of what some would consider the most dangerous threat ever to humanity. Others believe that the German failure in constructing an atom bomb was simply due to Heisenberg's inability to achieve a successful result. Some of them would even argue that not only was he incapable of fulfilling his task but also eager to succeed in building such a device for Hitler. The argument whether Heisenberg was incapable to achieve a successful result or sabotaged the project is stretched on either side ever since the war ended and remains unresolved to this day.

The goal of our research is to explore the events at that time through various sources and establish a conclusion regarding Heisenberg's goals in the uranium project. Questions that concerned the issue through the years are at the center of our attention. Mainly, we are concerned with creating a clear picture of Heisenberg's personal decisions, his moral dilemmas, professional capabilities to perform the assigned task, his influence on his colleagues' decisions, and other aspects which would help provide a thorough understanding of the issues concerning the object of our research. We were careful to keep an objective opinion; we ask readers to do the same.

As a first step it seems reasonable to concentrate on Heisenberg as an individual. It may serve our purpose to analyze parts of his life in order to shed some light upon the enigmas of Heisenberg's personality, and the decisions he made while participating in German atomic research. Indeed, besides the books, articles, scientific journals, documentaries, and diaries of individuals who participated in the project, we will make use of official documents; an interview conducted with Professor Jochen Heisenberg, the son of Werner Heisenberg, and other materials that concern the topic.

2. Biography

2.1 A Time of Youth

Werner Karl Heisenberg was born on December 5, 1901 in the city of Würzburg in the southern German state of Bavaria. Heisenberg and his brother Erwin were the only sons of Dr. August Heisenberg and Anna Heisenberg. Both parents were individuals who appreciated the importance of a good education; August worked as a school teacher of classical languages and later became a professor of Middle and Modern Greek at the University of Munich. His wife was the daughter of a Gymnasium principal.

Heisenberg entered elementary school at the age of five. His family had a great influence on his progress in the early stages of his education. While attending elementary school, Heisenberg constantly competed with his older brother in problems their father had assigned to them. The extended practice and competition between the two boys is viewed as one of the reasons why Heisenberg was one step ahead of his peers in the subjects of math and science. In 1910, Heisenberg's father was appointed professor at the University of Munich. That same year the Heisenberg family moved to the Bavarian capital. Heisenberg finished the last year of his elementary school at Elisabethenschule. Thereafter he enrolled at the Maximilians Gymnasium, a nine-year school that prepared students for universities.

Heisenberg attended Maximilians Gymnasium for nine years where graduated at the top of his class. Heisenberg's intelligence, ambition and drive to study on his own were qualities for which his high school teachers always praised him. In their remarks they characterized him as a student who exceeded the normal expectations. The main subjects taught at the time were classical Greek and Latin. Others included mathematics, physics, and religion. Heisenberg received grades of all 1's except for a single two (one being the highest, four the lowest).

His interest regarding math and physics "arose partly from the technological developments of the period—cars, airplanes, telephones, and radio—and partly from the encouragement of his excellent math and science teacher, Christoph Wolff."[2] In a short time Heisenberg attracted his teachers' attention. For instance, Heisenberg recalled, '"He [Christoph Wolff] tried to interest me and give special problems to me. He told me, 'Try to solve that and that.'"[3] During the gymnasium years Heisenberg became fascinated with the theory of numbers and mathematics of the number system. He believed that everything could be explained in numbers.

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[2] David Cassidy <http://www.aip.org/history/heisenberg/p03.htm>
[3] David Cassidy <http://www.aip.org/history/heisenberg/p03.htm>

The outbreak of World War I (WW I) in the summer of 1914 had a negative impact on the German economy, making daily life difficult. Major effects were seen in food and production of industrial fuel. The scarcity of resources had an impact on schools as well; they were closed for relatively long periods of time due to the coal shortage. Heisenberg's political and social views seem to have been influenced to a great extent by the war events. Just as any other child, Heisenberg had to face food shortages and long, cold winter nights; food was so scarce that Heisenberg, weak from hunger, once fell off his bicycle into a ditch.

Because schools were closed, students were forced to study independently at home. In addition to their studies, students were required to participate in military training. Tasks assigned to the student military units included bringing in harvest, especially during the fall of 1918. In this regard Heisenberg recalls, "Others, including myself, had been working two years earlier as farm hands on farms in the Bavarian Highlands. So the raw wind was no longer alien to us; and we were not afraid to form our own opinions on the most difficult problems."[4] In addition to the military unit, Heisenberg participated in voluntary work. After the Armistice in November of 1918, revolution swept through Germany, replacing the monarchy with a democratic republic. In Bavaria, a soviet republic modeled after the new Bolshevik republic in Russia was established. The government in Berlin led by the Social Democrats "was forced to call upon national socialist officers from both outside and inside Bavaria in order to assert its sovereignty."[5] In May 1919, troops dispatched from Berlin crushed the soviet republic in a battle through the streets of Munich.

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[4] David Cassidy <http://www.aip.org/history/heisenberg/p04.htm>
[5] Pinson, Pg. 388

> The Freikorps, headed by Ritter von Epp, and federal troops marched into Munich to restore order. Savage fighting raged for several days. The story of the brutalities committed by both sides during this civil war is one of the saddest pages in German history before the advent of the Nazis. Indiscriminate shooting of hostages and civilians, brutal treatment of prisoners, summary executions, and other forms of violence fill the authentic records of the events of these weeks. Between April 30 and May 8, according to official figures, 557 persons were killed. The government troops asserted their mastery over the city of Munich.

Some of the intellectuals who led the Munich Soviet Republic were executed. Max Levien and Eugen Leviné, the leaders of the Communist party in Bavaria (K.P.D), were condemned to death. Gustav Landauer, a philosophical anarchist and an independent ethical thinker, was brutally beaten to death. Ernst Toller and other leaders were sentenced to long prison terms.[6] During the restoration of moderate social democratic rule, Heisenberg and his schoolmates served in support of one of the units dispatched from Berlin.

While involved in the military unit Heisenberg was introduced to nationalist ideas. The outcome of the war led to extreme disappointment of German youth. Germany was defeated by the end of 1918, a fact that triggered the anger of the population toward their leaders. Heisenberg and his peers felt betrayed. Germany's monarchy collapsed and disillusionment reached its limit. Like many others, Heisenberg believed that life should be more than street fighting and political struggle. The war was the turning point for Heisenberg's generation. Young people turned to nature; they believed that traditional German culture could be restored. Heisenberg and his friends spent their free time in outdoor activities such as hiking, skiing, camping, and mountain climbing throughout Germany and neighboring countries. They met on a weekly basis. Meetings were concerned mainly with discussions of German culture, music,

[6] Pinson, Pg. 288-289

songs, and poetry. Indeed, the group maintained certain ethical norms which opposed drinking, interaction with women, and smoking.

Heisenberg was elected the leader of his Gymnasium military unit. The unit was associated with an anti-modernist group known as the New Boy Scouts *(Bund Deutscher Neupfadfinder).* Heisenberg's unit and New Boy Scouts favored the right-wing politics and supported the monarchy. New Boy Scouts displayed Anti-Semitic behavior[7]; however, Heisenberg's involvement in this organization did not influence his attitude toward his Jewish friends. He was an open minded individual who did not value his friends based on ethnicity or social ranking. Besides the leadership position and peer activities Heisenberg was involved in voluntary work aimed at educating adult workers. Heisenberg's involvement in such activities helped his reputation as a leader and individual. The leadership skills that he developed during this period had a positive effect later in his life. His participation in the German youth movement during WW I can be viewed as a major defining factor of his political and personal views. The youth group movements lasted until 1933, when Hitler banned all independent youth groups.

In the fall of 1920 Heisenberg enrolled in the University of Munich with emphasis in studying mathematics, but shortly after enrollment he decided to focus on physics. At the beginning of his studies Heisenberg had the opportunity to meet Arnold Sommerfeld, a physics professor, and Wolfgang Pauli, who later would become Heisenberg's best friends. Sommerfeld was one of the first professors at the University of Munich to recognize his talent. Sommerfeld

[7] David Cassidy <http://www.aip.org/history/heisenberg/p04.htm>

admitted Heisenberg to his advanced physics seminar. His participation exposed young Heisenberg to advanced topics in theoretical physics, which in turn led to his first work published in the physics journal, *Zeitschrift für Physik,* in 1922. The paper concerned the old quantum theory of the atom which was first developed by Bohr and later enhanced by Sommerfeld.

The friendship between Heisenberg and Sommerfeld grew stronger over time. Sommerfeld, who knew Heisenberg's history regarding controversial solutions to problems in quantum theory, suggested that Heisenberg conduct his doctoral dissertation in hydrodynamics. In fact, Heisenberg pursued his doctorate in the field of hydrodynamics and in record time (three years) received his doctorate from the University of Munich in 1923. The controversy around Heisenberg's final oral exam raises questions about his abilities as an experimental physicist. Heisenberg faced several difficulties in his oral exam. Wilhelm Wien, his laboratory professor, placed Heisenberg in a difficult position. The answers provided by Heisenberg to questions regarding laboratory knowledge and experimental procedures were deemed by Wien to be unsatisfactory. The well known professor believed that every physicist, including theorists such as Heisenberg, must be properly trained in the discipline of experimental physics. It should be noted that physics in those days meant primarily experimental physics. Theoretical physics, though rising in status, had not yet reached full acceptance as a branch of physics equal to experimental research.

Even though Heisenberg faced difficulties in experimental physics, he was not demoralized. The final oral exam was followed by the submission of a 59-page calculation titled, *On the Stability and Turbulence of Fluid Flow,* to the Munich faculty on July 10, 1923. The work done by Heisenberg concerned an earlier research contract Sommerfeld had received from a company channeling the Isar River through Munich. Heisenberg' assignment was to "determine the precise transition of a smoothly flowing fluid (laminar flow) to turbulent flow"[8]. The assignment was an extremely difficult mathematical problem; in fact, it was so difficult that Heisenberg offered only an approximate solution. Sommerfeld himself was aware of the difficult task assigned to Heisenberg; in this regard he stated, "I would not have proposed a topic of this difficulty as a dissertation to any of my other pupils."[9] Heisenberg's thesis was accepted by the faculty and Wien, who thus far had not agreed to give Heisenberg a passing grade for the exam accepted it for publication in the physics journal, *Annalen der Physik,* which he edited. The mathematical approach followed by Heisenberg conflicted with views of other mathematicians. For instance, Fritz Noether raised objections to the results in 1926, yet Noether's objections were disregarded when Heisenberg's approach was proven to be right nearly a quarter century later.

The road to Uncertainty Principle began around the fall of 1924 when Heisenberg joined the Institute for Theoretical Physics in Copenhagen. Heisenberg transferred there with Neils Bohr's help and both men worked together for many years. In the summer of 1925, Heisenberg worked on a new theoretical model of the planetary atom; in this application he made use of matrix algebra, a subject that he had not been taught before. In addition, Heisenberg proposed to use matrix theory for a reinterpretation of the basic mechanics. As a result, he worked with

[8] David Cassidy <http://www.aip.org/history/heisenberg/p05.htm>
[9] David Cassidy <http://www.aip.org/history/heisenberg/p05.htm>

Max Born and Pascual Jordan to develop a mathematical framework for atomic physics based on the matrix model; the model, which was referred to as matrix mechanics, led to accurate predictions that agreed with experimental results in atomic radiation. The publication of the matrix mechanics model had a great influence on Heisenberg's reputation as a theoretical physicist. For the time being Heisenberg continued working with Bohr at the University of Copenhagen and became Bohr's assistant. Both scientists developed a complete model of the atom frame. Besides working as Bohr's assistant Heisenberg was teaching theoretical physics and in October of 1927 was appointed Professor of Theoretical Physics at the University of Leipzig. It was Heisenberg's greatest achievement; he was the youngest German professor at the age of 25. While working at Leipzig Heisenberg kept contact with his friend Pauli, who at the time was working on determining the position of a particle and its momentum. Pauli's theoretical model predicted that if the position of a particle was controlled, its momentum would be uncontrolled. Pauli sent a letter to Heisenberg summarizing his work. Heisenberg took Pauli's theory a step further and discovered what became known as Heisenberg's Uncertainty Principle.

2.2 The Uncertainty Principle

In 1927 Heisenberg formulated the Uncertainty Principle, another aspect of quantum mechanics. Heisenberg stated that it was impossible to determine exactly both the position and momentum of fundamental particles. The principle states that "the more precisely the position is determined, the less precisely the momentum is known in this instant and vice versa."[10] To demonstrate his observation Heisenberg used a thought experiment. He argued that if we attempt to locate the exact position of an electron, we must use the radiation of very short wavelength such as gamma rays. While irradiating with gamma rays, the electron's momentum will be changed. On the other hand, if one uses a lower-energy wave, the momentum of the electron will not be much disturbed but then as lower-energy implies larger wave-length, such radiation will lack the precision to provide the exact location of the electron. The Uncertainty Principle removed absolute determinacy from physics for the first time and replaced them with statistical probability. Einstein and some other scientists were deeply troubled by this development but later it was generally accepted.

Besides the publications that concerned the Uncertainty Principle, Heisenberg submitted other works that involved relativistic quantum field theory. Heisenberg's contribution to physics was recognized by the German Physical Society with the highest award, the Max Planck Medal. In 1932 Heisenberg received the Nobel Prize in Physics for his contribution to quantum mechanics. Studying Heisenberg's work and contribution to physics provides a basis in understanding some of the reasons behind his involvement in the German nuclear research project. It seems that Heisenberg was the ideal leader for the project. As mentioned before, he displayed characteristics of a driven and ambitious individual since he was a child. His love for physics inspired his work and his extraordinary intellectual abilities led to successful results, yet there are other factors that should be considered before reaching a conclusion regarding Heisenberg's role and influence on the outcome of the project.

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[10] David Cassidy <http://www.aip.org/history/heisenberg/p08.htm>

2.3 A Time of War

In October 1927, at the age of 25, Heisenberg became a professor of theoretical physics at the University of Leipzig. Later he was appointed the head of the Institute for Theoretical Physics, which was a subsection of the university's Physics Institute. There Heisenberg was joined by Friedrich Hund and Peter Debye both theoretical physicists. The three men worked together for years. From 1930 to 1935 with Heisenberg as a leading physicist, Leipzig Institute produced major new quantum theories involving solid-state crystals, the structure of molecules, the scattering of radiation by nuclei, and the first neutron-proton model of the nucleus. In order to introduce quantum theory and connect it to the physics theory Heisenberg collaborated with his friend, Pauli and other theoretical physicists elsewhere in Europe. They made enormous strides toward joining together quantum mechanics and the theory of relativity into a relativistic quantum theory of fields such as electromagnetic and material fields. The work of these scientists established the foundations of high-energy physics research since the laboratory accelerators had not yet reached high energies. In other words, the work of physicists focused on the properties of the cosmic rays, which can be viewed as highly energetic particles streaming into the earth's atmosphere from outer space.

In January of 1933 Hitler came to power and a number of Jewish scientists were being dismissed from their positions. A year earlier, in 1932, Heisenberg was awarded the Nobel Prize, a fact that had boosted his reputation and helped him become a leading spokesman for modern physics in Germany.

Heisenberg himself was challenged by representatives of what was being called at the time 'Aryan Physics', due to his opinions regarding his Jewish coworkers and friends. He, among others attempted to oppose internments of Jewish physicists. This initiative got Heisenberg in trouble. By 1937 Heisenberg became subject of an investigation by the SS. Moreover, in an article of the SS newspaper titled "White Jews' in Science" Heisenberg was attacked for his contribution in advocating what was called 'Jewish science'. The article stated, "Heisenberg is only one example of many others … They are all representatives of Judaism in German spiritual life who must all be eliminated just as the Jews themselves."[11] Heisenberg remained under Nazi investigation for a year until SS cleared him of any accusations. Even though Heisenberg was publicly attacked and accused of supporting 'Jewish science' for almost a year and a half, he never thought of leaving Germany. He was not a Nazi himself. However, he thought that being a German; it was his duty to remain in Germany and preserve traditional scientific values developed for the next generation.

In 1939 Enrico Fermi asked Heisenberg why he stayed in Germany. Heisenberg reply was:

> I don't think I have much choice in the matter. I firmly believe that one must be consistent. Every one of us is born into a certain environment very early in life, he will feel most at home and do his best work in that environment. Now history teaches us that sooner or later, every country is shaken by revolutions and wars; and whole populations obviously cannot migrate every time there is a threat of such upheavals. People must learn to prevent catastrophes, not to run away from them. Perhaps we ought even to insist that everyone brave what storms there are in his own country, because in that way we might encourage people to stop the rot before it can spread[12].

Soon after the outbreak of the Second World War on September 01, 1939, Heisenberg was asked to join Germany's nuclear fission research as a part of its war effort. Initially he headed a small research group at Leipzig and at the same time he also visited Berlin

[11] David Cassidy <http://www.aip.org/history/heisenberg/p10.htm>
[12] Werner Heisenberg, <http://www.spartacus.schoolnet.co.uk/GERheisenberg.htm>

to advise a larger group working there on the same project. In 1942 Heisenberg became the head of the fission research group at Kaiser Wilhelm Institute (KWI) for Physics at Berlin. On the development of a nuclear reactor he worked with Otto Hahn, one of the discoverers of nuclear fission. Heisenberg's relocation marked a new era of the nuclear research; he became a key figure in German wartime fission research.

3. Main Body

3.1 Science and the Swastika

> Germany has sunk low indeed when it can found a new journal, *Deutsche Mathematik*, for no other purpose than that of substituting a narrow nationalism for the internationalism that has always ruled mathematics, when it is seriously proposed to change the inscription on one of the buildings of Heidelberg University from "Dem Lebendigen Geist" (To the Living Spirit) to "Dem Deutschen Geist,"…[13]

The essence of what German science and society were undergoing in 1936 is what the above excerpt from a New York Times article of the time conveys. The early years of National Socialism had already left their distinct mark upon Germany's cultural and scientific elite. Here is how Nobel laureate Philipp Lenard dedicates his first volume of "a great work"[14] to Dr. Frick, Minister of the Interior:

> German Physics! one asks. I might rather have said Aryan physics or the Physics of the Nordic Species of Man, the Physics of those who have plumbed the depths of Reality, seekers after truth, the Physics of the very founders of Science. But I shall be answered, "Science is and remains international." It is false. Science, like every other human product, is racial and conditioned by blood.[15]

The Nazi ideology had already extended its roots deep into the minds of the German people. It had started to infect the very heart of the society, its intellectual elite. Yet, there was

[13] German Science Goose-Steps, Pg.285
[14] German Science Goose-Steps, Pg.285
[15] German Science Goose-Steps, Pg.285

a part which still appeared to be healthy, a part which refused to compromise their moral integrity. The article in New York Times continues:

> High as anti- Semitism may run in the universities, Max Planck, Werner Heisenberg and Max von Laue reply to Stark and Lenard. Are theirs perhaps the more authentic voices? Evidently courage is not quite dead in the universities. Yet not since the time of Galileo has science been in such danger.[16]

Germany had a glorious tradition in science and technology long before the Nazis came to power. Fission, one of the most important phenomena in physics was discovered in Germany by Otto Hahn. In the early 1900s Albert Einstein published his theory on special relativity. With their discoveries, scientists such as Heisenberg, Schrödinger, Planck, Einstein and others were not only advancing science, they were revolutionizing our perception of the world. They did not just bring new developments in science and technology; they inspired the minds of generations to come. In this atmosphere where knowledge was shared among many with no boundaries or constraints, a new order was to reshape the world. National Socialism and its racial ideology would introduce something new to science; an issue which had not quite been dealt with until then, ethics and moral integrity.

> We often hear that the Nazis destroyed science and abandoned ethics. That was the view of Telford Taylor in his opening statement at the Nuremberg "Doctor's Trial" of 1946-1947, where he stated that the Nazi doctors had turned Germany "into an infernal combination of a lunatic asylum and a charnel house" where "neither science, nor industry, nor the arts could flourish in such a foul medium"[17]

It would be comforting to believe, that good science travels along with good ethics, but the sad truth seems to be that cruelty can coexist fairly easily with "good science."[18] This may have been what some of the physicians and scientists working under the Nazi regime may have understood at the time. Even if their work was at the service of the wrong politics, it still

[16] German Science Goose-Steps, Pg.285
[17] Proctor, Pg. 335
[18] Proctor, Pg. 335

remained scientifically pure. It should be noted that we are not referring here to research conducted on human subjects by scientists such as Joseph Mengele and Sigmund Rascher. In fact, it can be hard to judge many other scientists and physicians who worked under the Nazi regime. How did they deal with the ethical and moral issues involved with their work? Did they have any moral dilemmas at all? However limiting and unfriendly the Nazi regime and ideology may seem towards science, it did promote certain fields of research which had no financial support at the time.

German science and research suffered a considerable lack of financial support before the war. Heisenberg states that before the uranium project the budgets were extremely low and that they increased rapidly during the war. He also states that the Leipzig Institute of Physics at the University had a total budget for physics and theory of about sixty thousand marks per year. The sum is equivalent to $15,000. His total budget for the theoretical institute including the workshop was $800 a year excluding salaries.

Nazi-era scientists and engineers were pioneers of television, jet-propelled aircraft, guided missiles, electronic computers, the electron microscope and ultracentrifuge, atomic fission, new pesticides. The first magnetic tape recording was of a speech by Hitler and the V-2 emerged from a plan for intercontinental ballistic missiles designed to be able to reach New York City. Professor Robert N. Proctor of Stanford University argues that German cancer research at this time was the most advanced in the world:

> Nazi-era health reformers built on this research base, introducing smoke-free public spaces, bans on carcinogenic food dyes, and new means of controlling dust exposure on factory floors. The period saw extensive work in the area of occupational carcinogenesis, and in 1943, Germany became the first nation

to recognize lung cancer and mesothelioma as compensable occupational illnesses caused by asbestos inhalation.[19]

Large funds were allocated to several research projects during the Nazi era. Capable and devoted scientists who at the time had little or no financial support for their research would have certainly been inclined to accept these funds. Some of them may have compromised their moral integrity by working on government funded research projects which were of particular importance to the German war effort. Such projects included the Uranium research and the V-2 project. In reference to the establishment of the Uranium Club and the competition of scientists to get the scarce materials for their experiments, Heisenberg states: "…for the first time in a decade the government was willing to give money for physics and we were going to make best use of it."[20]

The appreciation of the Nazi support for science can help us understand the appeal that conducting research under the Nazi regime had on German scientists. Can these scientists be held responsible for what their work may have led to? Unfortunately it is difficult to draw a sharp border between science and politics in this case. However, conducting cancer research is much different from conducting research on what could potentially lead to the ultimate Nazi victory over the Allies. Scientists working on the German nuclear research project were anticipating the potential of bringing technology to the next level and at the same time possibly opening one of the darkest chapters in human history. Thus, there were theoretically three options for German scientists during the war: working under the Nazi regime willingly or unwillingly, deliberately refusing to cooperate, or complying while sabotaging their projects. It

[19] Proctor, Pg. 337
[20] Ermenec interview with Heisenberg, Pg. 8

has been claimed for instance, that Wernher von Braun was one of the scientists who sympathized with the Nazis for the sake of his career, self-protection, and rocket money.[21] 10,000 concentration camp prisoners lived and worked under ghastly conditions at Dora, a complex of underground tunnels near Nordhausen. Concerning the facts implicating him with such establishments, von Braun stated that he could have done nothing for the prisoners.[22] Were career, self-protection and money what motivated the scientists of the Uranium Project?

3.2 The Idea

The new age of the atomic fission started in the thirties. It was the contribution of James Chadwick, who discovered the neutron in 1932, the key to atomic fission that led to a new era in science[23]. The attention paid to this discovery did not have a great impact because the news circulated slowly. In 1935, Frederic Joliot-Curie went to Stockholm with his wife, Irene, to receive the Nobel prize for their discovery of artificial radioactivity; there he stated,

> We are justified in reflecting that scientists who can construct and demolish elements at will may also be capable of causing nuclear transformations of an explosive character. […] If the propagation of such transformations in matter can be brought about, in all probability vast quantities of useful energy will be released.[24]

Scientists had not yet understood the significance of this discovery, and even Joliot's prophetic words aroused no more that transitory interest.

It was Leo Szilard, a Hungarian theoretical physicist, who grasped the real meaning of the scientific revelation provided by the discovery of the neutron. In October of 1933, Szilard

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[21] Kevles, Pg. 23
[22] Kevles, Pg. 23
[23] Jungk, Pg. 48
[24] Jungk, Pg. 48

conceptually understood that "a chain reaction might be set up if an element could be found that would emit two neutrons when it swallowed one neutron."[25]

Further work was constantly being done on the subject, but with no great intention of accelerating the process until 1938. The discoveries contributed by Madame Irene Joliot-Curie in her three papers published on radium research and experiments, performed by Otto Hahn and his assistant, Fritz Strassman, led to the great discovery of uranium fission on December 22, 1938. Besides the experiments performed by these scientists, there was a contribution by Lise Meitner, Hahn's close colleague, and Otto Frisch, Meitner's nephew, who formulated the theoretical interpretation of nuclear fission. Based on their description, nuclear fission is the splitting of the nucleus of a uranium atom into other parts when it is bombarded with neutrons. Meitner and Frisch believed that the newly formed particles were not the same element, rather nuclei of barium: the created "nucleus had been fissioned into two large parts by the incoming neutron, releasing kinetic energies of 200 million electron volts (200MeV), thanks to the loss of a small amount of mass that was converted to energy."[26]

Moreover, the lighter elements formed from the uranium would not require as much '"neutron glue"' to hold together their individual nuclei as did the massive uranium atom. Therefore, the surplus of neutrons would be ejected in the fission process, and these would in turn go on to disintegrate further uranium atoms, which would then yield more neutrons. It was this "chain reaction" phenomenon occurring at the atomic level which led scientists to believe that it would be a great opportunity to produce high energy, "whether in a reactor, or in an unrestrained explosion of an immense power." A more formal explanation would be: a

[25] Jungk, Pg. 50
[26] Rose, Pg. 82

uranium-235 (U^{235}) atom absorbs a neutron and fissions into two new atoms (fission fragments), releasing three new neutrons and some binding energy. One of those neutrons is absorbed by an atom of uranium-238 (U^{238}) and does not continue the reaction. Another neutron is simply lost and does not collide with other atoms, also not continuing the reaction. However, the third neutron does collide with an atom of U^{235}, which then fissions and releases two neutrons and some binding energy. Both of those neutrons collide with U^{235} atoms, each of which fissions and releases between one and three neutrons. The latter can then continue the reaction. The phenomenon is known as the neutron multiplication factor; it became a key point for research.

Scientists at an international level started conducting research on their own and publishing their results regarding the neutron multiplication number. For instance, on March of 1939, von Halban and Joliot, who were working in Paris, reported on the rate of neutron production in fission; their results varied from “2.3 to 3.5 neutrons released per fission”, a number which they considered “high enough to maintain a chain reaction.”[27] In addition, the view of Neils Bohr was that fission was due to the isotope U^{235}, which is present in a small proportion in U^{238}, “roughly 1 to 140, virtually the whole of the remainder being composed of U^{238}”. He argued that fission depended on U^{235}, which fissions with slow neutrons, whereas, U^{238}, Bohr believed, had to be treated with fast neutrons with high energy in order to fission. He believed that the best way to achieve a chain reaction was to extract U^{235} and fission it as needed, but the technology at the time limited the large scale production of this element.

[27] Rose, Pg.82

The news of possible atomic energy, which could be used in weapon construction, was delivered to authorities from different scientists. The German army's chemical explosives consultant, Paul Harteck, informed the army about the possibility of nuclear power, followed by Nikolaus Riehl, a former student of Hahn and Meitner, who at the time held a position as an industrial physicist[28]. The reasons for these individuals for attempting to deliver the information about nuclear fission to government authorities ranged from patriotism and nationalism to ambition (including professional and personal).[29] For instance, Harteck's goal was to convince army officials to allocate funds for further research on the subject. If he was successful, it would allow him to use such funds to operate laboratories, which at the time urgently needed support. When asked about his letter to the army in 1967, Harteck responded,

> In those days in Germany we got no support for pure science. [...] So we had to go to an agency where money was to be obtained. I was always realistic about such things. The War Office had the money and so we went to them[30].

Harteck's letter triggered army leaders' interest on the subject. Thus, Army Ordnance (*Heereswaffenamt*) gathered information on nuclear fission and decided to focus on the uranium problem in the summer of 1939. On September 16 of that year, the first meeting was organized in Berlin by Kurt Diebner.

Besides the prospective of exploring the possibilities of the new discovery, scientists were also concerned with the practical applications of nuclear energy. They understood that nuclear energy could be used to build nuclear weapons besides its industrial uses. They feared using nuclear energy for military purposes could be harmful. As mentioned before, Szilard was

[28] Kant, Pg. 3
[29] Kant, Pg. 3
[30] Kant, Pg. 3

the first to realize the dark side of atomic fission. His worries regarding the undiscovered potential of the neutron were not unfounded. Otto Hahn, the founder of atomic fission, feared the worst and hoped that the day would never come when his own work would be used to harm civilization. In this regard Irving states:

> Poor Otto Hahn: […] Six and a half years later, on the evening when he heard for the first time of the use to which the Western Allies had put his discovery at Hiroshima, he confided to his companions in captivity that as soon as he realized the terrible consequences of his discovery back in 1939, he had been unable to sleep for many days; and had even deliberated the possibility of taking his own life.[31]

Further views associated with the use of the discovery of atomic fission were largely expressed in the scientific community at the time.

Paul Langevin, a French professor of physics at the *Collège de France*, who had put a great deal of effort to help refugees from the Third Reich, stated:

> Hitler? It won't be long before he breaks his neck like all other tyrants. I'm much more worried about something else. It is something which, if it gets into the wrong hands, can do the world a good deal more damage than that fool […]. It is something which-unlike him-we shall never be able to get rid of: I mean the neutron.[32]

It is certainly arguable that the work contributed to the discovery of atomic fission and the evolution of science overall was not in any degree meant to harm the human race. The way atomic energy has previously been used is regrettable, and it has left its mark on the path of scientific evolution. The contributions of scientists involved in the atomic research were remarkable, and there should be no regrets concerning the discovery of atomic energy.

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[31] Irving, Pg. 33

[32] Jungk, Pg. 50

3.3 The Club

On September 8th, 1939, Kurt Diebner instructed Erich Bagge to gather a group of nuclear physicists for a meeting with Army Ordnance, which was responsible for German weapons development, logistics and production. The group's task was to research Dr. Fluegge's work on harnessing atomic energy. The team was to consist of up to ten physicists, including Diebner, Bagge, and Fluegge.

On September 16th, 1939, nine scientists met at the *Oberkommando des Heeres*. They were Bothe, Geiger, Hahn, Harteck, Hoffmann, Mattauch, Diebner, Bagge, and Fluegge. The meeting began with greetings by Diebner's superior, the department head Dr. Basche. He explained that the publication of Dr. Fluegge's on the prospective of uranium fission by neutrons had presented the possibility of new sources of energy. It was presently unknown if this possibility was realizable – it would require additional research. The individuals present had been summoned to Berlin to answer this question. There was a war going on and it needed to be known if the answer was 'yes' or 'no.'[33]

The majority of the research and development began in the Kaiser-Wilhelm-Institut für Physik, (KWI). This was also the location of the discovery of nuclear fission by Hahn, Strassmann, and Meitner in 1938. Much of the German research in nuclear physics by the Uranium Club took place under Heisenberg. In 1942, Heisenberg became the head of the KWI. He joined the Uranium Club after being approached by his friend Carl Friedrich von Weizsäcker. von Weizsäcker, a long time associate and friend of Heisenberg, had worked with him on a variety of Physics problems. von Weizsäcker recalls:

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[33] Kleint and Wiemers, Pg. 21

> So I understood [...] that Joliot had indeed found Secondary Neutrons, so many in fact, that a chain reaction would be possible. Every nuclear physicist that heard such a thing would realize that bombs could be created.

von Weizsäcker continues to explain:

> I then went to Heisenberg and suggested that he takes part in the "Uranium Club." He replied: "[…] in such short time, [Hitler] won't be able to build an Atomic Bomb. Therefore, that prospect is unthinkable. Therefore, it would indeed be useful if we could work on it. So we should do it." So Heisenberg joined.[34]

Kurt Diebner was the scientist originally in charge of leading the Uranium Club when it was created by the Army Ordnance in 1939. Otto Hahn, a German chemist, discovered nuclear fission with Lise Meitner and Fritz Strassman in 1938. Hahn was one of the researchers who clearly expressed his disinterest in constructing an atomic bomb by stating: "if Hitler gets an atomic bomb because of my discovery, I'll kill myself!"[35] Paul Harteck was active at the Uranium Club while the Director of the Institute of Physical Chemistry at the University of Hamburg.

The purpose of the Uranium Club was the research and development of possible military applications of nuclear energy. In the forefront of the Army Ordnance's interest was the atomic bomb. In total, there were nine lead scientists active in the Uranium Club. Each of these was the head of a specific department with a group of researchers assigned to them. The leaders of each research group are listed below. The location where each research was conducted is in parenthesis. The corresponding task of the team and the number of scientists involved are listed under each group leader's name:

- Walther Bothe (KWI for Medical Research Heidelberg / Dept. for Physics)
    - Measurements of nuclear constants

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[34] Schaaf, Pg. 120. All quotations in this section were translated by Martin Boeker.
[35] Schaaf, Pg. 121.

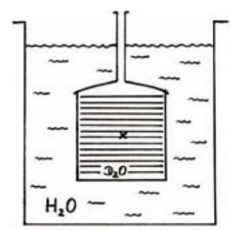
    - 6 physicists
- Klaus Clusius (University of Munich)
    - Isotope separation and heavy water production
    - 4 phys.chemists and physicists
- Kurt Diebner (Army Ordnance Laboratory in Gottow nearby Berlin)
    - Measurements of nuclear constants
    - 6 physicists
- Otto Hahn (KWI for Chemistry Berlin)
    - Transuranic elements, fission products, isotope separation, measurements of nuclear constants
    - 6 chemists and physicists
- Paul Harteck (Univ. of Hamburg)
    - Heavy water production and isotope separation
    - 5 phys.chemists, physicists, chemists
- Werner Heisenberg (Univ. of Leipzig; advisor at the KWI for Physics Berlin)
    - Uranium machines isotope separation, measurements of nuclear constants
    - 7 physicists and physical chemists
- Hans Kopfermann (Univ. of Kiel, later Univ. of Göttingen)
    - Isotope separation
    - 2 physicists
- Nikolaus Riehl (Oranienburg nearby Berlin; Auer Company)
    - Uranium production

- 3 researchers

- Georg Stetter (Univ. of Vienna)
  - Measurements of nuclear constants and transuranic elements
  - 6 physicists and phys.chemists[36]

The scientists conducting research for the Uranium Club had a common underlying task: researching the requirements and feasibility of creating an atomic bomb. Early on, however, many of them felt that such a project was completely unfeasible given the limited resources available from the German military. This led them to focus their attention on other atomic physics projects, primarily the *Uranmaschine* – today referred to as a nuclear reactor.

This illustration on the right is Michael Schaaf's copy of the sketch that Heisenberg and von Weizsäcker showed to Bohr during their meeting in Copenhagen. This design of the *Uranmaschine* was developed at the KWI as part of the Uranium Club project and clearly shows that the research and development did not focus solely on an atomic bomb.



Angebliche Reaktorskizze (x: Neutronenquelle, —— UranMetallplatten) (Skizze: Michael Schaaf).

> On June 4th, 1942, Heisenberg presented a lecture about military significance of atomic energy at the Harnack-Haus in Berlin. […] To a question by Generalfeldmarschall Milch, [Heisenberg] replied that a bomb that could destroy a city the size of London would need to be approximately the size of a pineapple.[37]

Historically, there is no question that Heisenberg's and Döpel's experiments with uranium and heavy water first demonstrated the possibility of releasing nuclear energy through uranium fission. They reported their work in 1942 at Harnackhaus, Berlin-Dahlem, to a board of government officials, generals, admirals, and fellow scientists. Despite the war and the

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[36] Kant, Pg. 19
[37] Schaaf, Pg. 146

restraints it had placed on the Uranium Club, both in terms of liberty to follow desired fields of research and the resources available, there is a question that they were at most a few months away from successfully completing the *Uranmaschine*, the nuclear reactor.[38]

3.4 Exploring Fission

3.4.1 Uranium

The German scientists had not yet reached a definite conclusion after the Berlin meeting of September 16th as to which uranium isotope was the fissionable one. However, it was strongly suspected uranium 235 was the isotope that fissioned with thermal neutrons. The obvious course of action was to separate the uranium isotopes and study their behavior under neutron bombardment.[39] After the second meeting on September 26, the German scientists faced two tasks: developing a process for the large-scale separation of uranium-235 isotope and establishing, by measuring the "effective cross-sections" of all the possible moderator substances, to what extend the slow neutron uranium pile was feasible.

A general program drafted by Diebner and Bagge, dated September 20, 1939, states that Heisenberg was assigned the task of theoretically investigating whether or not a chain reaction in uranium was possible. Bagge was assigned the task of measuring the collision cross section of the heavy hydrogen nucleus. It is important to understand that the larger the cross section of a nucleus, the greater the probability that it will capture a neutron. The result would prove crucial in enabling the scientists to determine whether heavy water had the potential to

[38] Kleint and Wiemers, Pg. 15
[39] Irving, Pg. 46

be a moderator in a uranium pile. Harteck was to continue his attempts to separate the uranium-235 isotope and the building of an apparatus that measures the dependence of neutron multiplication on the design of the uranium pile.

At this crucial starting stage, Army Ordnance had the intention of having all the scientists participating in the project transferred to KWI. This would have enabled all these masterminds to work together in the same facility. Despite the intentions of Army Ordnance announced by Professor Schumann, the idea never came into being.

Early in December of 1939, before the report of December 6th to Army Ordnance, Heisenberg explained to Bagge that if 1.2 tons of uranium and a ton of heavy water were mixed into a paste and enclosed in a sphere of 60 centimeters radius, surrounded by water as a reflector shield, it would stabilize at a temperature of about 800 degrees centigrade. The relevance of this piece of evidence shows that up to December 1939 Heisenberg was not focusing his theoretical and experimental analysis on an atomic bomb, but on a nuclear reactor. In the meantime considerable efforts were made by Harteck and his group in achieving large-scale isotope separation in Hamburg.[40]

Four physical processes for the enrichment of uranium were used in the Manhattan Project: "gaseous diffusion (effusion), electromagnetic separation, liquid thermal diffusion, and centrifugation."[41] The first three were used at Oak Ridge in order to produce enriched uranium for the Hiroshima bomb. Centrifugation was later abandoned since the technology required was not practical for large-scale separations. However, the other three methods were all employed each to a certain extent. "Later, gaseous diffusion alone became the process for

[40] Irving, Pg. 52
[41] < http://www.chemcases.com/nuclear/nc-07.htm> (Dr. Frank Settle)

producing both weapons-grade and reactor-grade U-235."[42] On the other, hand the Germans had by the end of 1941 seven different processes under investigation for enriching uranium-235:

> The mass spectrograph at von Ardenne's laboratory; thermal diffusion; the separation column - a variation of thermal diffusion; "washing out" - the application of Nernst's distribution law, using liquid uranium compounds; Dr. Bagge's isotope sluice; the diffusion of isotopes in carrier metals; and now the ultracentrifuge.[43]

It is clear that the Germans investigated all the methods which the Americans used to produce the atomic bomb except gaseous diffusion. The thermal diffusion process was abandoned by the Germans because it was concluded that no uranium compound was known with which it would work.[44] The gaseous diffusion of uranium hexafluoride through porous barriers was a process originally developed by the German Gustav Hertz, who was not working on the Uranium project due to his Jewish background. However, this possibility seems to have been entirely overlooked by the scientists of the *Uranverein*. On June 1, 1942 the pilot experiments using the ultracentrifuge had proven successful. On June 26, Harteck writes to the War Office:

> As is well known, two methods can be adopted for building a uranium reactor:
>
> *Reactor Type I* consists of natural uranium and about five tons of heavy water;
> *Reactor Type II* consists of uranium metal enriched in uranium- and consequently smaller in quantity, together with smaller quantities of heavy water or even ordinary water.
>
> The German research group has been following the first method, while the Americans will probably have adopted the second. Only experience will show which of the two is the more practical in the long run. In any event, the second method will result in significantly smaller reactor units, which might possibly be usable for driving Army vehicles.
> This latter method is, furthermore, more akin to the manufacture of explosives.[45]

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[42] <http://www.chemcases.com/nuclear/nc-07.htm> (Dr.Frank Settle)
[43] Irving, Pg.101
[44] Irving, Pg.104
[45] Irving, Pg.145-146

From his encouraging results with the ultracentrifuge experiments, Groth had concluded that more energy should be devoted to the second reactor type. From its first run, early in August, the ultracentrifuge was able to produce 3.9 percent enrichment of uranium-235. The values were less then predicted because of contamination as the samples were drawn off. However, Harteck created an improved design which would multiply the effect several times just in one double centrifuge. Heisenberg and his team in Berlin had concluded that a total enrichment of 11 percent would be enough for a reactor using ordinary water. Notice that if heavy water is to be used, less enriched uranium would be needed. In any event, the results meant that a battery of such ultracentrifuges would be needed.[46]

> Reporting on the importance of the ultracentrifuge to Reichsmarschall Göring, Professor Esau predicted that as soon as its development was complete such machines would have to be manufactured in large numbers to meet Germany's requirements of uranium-235.[47]

On June 4, 1942 the scientists of the Uranium project met with Reichsminister Albert Speer and his senior Munitions Ministry officials to decide on the future of nuclear research in Germany. According to Speer's account:

> Heisenberg declared, to be sure, that the scientific solution had already been found and that theoretically nothing stood in the way of building such a bomb. But the technical prerequisites for production would take years to develop, two years at the earliest, even provided that the program was given maximum support.[48]

Speer's account agrees with that of Heisenberg, who explained to Speer in the meeting that progress was impeded by the lack of a German cyclotron. The Americans had several, while the Germans could only rely on Frédéric Joliot-Curie's cyclotron in Paris. In turn, Speer stated that "his ministry could surely build big cyclotrons to match those of the Americans. Heisenberg

[46] Irving, Pg.147
[47] Irving, Pg.147
[48] Powers, Pg.147

objected that the Germans lacked experience in the field and would have to experiment first with a small machine."[49] Heisenberg never mentioned to Speer that a battery of ultracentrifuges may be required for the project. Was he not aware that the ultracentrifuge experiments had proven to be successful 3 days earlier? In any event, he must have certainly been aware of the ongoing of such experiments. Earlier that year Groth's idea had been considered as promising and the blueprints for an ultracentrifuge had been finished since October 22, 1941. It may be possible that Heisenberg believed evidence was not sufficient that centrifuges would be successful. It is also important to emphasize another point. While a cyclotron is crucial in the construction of a nuclear reactor and the production of plutonium, the ultracentrifuges are not. As we stated earlier, the scientists of the Uranium Club had determined that a working nuclear reactor could also be constructed with natural uranium and about five tons of heavy water. Evidence shows that such a fact was familiar to Heisenberg, since he had already been conducting experiments with a pile consisting of natural uranium and heavy water.

3.4.2 Water or Carbon?

One of the fundamental elements in building a nuclear reactor was the moderator. The German scientists soon realized that there were two substances which could potentially have all the right characteristics to be the moderator used in the *Uranmaschine*. One of the substances was graphite (carbon), a very convenient choice since it was abundant and inexpensive. Heavy water, the second substance that could fulfill the requirements of a

[49] Powers, Pg.148

moderator, was much more difficult to produce in large scale. The only industrial establishment that could produce such a substance on a commercial scale was the hydrogen-electrolysis plant of the Norwegian Hydro-Electric company at Vemork, near Rjukan in southern Norway.[50] In order to convey an idea of how much of a limited resource heavy water was at the time, it would be enough to state the fact that between the end of 1934 and 1938 the Vemork plant had produced only forty kilograms. By late 1939 the plant produced only ten kilograms per month, while the Germans needed one hundred kilograms per month.

In June 1940, Professor Bothe in Heidelberg measured the diffusion length of thermal neutrons in graphite. The measurement of the same constant for heavy water was done later that summer by Heisenberg, Döpel, and his wife at their laboratory in Leipzig. The neutron absorption coefficients were to be obtained for both graphite and heavy water. These experiments were absolutely necessary for the scientists to determine which substance was to be used as a moderator for their nuclear pile. If the neutron absorption coefficient of the moderator was too high the chain reaction would not be able to occur since the moderator would absorb more neutrons than it would usefully slow down, resulting in a weak short lived chain reaction.

In 1967, Heisenberg claimed that Boethe's experiment on graphite was not correct – his values of the neutron absorption coefficient were too high, which was a result of his failure to recognize the presence of nitrogen in the graphite pile on which the experiments were conducted. Heisenberg states, "In between the graphite pieces there was always some air and

[50] Schaaf, Pg. 95

the nitrogen of the air has high neutron absorption."[51] At the time, the scientists had no knowledge of the flaw in Boethe's experiment, thus they assumed the data provided by him to be correct. As for the reason why Boethe made the mistake, Heisenberg offers no explanation. He does, however, feel that Boethe making such a mistake is understandable. Thus, the carbon line was ruled out by Bothe's experiment and heavy water was chosen as the moderator.

During January 1940, there was every indication that "given sufficient heavy water a chain reaction could be induced in a pile using ordinary uranium." In December 1940, Professor Heisenberg, von Weizsäcker, Wirtz and two other physicists began to build their first uranium pile in what was called the Virus House. The laboratory was situated in a wooden barracks near the Institute of Physics, in the grounds of the institute of Biology and Virus Research. The first nuclear pile experiment that Heisenberg and his team conducted in the Virus House consisted of a domed aluminum cylinder standing upright and packed with thick layers of uranium oxide, separated by thin layers of paraffin wax as moderator.[52]

Up to this point the German scientists had not yet been able to separate the uranium-235 isotope. From the first two experiments conducted at the Virus House, Heisenberg had concluded that a uranium pile could not be built using light water or paraffin. However, he had suggested that heavy water might make a uranium pile possible. The situation seemed favorable, considering that the Germans had controlled the Vemork hydrogen plant since May 3, 1940. Unfortunately for the German scientists no heavy water was found in the plant since all 185 kg in stock had been evacuated to France a few weeks prior to German invasion.

[51] Interview, Ermenec

[52] Irving, Pg. 80

Meanwhile, Norwegian-Hydro had volunteered to increase its heavy water production up to 1.5 tons per year, after the appropriate expansion of their electrolysis plant was completed. [53]

At this point Army Ordnance on its own initiative decided that experiments were to be conducted using uranium metal. By the end of 1940 the German nuclear scientists had made no suggestion concerning this approach. The uranium metal production in Germany had a maximum output of one ton per month. In America almost no uranium metal was available until the end of 1942, an indication of how far ahead the German effort was compared to the Americans at the end of 1940.

While the crucial calculations for developing a working nuclear pile concerned heavy water and ordinary uranium, there was one calculation in particular which would prove fundamental in establishing the feasibility of an atom bomb. The critical mass calculation would determine the minimal amount of fissionable uranium needed in order for a nuclear explosion to take place.

3.4.3. The Calculation

Winston Churchill, with the help of his personal scientific advisor Professor F. A. Lindermann, wrote to the Secretary of State for Air a letter where he suggested there were several reasons why the rumors of a new secret Nazi explosive were without any foundation. One of these reasons was that "the chain process (chain reaction) can take place only if the uranium is concentrated in a large mass."[54] Therefore, according to Churchill, Britain need not worry about researching the matter, since such a 'large mass' of uranium is virtually impossible

[53] Irving, Pg. 66
[54] Irving, Pg. 38

to obtain. Fortunately enough for him and our civilization, the British science community did not share his thoughts on the matter. As one can easily understand from the previous example, the critical mass value had a misleading power which could ultimately prove defining, in the decision of building an atomic bomb.

In his 1939 report, Heisenberg made a calculation resulting in the correct critical mass value for enriched natural uranium fuel. What is remarkable is that he did not take the next step. He did not study the case of pure uranium-235 and ask how much was needed to make a fast fission bomb. Another interesting fact is Heisenberg's claim that "he never studied the critical mass question because he did not see how to separate significant quantities of this isotope."[55]

As mentioned before, isotope separation was already under serious investigation. Harteck was particularly involved in the task of uranium isotope separation. In order to accomplish this crucial task, several different approaches were considered, the main one being the Clusius-Dickel process. In early 1940, almost nothing would have suggested that uranium-235 isotope separation in large scale was utterly impossible. Thus, there could not be any technical reason that would lead to neglecting a critical mass calculation for pure uranium-235. However, it has been suggested that Heisenberg deliberately manipulated the mathematics in order to provide an overestimation of the critical mass, in such a way that would make an atomic bomb appear virtually impossible. At the secret conference of June 4, 1942 General Erhard Milch asked Heisenberg: '"How big must a bomb be in order to reduce a large city like

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[55] Bernstein, Pg 913

London to ruins?"'[56] Heisenberg replied '"About as big as a pineapple."'[57] It is hard to determine what critical mass value Heisenberg was thinking of when he made this statement. If Heisenberg was indeed referring to the size of the uranim-235 core of a bomb, a simple calculation would yield the mass of uranium to be anywhere between 10 kg and 40 kg. Due to the large density of uranium, even a small increase in its radius would yield a considerably greater mass.

During the war years, work on atomic energy was also being conducted at the Berlin-Lichterfelde laboratory of Baron Manfred von Ardenne. Professor Fritz Houtermans began work at von Ardenne's laboratory on January 1, 1941. His first task was to investigate the cost efficiency of the isotope-separation methods. Houtermans completed a 39 page report eight months later on the question of unleashing chain reactions. In this report " he surveyed the whole theory of the project so far, and for the first time made explicit calculations on fast neutron chain reactions and the critical mass of uranium-235 – i.e., the mass which, when assembled, would result in a spontaneous fast-neutron chain reaction and a violent explosion."[58]

At a lecture in 1943 Heisenberg used a diagram which schematically illustrated the fast-neutron process inside a mass of uranium-235, and he improved on Houtermans's criticality theory on the basis of 1943 fast-neutron fission cross-section measurements of uranium-235 made by the Viennese physicists Jentschke and Lintner. However, Houtermans's report concentrated primarily on the importance of the plutonium alternative. These facts are

[56] Powers, Pg.148
[57] Powers, Pg.148
[58] Irving, Pg. 92

extremely important since various historians have stated that the Germans did not investigate the critical size of a mass of uranium-235, or elaborate on the importance of fast-neutron chain reactions. [59] The German scientists were clearly thinking about both these problems. Apparently, explicit calculations had also been made concerning the critical mass of uranium-235. However, did Heisenberg himself ever make any such calculations? It is clear that he had knowledge of the research conducted upon the critical mass issue as he apparently improved on Houtermans's criticality theory.

Jeremy Bernstein goes further and states that Heisenberg did in fact make very similar calculations before Houtermans. In his 1939 paper Heisenberg asked a question:

> Suppose that one enriched the natural uranium fuel, which is over ninety-nine percent U(238), by replacing some of the U(238) by U(235). What would happen? Why exactly he wanted to know the answer is not entirely clear. It has been suggested that he was investigating a reactor bomb. It is very likely that he was thinking in terms of this replacement to reduce the amount of uranium that is needed to make a critical reactor and was concerned about a possible explosion.[60]

However, Heisenberg did arrive at the correct value for the critical radius of enriched uranium fuel. "What is remarkable is that he did not take the next step."[61] Heisenberg did not calculate how much U_{235} would be needed to make a fast fission bomb. It is important to constantly keep under consideration the chronology of events. From the report which Professor Bernstein refers to, it can be understood that up to late 1939 Heisenberg indeed did not make explicit calculations on the critical radius of a U_{235} mass, but he had in fact made a very similar calculation for enriched uranium fuel.

[59] Irving, Pg. 92
[60] Bernstein , Pg. 914
[61] Bernstein, Pg. 915

By 1943 Heisenberg was extremely familiar with reports of several researches done on this issue, Houtermans's paper being one of them. He had also apparently improved on his colleagues' theory. What is also striking is an event which Irving appears to place somewhere in mid 1940 and which shows how much Heisenberg knew about the critical mass of uranium-235 needed.

> In personal exchanges between the Dahlem laboratories and his own laboratory in Lichterfelde, von Ardenne had asked both Hahn and Heisenberg outright how much pure uranium-235 was necessary for an atomic explosion. He was told it would be only a few kilograms. "During these discussions," von Ardenne describes, "I expressed an opinion that it was technically quite feasible, by means of high-yield electromagnetic mass-separators (which we had already in our drawing boards) to make quantities of a few kilograms of uranium-235 available, if only the Reich government would resolve to direct the talents of the big electrical combines to that end.[62]

This view von Ardenne had presented to Minister Ohnesorge of the Post Office, who did not hesitate to secure an audience with Adolf Hitler soon after his discussions with von Ardenne. He informed Hitler about the uranium bomb but, the Führer, who had other preoccupations in late 1940, had no time or will to devote to the newly presented idea. Hitler's reaction seems to be very consistent with the unsupportive attitude of the Nazi government towards science, an attitude which Heisenberg recalls in his interview with Ermenec: "The government had the idea that science in general, and physics especially, was not interesting or important and should not be publicized."[63] Interestingly enough, von Weizsäcker visited von Ardenne's laboratory on October 10, and very emphatically declared that he and Heisenberg believed atomic bombs were not feasible for a technical reason: as the effective cross-section of uranium would decrease with rising temperature, the chain reaction would prematurely shut down. In this regard, von Ardenne had no alternative but to believe him and for the rest of the year he

[62] Irving, Pg. 77
[63] Ermenec, Pg. 4

concentrated on stressing to his Minister the importance of constructing atom smashing installations in Germany. The last two excerpts clearly show that in 1940 Heisenberg and Hahn where at least aware of the order of magnitude of the critical mass needed to build a bomb using U_{235}. Why did von Weizsäcker visit von Ardenne on October 10, 1941? The Reich's Post Office Ministry had agreed to fund von Ardenne's laboratory. As Heisenberg later recalls, he and a few other scientists working on the atomic project felt von Ardenne had too many government connections and that Heisenberg's circle of scientists did not want to publicize the possibility of a feasible atomic bomb. Thus, they decided to keep him from conducting any research in atomic bombs. However, historians still remain skeptical about Heisenberg's later statement.

In 1970, almost thirty years after von Weizsäcker's visit to von Ardenne, Heisenberg sends a letter to his American editor Ruth Nanda Anshen. He had offered to review one of Anshen's books, *Science: The Center of Culture* by I. I. Rabi, but he warned her he would vigorously protest Rabi's views on the German bomb program. Anshen discussed the issue with Rabi and wrote Heisenberg that Rabi would regret public argument on this issue; Heisenberg never wrote the review. Powers states,

> In her book, *Biography of an Idea* (Moyer Bell, 1986), 170 ff., Anshen refers to this episode and says Heisenberg wrote her a letter which he concluded by saying , "Dr. Hahn, Dr. von Laue, and I falsified the mathematics in order to avoid development of the atom bomb by German science." However, nothing like that is to be found in the copies of Heisenberg's letters to Anshen in Heisenberg's archives, and Anshen has declined to make her own copy available.[64]

[64] Powers , Pg. 116, 507

According to Powers, Ashen knew Heisenberg very well. She had published two of his books in English. If Anshen's testimony was to be confirmed as true, then what exactly does 'falsifying the math' mean? Was Heisenberg alluding to the critical mass calculations? Hence, was von Weizsäcker's meeting with von Ardenne the result of such a manipulation as an attempt to conceal the secret of the real possibilities in building a nuclear bomb? Maybe Heisenberg and his circle were simply trying to avoid competition for funds and resources with von Ardenne. Such a case may very well be true. However, if the original critical mass estimate were to be made public to other German scientists, the information would have most probably been picked up by the German government. Such a situation might have triggered more direct action from Nazi officials. A critical mass of a few kilograms in estimate would have suddenly implied for the Nazi officials that an atomic bomb was within reach. A quick mobilization of the whole science community would have probably occurred under the direct pressure from the Reich and there would most likely be no room for competition. The most probable course of action for the Nazi government would have been to unite all the research projects into one effort and the scientists in the Uranium Club must have certainly realized that taking such a risk would have given them no other choice but to build the bomb. It should be noted that the German effort was at the stage of research throughout the war. There was never a real attempt to construct an atomic bomb. Such an attempt would have involved hundreds of thousands of manpower.

In any event the evidence above shows that Heisenberg together with a few other scientists believed at least by October 1940 that only a few kilograms of uranium-235 were needed for an atomic explosion. His statement of 1940 is confirmed by both von Ardenne's memoirs and Heisenberg's accounts. Heisenberg's son, Professor Jochen Heisenberg of the

University of New Hampshire at Durham, claimed that in a scientific report dated February 1942 titled, *Energiegewinnung aus Uran* the estimate of the critical mass of a uranium-235 bomb ranged between 10 and 100 kilograms. On that same occasion, an interview conducted by the IQP team, Professor Jochen Heisenberg also claimed that his father was one of the authors of that report. This fact was impossible for our team to verify since the evidence in the copy of the original document did not suggest beyond reasonable doubt that Heisenberg was indeed one of the authors of the report. However, Werner Heisenberg's name appears on a list of professors and references titled, *Verzeichnis der Geheimberichte,* (Listing of the Confidential Reports) on page 136. Reference in the report is made to a portion of Heisenberg's 1939 paper *Über die Möglichkeit der Energieerzeugung mit Hilfe des Isotopes 238*. If Professor Jochen Heisenberg's statement concerning his father's co-authorship of the 1942 report is correct then there is no question that Heisenberg had by February 1942 made explicit calculations concerning the critical mass issue. Despite the question whether Heisenberg had made these calculation, it is clear from the report that at least some of the scientists had clearly done so. The estimate mentioned above does come fairly close to the correct value which was in the order of a few kilograms of uranium-235. In fact Rudolph Peierls, a Jewish physicist working in Great Britain at the time and Heisenberg's former student back in Leipzig, had reported that the critical mass value for uranium-235 would probably be eight kilograms or less.

Asked whether Heisenberg deliberately manipulated the calculations in order to keep the Nazis from producing a nuclear bomb, Professor Jochen Heisenberg responded that his father did not have to take such an action since the estimate he gave in the 1942 report was fairly accurate given the stage at which the research was in. He believes that his father's situation was a fortunate one since the information he provided was an accurate estimate and it was exactly what was needed to deter the development of an atomic bomb. In response to a question about a possible mistake in his father's wartime estimates of the critical mass of U_{235}, he emphasized the preliminary nature of the calculations and stressed again that his father produced a reasonable early stage estimate of the critical mass being between 10 and 100 kg. This result was accurate enough for Werner Heisenberg and he thought that a more precise calculation would only be necessary if the government made the final decision to actually initiate the construction of an atomic bomb. Interestingly enough Jochen Heisenberg seems to be not the only one supporting the perspective that the value of 10 to 100 kg was a reasonable early stage estimate for the critical mass of uranium-235. The limits of the possible range of this value were set even wider in America. On November 6, 1941 the U.S. National Academy of Sciences committee reported this verdict: "[…] the mass of uranium-235 required to produce explosive fission under appropriate conditions can hardly be less than 2 kg., nor greater than 100 kg." [65]

3.4.4. The Possibility

Even before the conference of nuclear physicists at the Army Ordinance on September 26, 1939, Heisenberg had been clear concerning the two possibilities of "extracting energy from the uranium nucleus."[66] This could either happen in controlled amounts in some kind of uranium furnace or in an explosion. The first option would involve mixing uranium with a

[65] Irving, Pg.111
[66] Irving, Pg. 47

substance capable of slowing down the fast neutrons emitted during fission. The second alternative would involve the use of the uranium-235 isotope, which was felt to be the isotope that fissioned with thermal neutrons. After that meeting Heisenberg must have certainly been under the impression that heavy water was at the very least a potential candidate for a nuclear pile moderator. Such a conclusion can certainly be deducted from the fact that one of the main tasks assigned after the September 26 meeting was measuring the collision cross section of the heavy hydrogen nucleus. Thus, Heisenberg, by the end of 1939 – beginning of 1940 had a fairly clear picture of where the German project could potentially lead both scientifically and economically.

Up to June 1940 Germany had been able to benefit from the results of physical investigations published in American scientific periodicals, which were vital to a uranium bomb project.

> Thanks to notes published in the American *Physical Review* during March and April 1940, it was now known to Germany that there was experimental proof that slow neutrons actually had greater probability of fissioning uranium-235, and that neutrons of certain energy were very likely to be captured by uranium-238, producing uranium-239.[67]

The new element, Number 94 (uranium-239), was named plutonium and was determined to be fissionable like uranium-235. In July of that same year, before the previous month's edition of the American Physical review got to him, von Weizsäcker, the theoretical physicist, had reached theoretically much the same conclusion as the Americans. His theory was wrong in one detail: he believed that the decay process would stop at element Number 93 (neptunium). He attributed the fissionable and explosive characteristics to this element. At the

[67] Irving, Pg.73

end of 1940 Viennese physicists F. Hernegger and J. Schintlmeister reported the identification of plutonium. In the meantime von Weizsäcker had presented a five-page report to the War Office '"on the possibility of extracting energy from uranium-238."'[68] In this report he mentioned the potential use of this new element as an explosive. In any event, it can clearly be understood that by the end of 1940 the Germans knew that a new element just as fissionable as uranium-235 could be produced from a reactor and that this element could also be used in producing an explosive.

The new discovery contributed in pushing the German scientists to focus on the design of a reactor. The construction of such a machine would make possible the production of another fissionable element, for which evidence showed it was chemically different from uranium-235. Such a property meant that "the new element could be separated by relatively simple chemical means."[69] The success in constructing a working nuclear reactor would imply a very high probability of success in the construction of a bomb. Therefore, focusing on the reactor research would be a more convenient option given the risks and the available resources. Evidence suggests that scientists were aware of the extremely high costs that a full scale nuclear project would result in. This was certainly true in 1941:

> On September 11 (1941), Bagge was called before Professor Schumann, chief of military research, in Berlin: "Conference, together with Dr. Basche," wrote Bagge in his diary. "The whole thing like an interrogation with an apparently favorable outcome." It was probably on this occasion that he learned the reason for this continuing interest in uranium-isotope separation. He overheard Diebner and Basche discussing the mounting cost of the whole project: how could they subscribe to the continued tying down of manpower and money on isotope separation if, as seemed so likely, a uranium reactor could be designed to run with natural uranium, with heavy water as moderator? Diebner replied at once that even

[68] Irving, Pg.74
[69] Irving, Pg.74

> if the separation of uranium-235 was not vital for reactor purposes, it was necessary for its exploitation as an explosive. It was Bagge's first introduction to this possibility.[70]

Despite the new possibilities that the uranium research was offering, the question of limited resources and manpower seemed to have been a matter of concern for the German scientists.

3.5 The Man Behind the Scientist

3.5.1 The Wednesday Society

The German resistance had existed in several forms throughout the war. One of the shapes in which this movement manifested itself was the secret societies or clubs which were formed by select members of the society's elite. Some of the high ranking officials associated with the German resistance were Ernst von Weizsäcker of the Foreign Office, the father of Heisenberg's friend, Admiral Wilhelm Canaris, leaders of the Christian resistance in the Kreisau Circle and a group of military conspirators.[71] Heisenberg was clearly affiliated with such circles. He was a member of the *Mittwochsgesellschaft* (Wednesday Society), which was a small but venerable discussion group.

> The Wednesday Society selected its members from among the leaders of Berlin's cultural, academic, administrative, and military life. The group met every several weeks (on a Wednesday, naturally) in the home of one of its members. …the Wednesday Society also served during the Third Reich as a meeting place for many members of the conservative Prussian military and professional opposition to Hitler and as a breeding ground for the hapless conspirators of the failed coup d'état of July 20, 1944. Members were chosen for their sympathy with the views of the non-Nazi German and Prussian cultural elite, which though patriotic and nationalistic,

[70] Irving, Pg. 99
[71] Powers, Pg. 340

insisted on moral rectitude. Heisenberg, whose sentiments harmonized to an extent with the members of the society… attended his first meeting as a member in December 1942.[72]

According to the published records of the Wednesday Society, Heisenberg attended most of its meetings and hosted two of them, including its last, on July 12, 1944. "Among the most enjoyable aspects of my life in Berlin were the meetings of the so-called Wednesday Society," recalls Heisenberg.[73]

Heisenberg traveled frequently between Berlin and Hechingen throughout 1944, while stopping several times in Urfeld to visit his family. By this time part of the atomic project had been relocated to Hechingen, a small town in southern Germany. Meanwhile reactor experiments and research was still being conducted inside a bunker in Berlin-Dahlem by Heisenberg's close friend Karl Wirtz and a few other scientists. It was not until late 1944 that Wirtz and his research moved to Heigerloch. During one of his visits in Berlin, early in the summer of 1944, Heisenberg received what proved to be an interesting visitor; an old friend of his from the *Wandervogel* (German Youth Movement) days of his youth, Adolf Reichwein, a sociologist and a political scientist. Reichwein led a very politically active life. "He had belonged to the political wing of the Youth Movement that felt close to the socialist and the pedagogical movement early on."[74] He had fought in the Spanish Civil War and had an important role as a Social Democrat in the underground resistance.[75] Heisenberg's old friend asked him "point-blank if he would be willing to participate in a conspiracy against Hitler. Heisenberg was horrified by Reichwein's careless indiscretion – he spoke in a loud voice and without any

[72] Cassidy, Pg. 441
[73] Heisenberg, Pg. 184
[74] E. Heisenberg, Pg. 99
[75] Powers, Pg. 339

concern – he said to himself that if the enemy was being underestimated to this degree the whole enterprise had to fail."[76] Heisenberg refused to participate. He warned Reichwein and advised him to practice caution if he wanted to achieve his objective.[77] One or two weeks after the visit, on June 22 Heisenberg's friend and Julius Leber, one of the conspirators, attended a clandestine meeting with three members of the Communist underground. One of them was an agent of the Gestapo. On July 4 Reichwein was arrested.[78] Heisenberg talked to his wife, Elisabeth, about this event in great agitation.

On June 14, 1944 Heisenberg attended his first meeting in eight months. The work at Hechingen had probably kept him busy during that time. The atmosphere in the circle was somewhat depressed. On June 28 Heisenberg was again present. It seemed that something was decided and that word about the assassination plot had been circulating within the Wednesday Society.[79] Did Heisenberg have any knowledge about such a plot?

Elisabeth Heisenberg writes that "in the winter of '43-'44"[80] he was asked to stop by the house of Johannes Popitz, who lived close to Elisabeth's parents. Popitz was a member of the Wednesday Society and finance minister of the Prussian state.

> During his visit, Heisenberg learned that a large coup was planned, and that thought was being given to the matter of how Germany should be better organized thereafter, when the Nazi regime had been removed and the war had ended through capitulation. Since Heisenberg himself constantly thought about this kind of question, an exceptionally fruitful and intensive discussion took place, creating a very trusting, albeit short, friendship.[81]

[76] E. Heisenberg, Pg. 99
[77] E. Heisenberg, Pg. 99
[78] Powers, Pg. 340
[79] Powers, Pg. 342
[80] E. Heisenberg , Pg. 100
[81] E. Heisenberg , Pg. 100

The accuracy of this statement further implicates Heisenberg in the anti-Nazi movement that was present in Germany during the war years. Another piece of evidence seems to support the validity of Elisabeth Heisenberg's account.

The widow of Wolfgang Schadewaldt, a member later executed, said she overheard Heisenberg, Hassell and Ferdinand Sauerbruch talking politics after one meeting in March 1943: "Heisenberg, in somewhat subdued terms, and, Sauerbruch, in his spirited manner, grumbled about 'Schimpanski,' that was the code name for Hitler."[82] Thus, it seems reasonable to assume that Heisenberg had knowledge concerning a possible assassination attempt to Adolf Hitler and of a potential plan to assume control of the German government by anti-Nazi exponents. Whether he knew how close was the resistance to assassinating Hitler this is impossible to determine at this stage.

If Heisenberg, by the summer of 1943, had knowledge about a *coupe d'état* plan, this would bring his actions on the *Uranprojekt* under a different light. Would such a situation have led him into joining the conspiracy against the Nazis? Would he have acted in his own field of expertise to sabotage the regime as the rest of 'The Society' was planning? It might have certainly been so, but Elisabeth Heisenberg has a different view on the matter. Referring to Reichwein's offer to her husband in the summer of 1944 she writes: "Heisenberg was not a revolutionary, and in addition, he considered the time much too late for a revolutionary action."[83] Based on the facts stated above Heisenberg may very well have known about a possible *coup d'état* since March, 1943. However, the most critical events for the *Uranprojekt* were taking place in the summer of 1942, when Heisenberg was beginning to distinguish signs

[82] Cassidy, Pg. 460
[83] E. Heisenberg, Pg. 99

of insecurity and instability in the future of the Third Reich. On June 4, after the most crucial secret conference of the atomic project with Reichsminister Speer and his senior Munitions Ministry officials, Heisenberg had a conversation with Speer. Heisenberg asked Speer how he thought the war would end, "The Minister turned and looked blankly without uttering a word. The professor found it an eloquent silence."[84] Interestingly enough Heisenberg was a member of the Wednesday Society at least since October 28, 1942. The events of 1942 must have played a key role in his decisions to follow. However, Heisenberg was certainly discussing his research and the potential it possessed with the members of 'The Society'. Heisenberg was the host of the Wednesday Society meeting on July 12, the last before Stauffenberg's effort to assassinate Hitler with a bomb. He had a talk titled "What Are the Stars?", but his real subject had been nuclear fission.[85] It is reasonable that Heisenberg could have thought such a topic would be of interest to the members of the society. However, considering the extremely high risks involved in disclosing military secrets to unauthorized individuals, there must have been a stronger reason for him in doing so. It had been clear to many intellectuals in German society that the morality of the Nazi regime was highly questionable at best. Highly esteemed officials such as General Beck, one of the most active members of the Wednesday Society, had disapproved Nazi politics since Hitler's invasion of Czecoslovakia. If Heisenberg was contemplating a possible sabotage of the German nuclear project, the support of the members would have certainly been a good reason for disclosing military secrets.

[84] Irving, Pg. 121
[85] Powers, Pg. 343

3.5.2 Copenhagen

From September 1941 the German scientists saw an open road ahead of them leading to the atomic bomb. They knew that the research was on the right track and they could sense success.[86] The L-III experiment performed in Leipzig by Heisenberg and Döpel during the summer of 1941 was one of the main events which triggered a special optimism within the scientists of the *Uranverein* (Uranium Club). This experiment involved 142 kilograms of uranium oxide enclosed in an aluminum sphere 75 centimeters in diameter. The results showed that there had been a positive neutron production of about 100/sec.[87] Thus, Heisenberg's relative weakness in experimental physics did not prove to be determinant in the outcome of the German Uranium Project. Heisenberg's other successful experiment, L-IV, proved without doubt that there were more neutrons escaping the pile's surface than were being injected at the neutron's source at its center. The result meant that expanding the pile would enable the German scientists to build the first chain-reacting pile in the world. In August 1941, von Ardenne circulated Houtermans's paper, *On Triggering a Nuclear Chain Reaction*. Among others many leading physicists throughout Germany, including Heisenberg, von Weizsäcker, Harteck and Bothe received copies of this report.[88] The circulation of Houtermans's document meant that the possibility of atom bombs was now entering the realm of common knowledge.

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[86] Irving, Pg. 102
[87] Irving, Pg. 102
[88] Powers, Pg. 112

After the latest events Heisenberg and von Weizsäcker had a conversation in 1941[89] concerning the development of nuclear weapons in the United States and Germany. It was in this conversation that the idea to visit Niels Bohr in Copenhagen appears to have originally been suggested to Heisenberg by von Weizsäcker. Heisenberg believed that in light of such new and exciting possibilities concerning the use of nuclear energy for military purposes, it might be extremely difficult to keep the U.S. government from conducting a nuclear weapons project. On the other hand, the tremendous aftermath that the employment of such weapons could produce might very well restrain them from their efforts.[90] Thus, Heisenberg began to seriously consider a visit to his old friend Bohr with whom he had closely worked in his institute in Copenhagen years ago to get his advice about how to proceed. It appears the two scientists were looking for the opinion and guidance of a trusted friend and an experienced physicist on what was the right course of action to take at this stage. It is important to understand that Heisenberg was not alone in his moral dilemma."[91]

> According to Paul Rosbaud, a number of German scientists "who kept their moral integrity all during the Nazi regime and the war" compiled a list of those who deliberately restricted themselves to basic research and sent copies of it to A. Westgren in Sweden and W. G. Burgers in Holland after the war began. The signers had no practical aim in mind, but only wanted to register the fact that conscience was not dead in the German scientific community. Jensen and Houtermans also spoke of "moral absolution" as one goal of the decision to discuss these matters with Bohr[92].

Powers states that he was not able to find the list; therefore it is impossible for us to determine whether Heisenberg was part of this group.

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[89]The source does not specify exactly when, but it seems acceptable to assume mid 1941.

[90] Powers, Pg. 113

[91] David Cassidy < http://www.aip.org/pt/vol-53/iss-7/p28.html>

[92] Powers, Pg. 115

Earlier in April 1940, after the German invasion of Denmark, Heisenberg and von Weizsäcker had discussed the issue of protecting Bohr. Heisenberg and von Weizsäcker knew that Bohr was in grave danger at the time. The well known scientist was half Jewish and many Jews worked in his institute. Bohr also refused to establish any sort of cooperation with the Nazis.[93] Jochen Heisenberg states that his father and von Weizsäcker had ensured Bohr's protection through von Weizsäcker's father, Ernst, who had been the German ambassador to Denmark during the 1920s and was vice minister of the Reich's Foreign Office.[94] One of the questions that came up in the 1947 trial of Ernst von Weizsäcker in Nuremberg was whether he protected Bohr during the war. Heisenberg and the younger von Weizsäcker testified in his defense.[95]

However there had not been any communication between Bohr and Heisenberg in nearly a year after the occupation of Denmark. They had already quarreled once about Heisenberg's refusal to leave Germany.[96] Considering what had happened up to that time it would be an extremely delicate matter to approach Bohr. Heisenberg must have realized this fact even before taking the trip to Copenhagen. On August 14, 1941 von Weizsäcker wrote a very elaborate courtesy letter to Bohr informing him of the trip himself and Heisenberg were to take in September of the same year. The two scientists would be attending a seminar on astrophysics at the Deutsches Wissenschaftliches Institute between September 18 and 24.

> On the evening of Sunday, September 14, Heisenberg boarded the overnight train from Berlin to Copenhagen. He arrived at 6:15 on Monday evening and took a room at the Turisthotellet. His formal

[93] Powers, Pg. 114
[94] Interview with Jochen Heisenberg
[95] Cassidy, Pg. 439
[96] Powers, Pg. 111

lecture on high energy physics did not take place at the Deutsches Wissenschaftliches Institut until Friday evening, September 19.[97]

Heisenberg went to Bohr's institute on Blegdamsvej for lunch several times that week. On one of these occasions Heisenberg had stressed the importance of Germany winning the war. He stated that the occupation of Denmark, Norway, Belgium and Holland was a sad thing, but regarded the invasion of East Europe as a good development since according to him these countries could not govern themselves.[98] Niels Bohr was not present at the moment Heisenberg made these statements. He did, however, learn of them before his famous meeting with Heisenberg. The two physicists met several times during that week and one evening Bohr invited him for dinner. The Danish physicist found it hard to decide where the dinner was going to take place. He had to deal not only with his objections to Heisenberg's visit, but also with those his wife had concerning the dinner taking place in their house. "His assistant Aage Petersen suggested that Bohr should write down his objections to Heisenberg's visit, then read them carefully a day or two later, and decide."[99] The evidence suggests that Bohr did indeed have strong feelings about Heisenberg's visit in Copenhagen. However, the dinner did take place in his house. The old scientist had to make a compromise with his wife that the discussions would not involve politics.

After dinner, Heisenberg invited Bohr to take a walk outside. Indeed, it is here that the disagreements among several reports start. In his accounts Heisenberg claims that the crucial conversation took place "during a nocturnal walk in Pilealle."[100] In a letter to Robert Jungk

[97] Powers, Pg. 121
[98] Powers, Pg. 121
[99] Powers, Pg. 122
[100] Heisenberg, Pg. 201

dated January 18, 1957 Heisenberg states that he thought they walked in “a district near Ny-Carlsberg.”[101] On the other hand, Bohr claims that the meeting took place in his office.

> I also remember quite clearly our conversation in my room at the Institute, where in vague terms you spoke in a manner that could only give me the firm impression that, under your leadership, everything was being done in Germany to develop atomic weapons and that you said that there was no need to talk about details since you were completely familiar with them and had spent the past two years working more or less exclusively on such preparations.[102]

Abraham Pais supports the view that the conversation took place in Bohr’s study[103]. It is highly improbable that Heisenberg would choose Bohr’s office if he had previously established what he was going to tell Bohr. Heisenberg must have realized that Bohr’s office could have been under the surveillance of the German secret police. The controversy on what exactly was said in the meeting of September 1941 has not been cleared even by Bohr’s recently published letters which were never sent to Heisenberg. Bohr’s point of view is not as well documented as that of Heisenberg’s, partly due to the fact that Bohr never said or wrote anything publicly concerning his discussion with Heisenberg in 1941. Early in their conversation Heisenberg presented to Bohr his view concerning the war. He said that Germany would defeat Russia and that it would be a good thing.[104] Such a statement did not constitute a delicate approach, especially considering the fact that Bohr knew about Heisenberg’s remarks concerning the war earlier that week. Heisenberg also advised Bohr to make contact with the German Embassy. Apparently this was part of the effort to ensure Bohr’s safety in occupied Denmark. Heisenberg went on and asked Bohr if he felt it was right for physicists to do a research on uranium during wartime. In return Bohr asked whether Heisenberg thought that uranium fission could be

[101] Jungk, Pg.103
[102] Niels Bohr Archive
[103] Pais, Pg.484
[104] Heisenberg, Pg. 175

utilised for the construction of weapons. Heisenberg answered that it was possible in principle and that it would require a terrific technical effort. In his account of 1971 Heisenberg states:

> Bohr was so horrified that he failed to take in the most important part of my report, namely, that an enormous technical effort was needed. Now this, to me, was so important precisely because it gave physicists the possibility of deciding whether or not the construction of atom bombs could be attempted. They could either advise their governments that atom bombs would come too late for use in the present war, and that work on them therefore detracted from the war effort, or else contend that, with the utmost exertions, it might just be possible to bring them into the conflict. Both views could be put forward with equal conviction.[105]

The discrepancy in the recollections can almost be viewed with a sense of humour as one studies the recently published archive of Niels Bohr. In one of his unsent letters to Heisenberg written after Jungk's first publication of "Brighter than a Thousand Suns" in 1957, Bohr recalls:

> I listened to this without speaking since [a] great matter for mankind was at issue in which, despite our personal friendship, we had to be regarded as representatives of two sides engaged in mortal combat. That my silence and gravity, as you write in the letter, could be taken as an expression of shock at your reports that it was possible to make an atomic bomb is a quite peculiar misunderstanding, which must be due to the great tension in your own mind. From the day three years earlier when I realized that slow neutrons could only cause fission in Uranium 235 and not 238, it was of course obvious to me that a bomb with certain effect could be produced by separating the uranium.[106]

In the above excerpt, Bohr refers to Heisenberg's letter to Jungk. As one further investigates the notes and accounts of both physicists, it is unavoidable to find the discrepancies especially striking. On Bohr's reaction after Heisenberg's statement concerning the possibility of nuclear weapons Heisenberg gives this statement to *Der Spiegel* on July 3, 1967: "Bohr told me in 1947 that he became so extremely shocked about my statement that now we knew one could build atomic bombs."[107] Therefore, it appears that either Bohr is contradicting

[105] Heisenberg, Pg. 182
[106] Neils Bohr Archive
[107] Heisenberg interview with *Der Spiegel*

himself or that Heisenberg has a bad recollection of what had happened that night in Copenhagen. However, he must have been extremely confident in his recollections to have written this in his published memoirs and to have stated it in a well known magazine such as *Der Spiegel*. The disagreement on what was said that night and on where it was said is not all there is.

On a further inspection of both accounts, another fact is noticeable. Powers cites a letter by von Weizsäcker written to Bohr on August 14, 1941. The letter states that "[…] he [von Weizsäcker] and Heisenberg would be attending a seminar on astrophysics at the institute between September 18 and 24 […]" According to Powers, that week (it is reasonable the author is referring to the days between the 14^{th} and 19^{th}) Bohr invited Heisenberg to dinner. After that dinner the extremely controversial discussion took place. To our surprise Heisenberg writes the following in one of his letters to Jungk on January 18, 1957, "My visit to Copenhagen took place in the fall of 1941; I seem to remember that it was about the end of October."[108] It is plausible that both men may have had different perceptions of what each other meant by what they said or what they did not say. Such a scenario seems possible if one is to consider the fact that they were under extreme emotional stress given the time and the surroundings. Bohr seems to acknowledge such a situation in his recollections later after the war, "Personally, I remember every word of our conversations, which took place on a background of extreme sorrow and tension for us here in Denmark."[109] It must have very well been an extremely tense situation for Heisenberg as well, considering the fact that he was disclosing highly secret military

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108 Heisenberg in a letter to Jungk, <http://werner-heisenberg.unh.edu/Jungk.htm>
109 Niels Bohr Archive, <http://nba.nbi.dk/papers/docs/d01tra.htm>

information to a half Jewish citizen of an occupied country, who had expressively refused any sort of cooperation with the Nazis. Heisenberg was taking an enormous risk by having that conversation. Such an action meant only one thing, treason, and it was punishable only by death. A misunderstanding due to the language used in the conversation is highly improbable regardless of the language spoken, since both men were very well acquainted with both German and Danish. Such a fact was also confirmed by Professor Jochen Heisenberg in his interview with the IQP team. Despite the controversies and the disagreements, the friendship between Bohr and Heisenberg did not suffer any irreparable damage. Professor Jochen Heisenberg's statement concerning the topic confirms such a fact, and some of the other points mentioned above.

According to Professor Jochen Heisenberg there were three separate meetings that took place between Heisenberg and Bohr, but the crucial discussion which has been subject to much debate took place outdoors. Professor Jochen Heisenberg also believes that the misunderstandings and arguments between his father and Niels Bohr were never severe.

He recalled his father taking his family for a tour of Copenhagen in 1956, during which they visited Bohr in his home where the two scientists spoke primarily Danish. Professor Jochen Heisenberg was not able to tell whether these conversations took place in Danish because of an effort by the men to conceal their meaning or due to the fact that speaking in Danish felt more comfortable for both of them. Professor Jochen Heisenberg also recalls that the issue of the Atomic Bomb was a common topic. Werner Heisenberg often elaborated on the events that took place during the forties and he was always open to discussions about these events. In order to further illustrate the relationship between his father and Niels Bohr, Professor Jochen Heisenberg mentioned that both families went on vacation once after the war.

However, the meetings between Bohr and Heisenberg did not always happen during family gatherings and vacations. According to Professor Jochen Heisenberg, the two men met repeatedly after the conflict, especially once in 1947, for the purpose of "clearing up" their problems. In these meetings, according to Professor Jochen Heisenberg, the two men made a decision about what had happened in Copenhagen in 1941: "They agreed to let it go by." The real controversy started after the publication of Jungk's book *Brighter than a Thousand Suns*. Jochen Heisenberg states that Bohr became angry at what Jungk had written about the Copenhagen meeting. Apparently, he expressed particular disapproval about the fact that Jungk had published comments based on only excerpts of letters between him and Heisenberg which were taken out of context.

When asked about what exactly the misunderstanding was between Bohr and his father, Professor Jochen Heisenberg said that after his father mentioned the fact that nuclear weapons were possible in principle, Bohr became angry and irrational. Professor Jochen Heisenberg did not forget to also point out a letter of his father from Copenhagen directed to his mother, in which he says in regards to his meeting with Niels Bohr: "It is hard to talk to Bohr when he is in such a mood." Interestingly enough about a year or two after Heisenberg's visit to Bohr, another German scientist by the name of Jensen went to Copenhagen to meet Bohr. Jensen was also a friend of Heisenberg's.

According to Professor Jochen Heisenberg, talking to Bohr about the nuclear weapons issue was not the only purpose of Heisenberg's visit in Copenhagen in 1941. The German scientist wanted to ensure that Bohr could safely escape from Nazi occupied territory and that he would be reinstated as head of his institute after the war was over. According to Professor Jochen Heisenberg, his father talked to officials in the German Embassy in Denmark to protect Bohr. Indeed, Professor Jochen Heisenberg brought to our attention the fact that von Weizsäcker's father was an important official in the German State Department during the war, thus Werner Heisenberg knew who in the embassy could be trusted. At about the same time as his visit in Copenhagen, Heisenberg writes to his mother: "[…] we have to take care of our Scandinavian friends."[110]

During their conversation Heisenberg gave Bohr a piece of paper with a simple drawing on it. The drawing represented the sketch of a nuclear reactor as the scientists at Los Alamos were later able to determine when Bohr brought it with him to America. This is probably the most important piece of evidence from that famous meeting. By handing to Bohr that simple drawing Heisenberg had clearly put himself in grave danger even more so than he already was in before. If Heisenberg was indeed sent by the Nazis to find out more about the American atomic project, why would he give Bohr such strong evidence that proved the most secret information, the existence of the German atomic project? In fact that piece of paper did not only show the existence of the German project, but it also gave a hint as to what the Germans were working on. Given Bohr's irritation at Heisenberg for mentioning atomic weapons, the latter may have felt forced to prove to his friend that what he was working on was not a bomb.

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[110] Interview with Jochen Heisenberg by the IQP team

As Heisenberg claims, the visit to Bohr may have certainly had the intention of discussing the development of atomic weapons. However, the idea that he went to Copenhagen to try and get all the scientists to agree on not working on atomic weapons does not appear to be well supported. Nevertheless, the idea could have certainly come up during the conversation even though that was not the original intention of Heisenberg. It is understandable that this may have not been clear to Bohr at the moment the conversation was taking place. A more acceptable version would be the one in which Heisenberg intended to seek advice on the moral and ethical issues concerning his involvement in the atomic research, as well as a possible course of action for the time to follow.

3.5.3 Cracow

Heisenberg's 1941 visit to Copenhagen has been subject to much debate. However, his 1943 visit in Cracow may prove to be of a similar controversial nature. In May, 1941 Heisenberg received the first invitation to visit Poland. The letter was signed by Wilhelm Coblitz, the director of the *Institut für Deutsche Ostarbeit* (Institute for German Work in the East), an institution devoted to studies aiding the colonization of the eastern countries. The astronomy and mathematics section of this institute used Russian forced labor and much of the research was aimed at the Jewish question and to racial matters in general.[111] Hans Frank, a well known Nazi exponent and general governor of the occupied Polish territories during the war, founded this institution in the spring of 1940. Heisenberg had known Frank since his youth years. At Maximillians Gymnasium, Heisenberg's older brother Erwin and Frank were classmates. In 1919,

[111] Bernsein, Heisenberg in Poland, Pg. 302

Heisenberg became a *Pfadfinder* (pathfinder), German Boy Scout and later he joined the *Neupfadfinder* (new pathfinder), a group that added Teutonic romanticism to hiking and camping. Around the same time Hans Frank also joined the *Neupfadfinder*. "For Frank, and others, this Teutonic mystic romanticism led to embracing National Socialism. Heisenberg neither then, nor ever, was a member of the Party, nor any of its offshoots."[112]

Frank, however, by 1923 had become a Storm Trooper and a member of the Nazi Party. He participated in Hitler's Beer Hall putsch in Munich and moved up in the Party's ranks by defending various Nazis in libel suits. Frank became the Party's chief legal counsel and Hitler's personal lawyer. On September 1, 1939 Nazi Germany invaded Poland. Frank was appointed governor general of Poland with headquarters in Cracow.

> An enthusiastic proponent of Nazi racist ideology, Frank ordered the execution of hundreds of thousands of Poles, the wholesale confiscation of Polish property, the enslavement of hundreds of thousands of Polish workers who were shipped to Germany, and the herding of most of Poland's Jews into ghettos as a prelude to their extermination. Frank remained as governor-general until the war's end, although Hitler stripped him of his other posts in 1942.[113]

During the entire period Frank maintained a journal comprising forty-three volumes. His diary still serves as an important source for World War II historians. In a speech addressed to his cabinet on December 16, 1941 Frank states:

> As far as Jews are concerned, I want to tell you quite frankly that they must be done away with in one way or another… As an old National Socialist, I must say: This war would only be a partial success if the whole lot of Jewry would survive it, while we would have shed our best blood in order to save Europe. My attitude towards the Jews will, therefore, be based only on the expectation that they must disappear... But what should be done with the Jews? Do you think they will be settled down in the 'Ostland,' in villages? This is what we were told in Berlin: Why all this bother? We can do nothing with them either in the 'Ostland' nor in the 'Reich kommissariat.' So liquidate them yourself. [114]

[112] Bernstein, Heisenberg in Poland, Pg. 300
[113] <http://www.britannica.com/eb/article-9035160/Hans-Frank>
[114] <http://fcit.coedu.usf.edu/holocaust/resource/document/DocFrank.htm>

The elimination of Jews was not the only objective of Frank and the SS. It is important to understand that the policy employed in Poland was part of a systematic effort to reduce the whole country to a colony without a culture. Frank himself made this objective clear, "What we recognize in Poland to be the elite must be liquidated."[115] He stated that Poland was to become a society of peasants and workers. On November 6, 1939, one hundred and 155 people, mainly faculty of the University of Cracow were arrested by the SS, in an operation which became known as the *Sonderaktion Krakau* (Special Operation Cracow). After a few days in jail, the prisoners were shipped to concentration camps. "News of these events got to other European scientists, and in part because of their protests, on February 8, one hundred and one, mainly men over forty, were released. When a letter was circulated in Germany protesting the arrest of the polish professors, the only physicist to sign it was Max von Laue."[116] Heisenberg knew early on that the Jews were being massacred in Poland. We can clearly see this in Elisabeth Heisenberg's account:

> I can still see my father standing in front of me. He was a man with a venerable and law-abiding outlook, who actually went into a rage when Heisenberg once showed him a report he had received from a colleague at the institute, who had been a witness to the first cynical mass execution of Jews in Poland. My father lost all self-control and started to shout at us: "So this is what has come to, you believe things like this! This is what you get from listening to foreign broadcasts all the time! Germans cannot do things like this, it is impossible!" He was not a Nazi; he had prematurely retired from his position following the National Socialist takeover.[117]

Thus, it is reasonable to assume that Heisenberg had in fact knowledge not only of the massacres of the Jews, but also of the persecution of scientists in Poland. However, Heisenberg did not travel to Cracow in 1941. The reason may have been the fact that, at the time, it was

[115] Bernstein, *Heisenberg in Poland*, Pg. 300
[116] Michale Burleigh, *Germany Turns Eastward*, Pg.253-254
[117] Elisabeth Heisenberg, Pg. 49

impossible for him to travel outside Germany. Heisenberg had been called a “White Jew” due to his association with Jewish scientists and his unwillingness to accept what was called Aryan physics. Even though the matter was resolved by an intervention from Heinrich Himmler, Heisenberg was not able to get permission to travel.[118]

> Coblitz renewed his attempt to get Heisenberg to visit Poland in May of 1943. This time he wrote in the name of Frank as well as himself to urge Heisenberg’s visit. In subsequent letters he conveyed Frank’s besten Grüsse (best greetings) and Heisenberg responded in kind. Coblitz said that Frank would personally attend the lecture that Heisenberg was scheduled to give. There was then a hiatus, because Frank’s summer vacation plans had not been fixed. But on September 29, Coblitz wrote, ‘‘Der Herr Generaldirektor lässt Sie und Ihre Frau einladen, seine Gäste auf Schloss Wartenberg, nahe bei Krakau zu sein.’’ (The Herr Generaldirektor invites you and your wife to be his guests at the Wartenberg Castle, near Cracow.)[119]

Heisenberg accepted the invitation and gave a lecture at the Institut für Deutsche Ostarbeit. Heisenberg stayed in Frank’s castle, a villa that was built between the First and the Second World War.

> Frank’s castles were furnished with masterpieces stolen from the Poles—some from museums and some from cathedrals. Frank estimated that ninety percent of the valuable art in his territory had been ‘‘safeguarded.’’ Frank furnished his domiciles with works of people like Leonardo daVinci, Raphael, and Rembrandt.[120]

On December 18, an article titled ‘‘The Smallest Building Blocks of Matter’’ appeared in the *Krakauer Zeitung*:

> Prof. Dr. Werner Heisenberg, Director of the Kaiser-Wilhelm-Institut für Physik, Berlin-Dahlem, lectured to a large audience of interested listeners in the great lecture hall of the Institut für Deutsche Ostarbeit about the central problems of scientific progress: contemporary aims of research in physics… After the enthusiastically received lecture, Governor-General Dr. Frank spoke personally as the president of the Institut für Deutsche Ostarbeit and praised the work of the lecturer, who is among the most eminent personalities of the internationally recognized German science. Heisenberg, a Nobel Prize winner at the age of thirty, belongs to the list of great German physicists, whose investigations in theoretical physics led to landmark discoveries.[121]

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[118] Bernstein, *Heisenberg in Poland*, Pg. 302
[119] Bernstein, *Heisenberg in Poland*, Pg. 302
[120] Bernstein, *Heisenberg in Poland*, Pg. 302
[121] Bernstein, *Heisenberg in Poland*, Pg. 302 (Exactly as it appears in the article)

No Polish physicists were allowed to attend Heisenberg's lecture and he must have certainly noticed their absence. In an Interview with David Irving in 1956, Heisenberg offered this explanation concerning his visit in Cracow:

> Here in Munich I was in school with some people who later became great Nazis, among them the Herr General Gouverneur of Poland, Frank. Frank was in the school class of my brother, and so naturally he knew us and *dutzten* us. [The phrase 'dutzten us'' is not directly translatable because in English there is no equivalent of *Sie* (the formal ''you'') and *Du* (the familiar ''you''). ''Dutzten'' is like the French *tutoyer* meaning employing the familiar *du* or *tu*. The implication of this choice of words is that the friendship was close enough so that the familiar *Du* was used.] I had completely lost sight of him and thought, O.K, I will have nothing further to do with him. But then around September of '43, if I remember correctly, he wrote that I should nevertheless come to Cracow, and give a scientific lecture there. I felt, this is stupid, what am I doing there in Cracow; Frank does not concern me anyway. But he wrote in such a friendly way: my dear friend! Can you not ... so that I wrote: Dear Frank! Well, I have so many other things to do here, unfortunately it is impossible for me to come. But then he sent me yet another letter, and was so pressing, and with implications that did not sound so pleasant, so I thought I do not really need to make an enemy. OK, I will give the lecture in Cracow. So in December 1943, if I remember well, I went to Cracow where first I was his guest in his castle, then I gave a lecture on the innocent theme of quantum theory, or something like it...[122]

Bernstein states that no letter from Frank to Heisenberg has been found and that the only correspondence known is between Heisenberg and Coblitz acting on Frank's behalf. He also concludes that there is no suggestion of a parallel correspondence with Frank. Heisenberg was clearly opposed to the Nazis and never an anti-Semite, yet he chose to visit the man who was responsible for some of the major atrocities during World War II. He defended scientists and supported the idea of an international science, yet chose to lecture on topics concerning the future of physics in the very heart of a country where physicists were declared outlaws. He defended Jewish scientists and talked about a future technology based on discoveries to which Jewish scientists had paid an immense contribution, yet he gave this talk at an institution where racial ideology was being raised to the level of pure science. Heisenberg's visit in Cracow may

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[122] Bernstein, *Heisenberg in Poland*, Pg. 303 (Exactly as it appears in the article)

have been a result of fear from the unpleasant consequences implied by Frank, but it may also have been an attempt from Heisenberg to rehabilitate himself after the attacks by the supporters of Aryan physics. In the Nuremberg trial, Hans Frank was found guilty and on October 16, 1946 he was hanged.

3.5.4 Farm Hall

From July 3 to December 3, 1945 ten leading German scientists were detained in Farm Hall, Godmanchester, 15 miles from Cambridge, England. The scientists detained were Erich Bagge, Kurt Diebner, Walther Gerlach, Otto Hahn, Paul Harteck, Werner Heisenberg, Horst Korsching, Max von Laue, Carl Friedrich von Weizsäcker and Karl Wirtz. Much debate and controversy has risen since the release of the Farm Hall Transcripts into the public domain on February 14, 1992. The most interesting part of this document is the transcripts which recorded the conversations held by the German scientists after the news first broadcast by the BBC at 6 pm on the evening of Monday, August 6, 1945, that the Americans had dropped an atomic bomb on Japan:

> President Truman has announced a tremendous achievement by Allied scientists. They have produced the atomic bomb. One has already been dropped on a Japanese army base. It alone contained as much explosive power as two-thousand of our great ten-tonners. The President has also foreshadowed the enormous peace-time value of this harnessing of atomic energy.[123]

A thorough investigation of the Farm Hall transcripts brings us again to a crucial topic which was previously discussed in detail, the critical mass. In the first discussion after the Germans heard about Hiroshima, Heisenberg states: "I consider it perfectly possible that they

[123] Irving, Pg.14

have about ten tons of enriched uranium, but not that they can have ten tons of pure U-235." Hahn immediately follows: "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, as the mean free path is still too big.
> HAHN: But tell me why you used to tell me that one needed 50 kilogrammes of 235 in order to do anything. Now you say one needs two tons.
> HEISENBERG: I wouldn't like to commit myself for the moment, but it is certainly a fact that the mean free paths are pretty big… [124]

Later that night Heisenberg speculated that 100,000 mass spectrographs could produce 100 grams of U-235 per day. He stated that such an arrangement "would give them thirty kilograms a year." Hahn asks:

> "Do you think they would need as much as that?"
> "I think so certainly, but quite honestly I have never worked it out as I never believed one could get pure 235."[125]

Heisenberg's statements in these conversations may not have been quite sincere. He had told von Ardenne in 1941 that the critical mass of U-235 was only a few kilograms. The same estimate von Ardenne had been told by Hahn shortly after Heisenberg. The confusion in Hahn's reaction to his colleague's statement is understandable since they had apparently discussed a very different estimate in 1941. Heisenberg then said that a bomb would require a ton of U-235, and maybe a quarter as much if the core was encased in a "reflector" of dense material which would reduce the number of neutrons escaping from the surface of the

[124] Farm Hall Transcript, 4, 2-5
[125] Farm Hall Transcript, 4, 17

fissionable mass. Two days later he came up with an estimate that the core of a bomb would be a sphere about 10 to 12 centimeters across.[126] The concept of the "reflector" introduced by Heisenberg is important in determining his understanding of the design of an atomic bomb. At Los Alamos such a device was referred to as a tamper. Victor Weisskopf, an Austrian American physicist who worked on the Manhattan Project, asked Powers whether Heisenberg understood the importance of a tamper, which Weisskopf took as a kind of litmus test for sophisticated thinking about bomb design. The Farm Hall Reports clearly answer Weisskopf's question. Only a week later on August 14, Heisenberg delivered a full-scale lecture on the physics of an atomic bomb. All the scientists at Farm Hall were present. In this lecture he came up with a critical mass estimate for U-235 of 15 or 16 kilograms. But, how had Heisenberg's estimates dropped in such a drastic way within a few days? First of all it is important to understand the fact that the critical mass value is affected by three principal factors: the "mean free path," the "multiplication factor" and the "reflector." The first term refers to the average distance which a neutron would travel in U-235 before striking the nucleus of another atom. The smaller the mean free path, the smaller the sphere of fissionable Uranium required for a bomb. The second term refers to the number of additional neutrons released on average by each fission reaction. The higher the multiplication factor, the lower the critical mass. At Farm Hall Heisenberg said he had previously used a multiplication factor of 1.1, which would yield a very large critical mass value. He then said he realized the number should be perhaps 2.5 or even 3.[127] On April 7, 1939 Professors Frédéric Joliot, von Halban and Kowarski reported from the College de France that within limits of error which in no way altered their findings' validity,

[126] Farm Hall Transcript, 5,11
[127] Farm Hall Transcript, 5, 22-23

on average 3.5 neutrons were emitted by the uranium nucleus fission. Approximately 2.5 is the accepted figure today. The discovery of the French physicists was published on April 22 in *Nature*. "Throughout the world of science, the ears of physicists suddenly, as one of them described, pricked up."[128] How could Heisenberg have neglected such a discovery which had been made public years ago? However, the basic nature of Heisenberg's lecture immediately struck Hans Bethe when he read the transcripts of their scientific discussions fifty years later:

> My first reaction is that Heisenberg knew a lot more than I have always thought-the fact he reached many of these conclusions in one evening is most remarkable. In his lecture it was clear he was talking to people who were quite ignorant. Heisenberg put everything on quite a low level, even going back to fundamentals. Apparently the other people didn't know very much about fission-even including Max von Laue, who was a great physicist. But especially Walther Gerlach- he knew very, very little-everything had to be explained to him as for the first time.[129]

The Farm Hall Transcripts along with Hans Bethe's comment show that Heisenberg reported very little to his superiors about basic atomic bomb physics before the end of the war.

3.5.5 Looking Ahead

Heisenberg played a very important role in the revitalization of German science after WW II. In 1946, after returning from England, Heisenberg became the Director of Kaiser-Wilhelm Institute. Heisenberg was interested in the philosophy of physics. He believed that new insights into everyday problems could help in visualizing and understanding microphysics. During the winter of 1955-1956 he gave a series of lectures at University of St. Andrews that concerned the relationship between physics and philosophy. In 1958 Heisenberg was

[128] Irving, Pg. 34
[129] Powers, Pg. 451

appointed Professor of Physics at the University of Munich. In 1953, he became the President of the Alexander von Humboldt Foundation. As president Heisenberg did much to further the policy of the Foundation, which was to invite scientists from other countries to Germany and to help them work there. Moreover, he supported nuclear energy and opposed the development of atomic weapons. Heisenberg contributed to a public campaign that concerned nuclear energy development and opposed Chancellor Adenauer's plan to involve Germany's army in tactical atomic weapons. The campaign was successful; West Germany was not involved in nuclear weapon development.

Heisenberg loved music and writing in addition to physics and saw a deep affinity between these two interests. He was an accomplished pianist. His son Jochen Heisenberg recalls:

> Music was my father's equivalent to emotional passion. [...]He played regularly for himself and with others, and music was a connector to the people who were not his scientific peers. As children we benefited from this common language our parents taught with such great care. If I know him so well now, it is partly because of the many hours of music we played together. It was through music that he shared the depth of his feelings about beauty and transcendence with us, although he did not go for the so-called romantic excess of emotion at all. A clean and classical exuberance was more his style, but above all else the slow movements were his true strength.[130]

Among books that Heisenberg wrote were: *Philosophical Problems of Quantum Physics* (1979), *Physics and Philosophy—the Revolution in Modern Science* (1958), and *Physics and Beyond—Encounters and Conversations* (1971).

Heisenberg gave an immense contribution to science. He believed that "almost every progress in science has been paid for by a sacrifice, for almost every new intellectual

[130] Interview with Jochen Heisenberg

achievement previous positions and conceptions had to be given up. Thus, in a way, the increase of knowledge and insight diminishes continually the scientist's claim of `understanding' nature."[131]

Heisenberg continued to be active in physics research and other social organizations until the end of his life. He was diagnosed with cancer and died on February 01, 1976 in Munich.

5. Conclusion

Our research has shown that determining the motivation, role, and impact of Werner Heisenberg's nuclear research during the war is extremely complex. Heisenberg had a key role in the German nuclear research effort. He was the leading theoretical physicist in the Uranium Club. The tasks assigned to him during wartime research clearly support this assessment. Two of the most important reports on German nuclear research were either authored or co-authored by him. The theoretical basis behind the Uranium Project was provided in a large part by Heisenberg. The establishment of the theoretical feasibility of the project was Heisenberg's domain. He had the crucial responsibility of establishing the type and amount of fissionable material needed for a reactor and an explosive. Heisenberg was the one who gave an approximation of the critical mass of uranium-235 as well as the level of enrichment needed for a reactor to work. Evidence suggests that Heisenberg had a fairly good idea of what the critical mass of uranium-235 needed to be. The estimates provided by Heisenberg, except for two

[131] Crease, Robert

occasions at Farm Hall, always included the right value of the critical mass. Although, one may not successfully argue that Heisenberg manipulated these calculations, he certainly is responsible for not providing a definitive answer to the problem. He avoided publicly mentioning any definitive figures relating to the critical mass, while emphasizing the technical and economical difficulties that made the production of a bomb highly improbable within two years.

His flawless reasoning and the similar mindset of other members of his team such as von Weizsäcker, Wirtz, Hahn and von Laue contributed to channeling the German nuclear research towards the construction of a nuclear reactor instead of a nuclear bomb. The reason behind the failure of Germany in the construction of an atom bomb lies partly in the attitude of the main scientists towards the project. Some of them feared that their involvement in a nuclear bomb project would put their lives and those of their families in grave danger.

Heisenberg showed an extremely impressive understanding of the physics and the details of an atomic bomb. His references to specific elements of a bomb such as the 'tamper'[132], almost immediately after Hiroshima, have been considered as signs of a considerably advanced knowledge on the issue.

Heisenberg and other important members of the Uranium Club had no affiliations with the Nazis. Heisenberg's involvement with anti-Nazi circles is a clear testimony of his political position. Even though he came from a right wing youth movement, which was host to many Nazi exponents of the era such as Hans Frank, Heisenberg remained open minded. In his early

[132] The concept of the "reflector" introduced by Heisenberg is important in determining his understanding of the design of an atomic bomb. At Los Alamos such a device was referred to as a tamper.(refer to 'Farm Hall')

years he was aware of the violence and political discrimination which occurred after the First World War in Germany. Despite the fact that he was thoroughly exposed to nationalism, anti-semitism, anti-communism during his youth, he never embraced such ideologies. Heisenberg was unquestionably a supporter of the view that science was international and in more than one occasion stood up in defense of his principles and of his Jewish friends.

In order to understand why Heisenberg was involved in the Uranium Club it is important to consider the political and social climate in Germany during the Nazi era. The extremely difficult times the scientific institutions were facing after the Nazis came to power, made scientists such as Heisenberg attempt to keep qualified personnel working. Perhaps, the main incentive to join the nuclear research project was also the fact that it would keep the scientists from the front lines.

The circumstances at the time spared Heisenberg the decision of advising the initiation of a full scale effort towards the production of atomic weapons. Heisenberg believed that a nuclear device could not be obtained by the end of the war given the conditions Germany was facing. Such reasoning was proven true when Germany capitulated. The situation of Germany's war effort did not favor a full scale atomic project. Heisenberg and his circle understood that. By 1943 there was no doubt that the development of an atom bomb was beyond their capabilities.

Heisenberg has certainly faced the moral dilemmas of the construction of a bomb. He was aware of the persecution of the Jews. There is no other reason more believable for his visit to Bohr in 1941 except discussing these dilemmas with his old mentor. From the accounts of

Elisabeth Heisenberg and Jochen Heisenberg we understand that Heisenberg was not a revolutionary and not a hero. He did what he had to and would have worked on constructing an atom bomb if he was ordered to. He would not have deliberately manipulated the calculations in order to sabotage the project.

Heisenberg did not attempt to emphasize the possibility of nuclear explosions. His account at Farm Hall shows that he had kept his superiors in the dark about several important aspect of the project. Did he do this on purpose? He might have certainly done so. None of the scientists in the Uranium Project would have taken the responsibility of standing up and suggesting the Reich officials to invest on a full scale nuclear bomb project. Was Heisenberg the only one in the position to make such a judgment? Certainly not, all the scientists would have to be on the same page. Most of them knew how much of a limited resource heavy water and uranium were at the time. One may ask, why did the American and British scientists deliberately suggest that their governments be involved in such an enormous project? It is important to keep in mind that the backbone of the nuclear research in the west was German émigrés and Jews who were driven away from their homes in Europe by the Nazis. They had all the psychological incentives to push for an alternative that would end the war as quickly as possible by defeating the Nazis. These individuals had seen their people massacred and exiled; there is little possibility they even considered a dilemma. The British had seen their capital being ruined by German V-2 rockets. They too had a strong incentive. The lack of a moral dilemma must have been true for a Nazi as well, but not for a normal German who did not believe or support the Nazi ideology. However, based on our research this is impossible to conclude beyond reasonable doubt. We are of the opinion, however, that ethically Heisenberg was a normal individual in extraordinary circumstances. If he was convinced in 1941 that it was possible for a nuclear bomb to be constructed by Germany before the end of the war, he would have advised its construction. It is hard to believe that someone would risk seeing his country annihilated. What he did during the war whether intentional or not, contributed to preventing the Nazis from possibly achieving a nuclear bomb. A devoted Nazi scientist of the caliber of Johannes Stark or Philipp Lenard may have produced quite a different outcome in Heisenberg's position. Heisenberg made a decision to remain in his native country and work as a physicist. He chose to face the problems instead of escaping from them. He stood up for his beliefs as a man and as a scientist when most chose indifference. We conclude that Heisenberg was a man to be admired for his vision of science and society in its darkest times, and for attempting to make something right when everything was going wrong. Even though, we attempted to explore any available information regarding the topic, we feel that further work remains to be done in order to shed more light on the German wartime nuclear research.

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All quotations from this work were translated by Martin Boeker.

Appendix

Original Text Translated by Martin Boeker

Schaaf, Pg. 114

> Teller: Weizsaeckers Beitraege waren, dass er wahrscheinlich der erste war, der die Arbeiten von Hahn und Strassman wirklich verstand. Es scheint, dass die Atomspaltung von ihm zuerst verstanden worden ist, obwohl ich dabei nicht ganz sicher sein kann.
>
> Ueber Heisenberg kann ich viel erzaehlen. Ich glaube, und ich glaube es auch in einer begruendeten Weise, dass Heisenberg die Atombombe nicht nur opponiert hat, dass er auch wirklich sabotierte.
>
> Ob es in Deutschland gelungen waere, wenn Heisenberg sein wunderbares Talent dahinter gesetzt haette, das weiss ich nicht. Aber das war ja nicht der Fall. Und dafuer ... ich habe die Verhaeltnisse studiert. Da gibt es eienen besonderen Punkt, den ich mitteilen muss.
>
> Als diesen [gefangenen] deutschen Physikern Hiroschima mitgeteilt wurde, haben sie es nicht geglaubt. Nach einigen Stunden rief Heisenberg die Gruppe zusammen, und er sagte: „Ja, es war eine Atombombe, und sie hat auf diese Weise funktioniert.“ Und das war falsch! Ich bin selbst darauf [herein]gefallen. Heisenberg hat einen Fehler gemacht! Und ich habe den selben Fehler gemacht, einige Jahre bevor die Atombombe explodierte. Es war ein natuerlicher Fehler. Wir haben daran gearbeitet und den Fehler in mehreren Wochen aufgeklaert. Heisenberg war ein stolzer Physiker. Er haette seinen Kollegen bewusst nie etwas Falsches ueber die Physik gesagt. Das ist eine Absurditaet.
>
> Heisenbergs Aussage zeigt, dass er ueber die Atombombe niemals ernstlich nachgedacht hat. Als er mit der Tatsache konfrontiert wurde, benahm er sich wie ein natuerlicher Anfaenger. Ich glaube da gibt es keine andere Erklaerung. Es ist nicht wahr, dass Heisenberg nicht erfolgreich sein wollte, er hat auch die wesentlichen Fragen praktisch nicht angeschnitten. Und ich kann sein Benehmen nicht anders ausdruecken.

Schaaf, Pg. 120

> Ich hatte also kapiert – und zwar auf einer kleinen internen Seminarsitzung bei Hahn, die wahrscheinlich im Februar [1939] gewesen ist – dass Joliot in der Tat Sekundaerneutronen gefunden hatte, und zwar so viele, dass eine Kettenreaktion moeglich waere. Damit war jedem Kernphysiker, der so etwas hoerte, klar, dass moeglicherweise Bombem entstehen wuerden.
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> Ich bin noch am selben Abend zu meinem Freund Georg Picht gegangen [... und sagte]: „Ich habe heute bei Hahn gelernt, dass man moeglicherweise eine Bombe bauen kann, von der ein einziges Exemplar genuegen wuerde, um ganz London zu zerstoeren. Was machen wir jetzt?"
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> Dann haben wir darueber die halbe Nacht lang geredet und haben drei Konsequenzen gezogen. Erste Konsequenz: Wenn Atombomben moeglich sind, wird es – so wie die Menschheit heute beschaffen ist – jemanden geben, der sie baut. Zweitens: Wenn Atombomben gebaut sind, wird es – so wie die Menschheit heute beschaffen ist – jemanden geben der sie militaerisch verwendet. Drittens: Wenn das so ist, dann hat die Menschheit nur die Wahl, entweder sich selbst zugrunde zu richten oder den Krieg als Institution abzuschaffen. Das war im Grunde unsere Reaktion.

Schaaf, Pg. 121

> Otto Hahn: „Aber wenn durch meine Entdeckung der Hitler eine Atombombe bekommt, dann bringe ich mich um!"

Schaaf, Pg. 146

> Am 4. Juni 1942 referierte Heisenberg im Berliner Harnack-Haus ueber die militaerische Bedeutung der Kernenergie. Neben Reichsruestungsminister Speer und seinen Fachleuten waren Staatssekretaere, Generale, Kernphysiker und Mitarbeiter der Kaiser-Wilhelm-Gesellschaft gekommen. Auf die Frage von Generalfeldmarschall Milch, wie gross denn eine Bombe sein

muesse, die eine Grosse Stadt wie London in Truemmer legt, soll Heisenberg geantwortet haben: „Etwa so gross wie eine Ananas."

Kleint and Wiemers, Pg. 15

Bagge: Historisch besteht kein Zweifel, dass die Professoren W.Heisenberg und R.Doepel bei ihren Versuchen mit Uranmetall und schwerem Wasser experimentell zum ersten Mal ueberhaupt die Moeglichkeit der Freisetzung von Kernenergie durch die Uranspaltung gezeigt haben. Sie berichteten darueber am 26. Februar 1942 im Harnackhaus Berlin-Dahlem vor einem Kreis von Regierungsvertretern, Generaelen, Admiraelen und Wissenschaftlern.

Das es bis zur Besatzung haigerlochs in Wuerttemberg am 20. April 1945 nicht doch noch zum selbsterregten Reaktor kam, waere trotz der ganzen Kriegslage im Grunde nur noch eine Frage von maximal wenigen Monaten gewesen.

Kleint and Wiemers, Pg. 21

Bagge: [...] Erklaerte Dr. Kurt Diebner, die mir zugedachte Aufgabe: „Wir muessen fuer den 16. September hier in diesem Hause eine Besprechung mit Kernphysikern organisieren, die Sie doch sicher alle kennen. Sie sollen die Arbeit von Fluegge ueber die Energiegewinnung aus Atomkernen ganz genau lesen, darum geht es, eine Tagesordnung fuer diese Sitzung vorbereiten und eine Liste der einzuladenden Herren vorschlagen. Es sollen aber hoechstens zehn Teilnehmer werden."

Das geschah dann auch, und dabei gab es sogleich ein Problem. Die Namensliste enthielt die Namen der Professoren Bothe, Geiger, Hahn, Harteck, Heisenberg, Hoffmann, Mattauch, und Dr. Fluegge. Mit Herrn Diebner und mir waren es zehn Personen, genau so viele, wie er wollte.

[...] Ohne weitere Diskussion wurden dann, ausser Heisenberg, alle uebrigen Herren zum 16. September nach Berlin eingeladen, und sie erschienen auch.

Die Sitzung begann mit einer Begruessung durch den Vorgesetzten von Herrn Diebner, dem wuerdig und sehr sachlich wirkenden Abetilungsleiter Dr. Basche. Er fuehrte aus, dass durch die Entdeckung der Uranspaltung mit Neutronen nach Fluegges Veroeffentlichung eine Situation entstanden sei, die eine Moeglichkeit der Erschliessung einer neuen Energiequelle erkennen lasse. Man wisse nicht, ob diese wirklich realisierbar sei. Dafuer werde weitere Forschungsarbeit notwendig sein. Die Anwesenden seien nach Berlin bestellt, um zu helfen, diese Frage zu beantworten. Es sei Krieg und man muesse wissen, ob die Antwort ‚Ja‘ oder ‚Nein‘ laute.