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From the Dawn of Nuclear Physics to the First Atomic Bombs

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This review gives a fresh look at the major discoveries leading to nuclear fission within the historical perspective. The focus is on the main contributors to the discoveries in nuclear physics, leading to the idea of fission and its application to the creation of the atomic bombs used at the end of the World War II. The present work is a more complete review on the history of the nuclear physics discoveries and their application to the atomic bomb. In addition to the traditional approach to the topic, focusing mainly on the fundamental physics discoveries in Europe and on the Manhattan Project in the United States, the nuclear research in Japan is also emphasized. Along with that, a review of the existing credible scholar publications, providing evidence for possible atomic bomb research in Japan, is provided. Proper credit is given to the women physicists, whose contributions had not always been recognized. Considering the historical and political situation at the time of the scientific discoveries, thought-provoking questions about decision-making, morality, and responsibility are also addressed. We hope that this work, referring to the contributions of over 20 Nobel Prize winners, will be inspirational and will stimulate interest in the history of physics not only in physicists but in other readers of all backgrounds, genders, and generations.

1 Introduction

Perhaps no other event in history has shaken the consciousness of physicists as deeply as the dropping of the two atomic bombs in Japan at the end of the World War II. Ironically, their creation was made possible due to one of the greatest achievements in the 20th century, the discovery of the nuclear fission. Several generations of scientists, both physicists and chemists, have been focusing their research and intellectual efforts, building on each other's accomplishments to reveal the secrets of the atom on a fundamental level. The results of their intellectual achievements have allowed humanity to build the foundations of nuclear medicine and radiation therapies, to create plants, capable of producing massive amounts of energy, but also make bombs of horrifying destructive power. Ever since nuclear fission was discovered, humanity has struggled not to let this newfound power go out of control. This added new moral and ethical responsibilities to the scientists who made the discoveries and had the knowledge and the ability to manipulate the energy of the atom.

2 Key Discoveries in Europe Preceding Fission

Even though the discovery of nuclear fission is a topic of multiple publications, very few know exactly how it came to be. Not many people other than devoted scientists truly understand how quickly fission was discovered. It took only seven years after the discovery of the neutron for scientists to unleash the power of the nuclei. The splitting of the nuclei is a unique story, and this section gives credit to the brilliant scientists who contributed to it.

A number of physicists and chemists dedicated their research to the development of the nuclear physics ideas, leading to the discovery of fission on a fundamental level. Among these scientists there were many women physicists and chemists who worked in early nuclear science. Here we will focus on the ones who played particularly important role and whose pioneering work motivated other female scientists. Historically their role was often undermined. This phenomenon and the resulting gender gap in science are present around the world even today. One of the few exceptions from this rule was Marie Sklodowska Curie (1867–1934), who received two Nobel

Prizes, one in 1903 and the other in 1911. She is the only person who has been awarded Nobel prizes in both Physics and in Chemistry [1].

Discovery of Spontaneous Radioactivity

Ever since the discovery of the radioactivity of uranium by Antoine Henri Becquerel (1852–1908) in 1896 [2], scientists have been on a quest for applying this new phenomenon to broaden the horizons of the humanity. For his discovery of spontaneous radioactivity, Becquerel (Fig. 1a) was one of the recipients of the 1903 Nobel Prize in Physics. The French scientists Marie Curie (1867–1934), a research student at Becquerel's lab, and her husband Pierre Curie (1859–1906) were among the first researchers who began to work in the new field of radioactivity (Fig. 1b). Their pioneering research resulted first in the discovery of two new elements, Radium and Polonium, in 1898 [3-5]. For their contributions, Henri Becquerel and the Curies shared the Nobel Prize in Physics in 1903 [1].

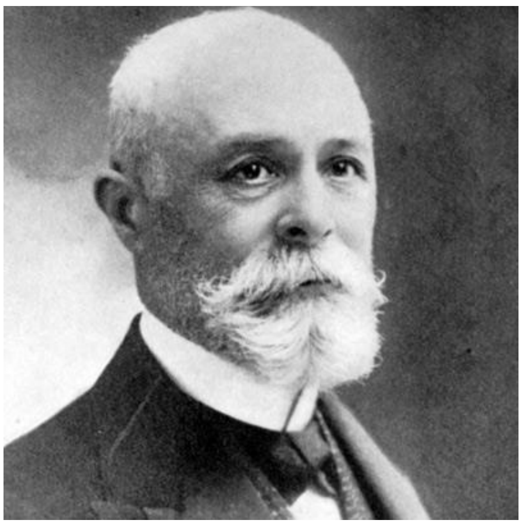

Fig. 1 (a, b). Henry Becquerel (**Fig. 1a)** shared the 1903 Nobel Prize in Physics with his research student, Marie Curie and her husband, Pierre Curie (**Fig. 1b)**. Marie Curie was also awarded the Nobel Prize in Chemistry in 1911.

Soon after Becquerel's contribution, J. J. Thomson discovered the electron in 1897. While exposing cathode rays to electrically positive and negative samples, he noticed that the deflection of the rays depended on the sign of the charge exposed to the tube. For this fundamental discovery, the father of the electron was awarded the Nobel Prize in Physics in 1906 [6].

Formulating a Fundamental Relationship between Mass and Energy

Another giant leap contributing to the discovery of fission was made by Albert Einstein in 1905, his Annus Mirabilis, when he published several seminal papers, including the one submitted on September 27, 1905, in which his famous equation, $E=mc^2$, was derived [7]. Theoretically deriving this equation by following the postulates of his special theory of relativity, Einstein showed that mass and energy are not independent and can be converted to one another. He opened the door for other physicists to think differently about mass and energy, and this equation became a tool for predicting how much energy is stored in nuclei, thereby allowing physicists to predict the amount of energy that nuclei would release when split. But many years passed after the formulation of Einstein's equation before progress was made in fission.

The First Artificial Nuclear Reaction

Presently considered the father of nuclear physics, Ernest Rutherford (1871–1937), a physicist from New Zealand who was one of J.J. Thomson's first students, was the first to formulate the concept of radioactive half-life. He first named and classified alpha, beta, and gamma radiation, and verified that radioactivity involved the change of one element into another. For his contributions, the physicist Rutherford was awarded the Nobel Prize in Chemistry, not Physics, in 1908, "for his investigations into the disintegration of the elements, and the chemistry of radioactive substances" [1]. In 1911, Ernest Rutherford discovered that the mass of an atom is concentrated mainly in the nucleus. Performing his famous gold foil experiment, in which he passed alpha particles through a thin gold sheet and noticing their deflection patterns, he concluded that the nucleus of the atom is positively charged [8]. In 1919, Rutherford performed the first artificial nuclear reaction. He was able to prove that bombarding a sample of Nitrogen gas with alpha particles results in an occasional collision that causes the formation of an Oxygen isotope [9].

In addition to being a very talented physicist, Ernest Rutherford was extremely supportive of women in science. His first graduate student was the Canadian physicist Harriet Brooks (1876-1933) who performed the pioneering experiments that led to the discovery of nuclear transmutation. Her research on radioactivity began in 1899 after graduating from McGill University with high honors and earning the first master's degree in physics given to a woman there. Her experimental discovery that Thorium gave out a radioactive gas with a smaller molecular weight than that of the original thorium was a critical key step in the history of nuclear physics. Harriet Brooks spent a year at Marie Curie's laboratory in Paris in 1906 and was considered "next to Marie Curie, the most outstanding woman in the field of radioactivity" [10].

It is important to note that two of the 1922 Nobel Prizes, the one in Physics and the one in Chemistry were also related indirectly to fission. The Nobel Prize in Physics was awarded to Niels Bohr (1885–1962) for "his investigation of the structure of atoms and the radiation emanating from them", while the Nobel Prize in Chemistry was awarded to Francis William Aston (1877–1945), for his discovery of the mass-spectra and isotopes [1].

Discovery of the Neutron

A major breakthrough leading to fission came in 1932 with James Chadwick's (1891–1947) discovery of the neutron [11]. Neutrons play a key role in fission because, being neutral, they can overcome the electric barriers of nuclei and penetrate them. Only after Chadwick discovered the neutron, he was finally able to perform such experiments, resulting in penetration into the nuclei of different atoms, an approach that failed when he was using charged alpha particles, incapable of penetrating the nuclei due to their positive charge. This neutron penetration would latter allow scientist to split nuclei by creating an unstable nucleus, which becomes more stable by separating into smaller fragments and releasing energy. For this discovery, the British physicist James Chadwick was awarded the Hughes Medal of the Royal Society in 1932, won the Nobel Prize in Physics in 1935, and was knighted in 1945.

Fig. 2 Albert Einstein in his Annus Mirabilis year, 1905. Nobel Prize in Physics 1921

Fig. 3 James Chadwick, 1935 Nobel Prize in Physics for the discovery of the neutron

Discovering the Impact of Neutron Moderation

By 1934, many experiments were performed with neutrons, but some of these experiments showed a unique feature. Based on multiple experiments of neutron bombardment, the Italian physicist Enrico Fermi (1901–1954) discovered that slow neutrons were captured more easily than fast neutrons. This unique neutron behavior, presently known as *moderation*, is important because it requires slowing down neutrons, which allows them to be easily captured by nuclei. By slowing the neutrons down, their energy can be lowered from a MeV to an eV. In 1934 Fermi worked on experiments bombarding many different elements with slow neutrons and developed a diffusion equation describing this phenomenon [12]. Some of the products of his experiments were new isotopes, which underwent beta-decay, resulting in production of new heavier elements. Fermi's expectation was that the neutron bombardment on Uranium 92 will result in a similar effect, producing an element with atomic number 93 (this element, presently known as Neptunium, was unknown in 1934; it was discovered in 1940 [13]), according to similar reaction he had observed with lighter elements:

$$\mathbf{n + {}^{238}U \;\text{–>}\; {}^{239}U^{*} \;\text{–>}\; {}^{239}\,[93] + e^{-} + nu} \qquad \mathbf{(1)}$$

Since the above reaction (Eq. 1) was not observed, Fermi was unable to understand the effect on the neutron bombardment on uranium. This became known in the scientific community as the Uranium Problem. Even though he missed fission, Fermi was awarded the Nobel Prize in Physics in 1938 for "his demonstration of the existence of new radioactive elements produced by neutron irradiation" and "for discovery of nuclear reactions brought about by slow neutrons" [1]. His multiple in-depth contributions to the topic were still to come.

Fig. 4 Enrico Fermi, Nobel Prize in Physics 1938

Fig. 5 Ida and Walter Noddack were proposed to receive the Nobel Prize for ten times, but were not awarded the prize

The First Statement of Fission

Following up on Fermi's published work, the German chemist, Ida Noddack[1] (1896–1978) who, together with her husband Walter Noddack (1893–1960), had discovered the new element Rhenium 75 and had named element 43 Masurium (presently known as Technetium) in 1925 [14], suggested that the reaction in Fermi's experiment could be of different type, a breakup of the unstable nucleus into lighter nuclei [15]. This idea was the first statement of fission. In her 1934 publication [15], Ida Noddack suggested that chemical analyses of the products could verify the presence of lighter elements. But the idea of breakup of the nucleus was quite unusual for its time to be accepted, because at that time the alpha particles were considered to be the heaviest particles that could be emitted from a nucleus. So these experiments were not performed in Fermi's lab. Surprisingly, Ida Noddack did not try to reproduce Fermi's experiment and to look for experimental evidence herself.

Discovery of Artificial Radioactivity

The daughter of Marie and Pierre Curie, Irene Joliot-Curie (1897–1968), along with her husband, Frederic Joliot-Curie (1900–1958) (Fig. 6) was also involved in radioactivity research. After Fermi, Iren and Frederic Joliot-Curie performed bombarding experiments of Uranium and found evidence of lighter element, Lanthanum 57 among

[1] It is interesting to note that Ida Noddack was one of the first women who received a master's degree in chemistry in 1919. In 1925, together with her husband Walter Noddack, she discovered two new elements missing in the Periodic Table, Rhenium (75) and Massurium (43), presently known as Technetium [14]. In 1934 Ida Noddack published the first statement of fission [15]. Ida and Walter Noddack were proposed to receive the Nobel Prize for ten times, but never did.

the products of the nuclear reaction. However, Iren and Frederic Joliot-Curie did not relate their experimental results to Ida Noddack's publication [15], so they missed the fission, even though they were very close.

In 1934 Irene Joliot-Curie and Frederic Joliot-Curie discovered the artificial radioactivity by bombarding Boron with alpha particles. They found that when the Boron broke down into Nitrogen-13 and a neutron, the Nitrogen-13 could be broken down further into Carbon-13, and an electron would be released. This Carbon-13 was the first radioactive element created artificially [16, 17]. For their discovery of artificial radioactivity [16, 17] Irene and Frederic Joliot-Curie received the 1935 Nobel Prize in Chemistry. This added two more Nobel Prizes to the famous family of two generations of scientists, who received a total number of five Nobel Prizes [1, 18].

Nuclear Fission Discovery

The Austrian-born Jewish physicist Lise Meitner[2] (1878–1968) was a contemporary of Irene and Frederic Joliot Curie. She was a student of Ludwig Boltzmann (1844–1906) and was greatly influenced by him [19]. In 1907 Lise Meitner went to Berlin to study with Max Plank (1858–1906) and joined the group of the chemist Otto Hahn (1879–1968), a former student of Ernest Rutherford at McGill University. Meitner worked with Hahn on radioactive substances for thirty years, with a short interruption due to the World War I. During the war she served as an X-ray technician in the Austrian Army for two years (1915–1917), handling X-ray equipment [20, 21].

Following the experiments by Fermi, Lise Meitner, Otto Hahn and Fritz Strassmann focused their research efforts on the Uranium Problem. Unfortunately, the historical and political situation of this time period forced Lise Meitner to leave Germany in 1938. Even though Meitner had become a Protestant in 1908, this did not help her when the most pivotal moment of Hitler's racial anti-policy, known as the "Night of the broken glass" came into power. After Lise Meitner, like many other Jews, fled from Germany, leaving everything behind, she became officially a member of Manne Seigbahn's new Institute in Stockholm [22]. Manne Seigbahn (1886–1978) was the recipient of the 1924 Nobel Prize of Physics and was supervising the design of a cyclotron similar to the one in the Lawrence's Laboratory in Berkley, for which Ernest O. Lawrence (1901–1958) won the 1939 Nobel Prize in Physics (Fig. 8). Even outside of Germany, she still continued to communicate with former collaborators Hahn and Strassman, who sent her regular updates on the current research and sought her advice [22].

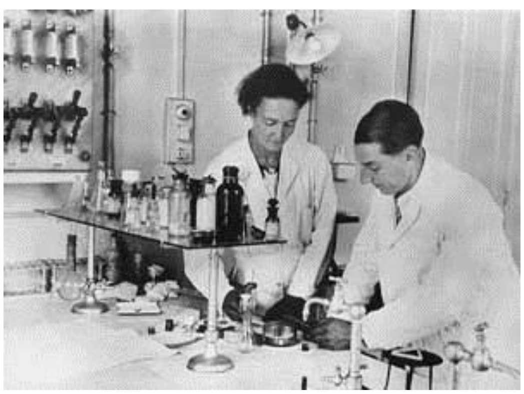

Fig. 6 Irene and Frederic Joliot-Curie, Nobel Prize in Chemistry 1935

Fig. 7 Lise Meitner and Otto Hahn in Berlin. Hahn was awarded the Nobel Prize in Chemistry in 1944

In November of 1938 Lise Meitner met with Hahn in Copenhagen to discuss the experimental results in the group. The experiments were done at Otto Hahn's lab in Berlin, but Meitner was informed about all the details and was still a vital part of the discussions. Later, analyzing the results from the experiments together with her nephew, the physicist Otto Robert Frisch (1904–1979), she identified the new product of the reaction as barium and the

[2] Lise Meitner was the second woman to receive a PhD in Physics in the University of Vienna in 1905, after the laws in Austria prohibiting women to attend academically rigorous secondary schools and universities had changed. This was fortunate for her, since science played a major role in her life. According to her nephew, the physicist Otto Frisch (1904–1979), who later become involved with the Manhattan Project, her mentor Boltzmann had given her "the vision of physics as a battle for ultimate truth, a vision she never lost." [19].

nuclear fission was discovered [20]. Meitner and Frisch calculated that the lost mass has been converted to energy as predicted by Einstein's famous equation $E=mc^2$ [7]. The credit for the discovery went to the group of Otto Hahn and Fritz Strassman at Kaiser Wilhelm Institute for Chemistry in Berlin, who published the evidence for nuclear fission in 1939. Even though the major contribution in the discovery and the explanation of the fission came from Lise Meitner, she was not acknowledged and published her discovery as a Letter to the Editor of Nature, entitled, "Disintegration of Uranium by Neutrons: a New Type of Nuclear Reaction". The paper was co-authored with her nephew, Otto Robert Frisch. It appeared in February 1939 and gave the physical explanation of the fission phenomena [23]. In 1944 Otto Hahn received the Nobel Prize in Chemistry "for his discovery of the fission of heavy nuclei". In his Nobel lecture, he did not acknowledge Lise Meitner's or Fritz Strassman's contributions.

Discovery of Neutron Chain Reaction

Otto Robert Frisch was the scientist who introduced the term "*fission*" to describe the splitting of a heavy nucleus into two smaller nuclei of about the same size. In 1939, he directly observed nuclear fission using an ionization chamber to detect the fragments from fission, an experiment that he managed to perform in only two days [24]. Even before the nuclear fission reaction was observed, the Hungarian-born Jewish physicist Leo Szilard (1898–1964) had postulated the possibility for controlled release of the energy of the atom via *neutron chain reaction*. He holds the first patent on the neutron chain reaction from the British Patent Agency, filed in 1934 and approved in 1936 [25]. In the case of Uranium-235 the nuclear fission reaction can produce two or three neutrons along with the fission products. The bombarding neutrons can initiate a chain reaction if at least one neutron from each fission process strikes another U-235 nucleus and causes fission.

In addition to the chain reaction postulate, Szilard's patent described the important concept of *critical mass*, the minimum amount of fissionable nuclear material necessary to start a chain reaction. His chain reaction postulate is what allows nuclear power plants and atomic bombs to exist. A chain reaction would mean that physicists could create a self-sustaining system that would continuously release large amounts of energy. It was quickly realized that this could have multiple practical applications. Nuclear fission had become the reaction of the future.

Early Particle Accelerators Used in Nuclear Research

To penetrate the atomic nuclei, particle beams of high energy have been instrumental for fundamental nuclear physics research since the dawn of nuclear physics. The two pioneering research teams focused on particle beam accelerators were John D. Cockcroft and Ernest Walton at the Cavendish Laboratory in Cambridge and the group of E. O. Lawrence in Berkeley. Walton and Cockcroft built an apparatus to accelerate protons to 700 kV in order to bombard Lithium atoms with the accelerated protons and split their nuclei to produce Helium nuclei. For their work, published in 1932 [28], they received the Nobel Prize in Physics in 1951 [1]. E. O. Lawrence invented a different type of accelerator, cyclotron, in which the charged particles accelerate while moving along a spiral trajectory. For this invention, which would later play an important role in the Manhattan Project, Lawrence was awarded the Nobel Prize in Physics in 1939.

Fig. 8 Lawrence with the 37-inch cyclotron, 1937. E.O. Lawrence was awarded the Nobel Prize in Physics in 1939.
(Courtesy Lawrence Berkley National Laboratory)

3 Nuclear Research in Japan

What was the situation with the nuclear research in Japan while these exciting discoveries took place in the West? The publications referring to nuclear fission and its application to the atomic bomb typically focus on the fundamental scientific discoveries made in Europe and on the Manhattan Project in the United States, secretly applying these fundamental principles into the creation and testing of an atomic bomb. Since Japan was the only country that experienced the impact of atomic bombs detonated over the cities of Hiroshima and Nagasaki, multiple publications speculate on nuclear research in Japan and its possible applications to nuclear weapons. To distinguish between the evidence-based scholarly publications on the topic and mere speculations, we review the existing publications in Section 5. The present section is an attempt to give a complete review of the nuclear physics development before the end of the World War II, including all aspects of nuclear research in Japan. A number of primary sources on the subject are available, although difficult to find in English.

An Early Model of the Atom

The earliest record about a Japanese scientist interested in radioactivity was of the Nagasaki native Hantaro Nagaoka (1865–1950), (Fig. 9). In 1900, he attended the First International Congress of Physics in Paris, where he heard Marie Curie’s lecture on radioactivity, which sparked his interest in atomic physics. Professor Nagaoka is the author of an early planetary model of the atom based on an analogy to the stability of the rings of Saturn, published in 1904 [26]. Some of the predictions of the proposed model were successfully confirmed by Ernest Rutherford (1871–1937), the recipient of the 1908 Nobel Prize in Chemistry. Rutherford referred to Nagaoka’s model in his 1911 publication of his famous gold foil experiment [8]. However, not all details of this early model were correct [26]. After 1925, Nagaoka was appointed as a head scientist at the Institute of Chemistry and Physics Research (RIKEN), where the first cyclotrons in Japan were built. However, Nagaoka left RIKEN to join the Imperial University of Osaka before that time and was not involved in cyclotron research there.

Fig 9. Hantaro Nagaoka (1865–1950) is the author of an early model of the atom.

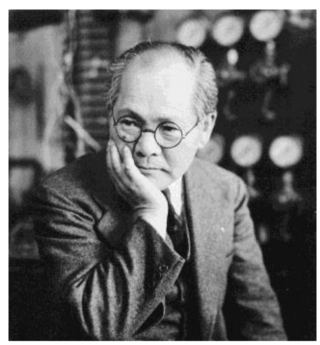

Fig. 10 Yoshio Nishina (1890–1951), the father of modern physics in Japan.

Another prominent figure among the Japan's leading nuclear physicists was Dr. Tadayoshi Hikosaka, a professor at Tohoku University. Dr. Hikosaka published his atomic physics theory and his idea of the shell-like structures of nuclei in 1934 [27]. He pointed out that atomic nuclei held a huge energy potential that could both generate electrical power as well as be used for weapons.

Pioneering Work on Nuclear Reactions Using an Accelerator

It is worth mentioning here the contributions of the Japanese physicist Seishi Kikuchi (1902–1974), professor at Osaka Imperial University, who built Cockcroft-Walton accelerator [28] in Japan in 1934 and performed series of experiments on neutron scattering, including excitation of gamma rays by neutrons, as well as fast neutron-scattering experiments, which were reported to be a pioneering performance on nuclear reactions using an accelerator not only in Japan, but also worldwide [29].

Birth of Modern Physics in Japan

Yoshio Nishina (1890–1951), (Fig. 10), a prominent Japanese physicist, just one generation after Hantaro Nagaoka, is famously known for the Klein-Nishina formula and is presently considered the father of modern physics in Japan. He graduated from the Imperial University of Tokyo in 1918 and was one of the brilliant young physicists who went to the Neils Bohr Institute in Copenhagen in the 1920s. He joined RIKEN as a researcher after that [30]. Among the generations of physicists mentored by him as a principle investigator at RIKEN were the first two Japanese Nobel Laureates in Physics, Hideki Yukawa (Nobel Prize in Physics, 1949) and Sin-Itiro Tomonaga (Nobel Prize in Physics, 1965). Yoshio Nishina was the leader of the nuclear research in Japan and was later approached by the Japanese Army and Navy regarding the possibility of developing a nuclear weapon program (See Section 5).

Fig. 11 Paul Kazuo Kuroda (1917–2001)

Fig.12 Kenjiro Kimura (1896–1988) [32]

Scientific Exchange and Collaborations with the West

Further evidence for the scientific exchange of information and collaborations between Japanese and European scientists in the 1930s and 1940s is given in the autobiography of the late Paul Kazuo Kuroda (1917-2001), a chemistry professor at the University of Arkansas who earned his doctoral degree from the Imperial University of Tokyo, the present-day Tokyo University. Kuroda was a student of the Chemistry Professor Kenjiro Kimura (Fig. 12) and, as a student, he also participated in research under the mentorship of Professor Nishina at RIKEN. Kuroda's autobiography [31] gives evidence of the status of the fundamental science in Japan before and in the beginning of the war. According to this reference, Japanese scientists Kenjiro Kimura and Yoshio Nishina attempted to discover the missing element 93, the next one after Uranium in the Periodic Table, while Nishina was a visiting researcher in Copenhagen in 1925 [32]. This account shows that Japanese scientists were aware of every major scientific achievement in the world, including the work of Enrico Fermi and that of his first PhD student, Emilio Segre [33, 34].

A number of Nobel Prize laureates from Europe visited Japan in the 1930s and even delivered lectures to the Tokyo University students. Those included Niels Bohr (1885–1962) and Francis William Aston (1877–1945), the laureates of the 1922 Nobel Prizes in Physics and of the 1922 Nobel Prizes in Chemistry [31].

The scientific community in Japan was up to date with the current research in Europe [31], including the work on the discovery of the newest elements in the Periodic Table. These included the element Hafnium 72, discovered by the Dutch physicist Dirk Coster and the Hungarian chemist George Charles von Hevesy in 1923, as well as the two elements, Rhenium 75 and Masurium 43 discovered by Ida and Walter Noddack. The discovery of element 43 was considered questionable for about twelve years until Emilio Segre, the first PhD student of Enrico Fermi, published three papers, one in Nature and two in Physical Review, reporting that the proposed element 43, currently known as Technetium, was the first to be discovered by the means of artificial synthesis [33-35].

Additionally, the manuscript of Kuroda provides information about the existence of a 26-inch cyclotron, constructed in 1936 in RIKEN, located in the town of Wako, Saitama prefecture, near Tokyo. It became operational in 1937 (Fig. 13). Even though this cyclotron was smaller than the currently existing 37-inch cyclotron in Berkeley California (Fig. 8), it gave a significant advantage to the Japanese researchers over Fermi's group of Italian researchers because it was easily accessible even to the students from the Tokyo Imperial University. As a student working on his dissertation in 1938, Kuroda was given a research project and was personally responsible for uranium purification. Following the publication of the successful discovery of nuclear fission in Otto Hahn's laboratory, Kuroda wrote that the experimental conditions at RIKEN would have allowed him to perform the same type of experiments and observe fission by registering barium six months earlier than Hahn and Strassmann , but that was not part of his assignment [31]. The cyclotron at RIKEN was in fact a significantly more advanced method of producing neutron flux compared to the radon-beryllium source used by Hahn's lab in Germany.

The high quality level of nuclear research in Japan is indicated by the publications record of the Nishina-Kimura group consisting of a paper in *Nature* in 1939 on the "Artificial Production of Uranium and Thorium" [36], followed by four papers in *Physical Review* in 1940 and 1941, co-authored by three physicists and two chemists [37-39]. These publications reported the discovery of the Uranium-237 isotope with a half-life of 6.5 days. A review on this discovery, based on the archival papers of Nishina and Kimura, was written by Nagao Ikeda, Professor at the University of Tsukuba and a former member of the Kimura Laboratory, involved on the project [32].

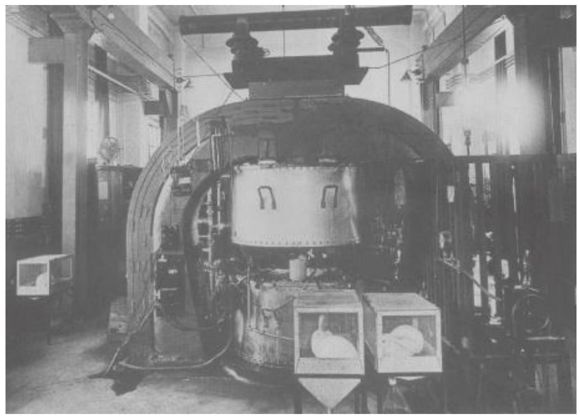

Fig. 13 The 26-inch cyclotron at RIKEN, constructed by Nishina [31]

Undoubtedly, nuclear physics was one of the most advanced fields for Japanese physics. The next stage of nuclear research during the war time is reviewed in Section 5.

4 Manhattan Project: Who were the Scientists and What Motivated Them?

The discovery of the controlled chain reaction by Leo Szilard [25, 40] and the discovery of fission by Meitner, Hahn, and Strassmann opened the doors for applying the released nuclear power in multiple ways. However, due to the political and historical situation of this time period, the first application outside of the scientific research labs was in the making of atomic bombs.

Shortly after the publication of Hahn and Strassmann on January 6, 1939 [41], fission was observed experimentally by Otto Robert Frisch, who also measured the energy of the fragments [24]. At that time he was working at Niels Bohr's Institute in Copenhagen. After spending the Christmas of 1938 with his aunt, Lise Meitner and realizing with her that fission was the only possible explanation of Berlin's group experiment, he informed Niels Bohr about this discovery upon his return to Copenhagen [42]. Otto Frisch was also credited with coming up with the term "fission," borrowing the idea from the concept of cell division [42]. From Frisch's experiments, Niels Bohr was able to both conclude that U-235 is the isotope of Uranium responsible for slow neutron fission (2) and understand why U-235 and U-238 respond differently to neutron bombardment [42]. Eq. (2) below shows one possible nuclear fission reaction resulting from neutron bombardment of U-235.

$$\mathbf{n + {}^{235}U \rightarrow {}^{141}Ba + {}^{92}Kr + 3\,n} \qquad \textbf{(2)}$$

In the end of January 1939, Niels Bohr announced the discovery of nuclear fission at the Fifth Conference on Theoretical Physics in Washington, D.C. The conference topic was low-temperature physics and superconductivity, but after Bohr's announcement, the focus was shifted to fission. Soon afterwards, many laboratories in Europe and America began duplicating the fission experiments [41]. At that time a new huge 60-inch cyclotron was built at Lawrence's lab in Berkeley and its particle beams were used to collide with target materials to create new elements. This cyclotron led to many important discoveries, including the discovery of neptunium and plutonium in 1940 by Edwin McMillan (1907–1991) and Glenn Seaborg (1912–1999), who won the1951 Nobel Prize in Chemistry, and Emilio Segre (1905–1989), the winner of the 1959 Nobel Prize in Physics.

During the Washington Conference, Robert Oppenheimer (1904–1967) calculated that the possibility of releasing massive amount of energy in the form of a bomb was quite feasible. In the case of the reaction in Meitner and Hahn's experiment (2), the total energy of fission is 176 MeV [42]. It should be noted here that the vast amount of energy released in nuclear reactions had been estimated by Rutherford and Soddy much earlier in their paper "Radioactive Change" in 1903 [43]. In this work, they estimated that the energy of radioactive change must be at least 20,000 times and possibly a million times as great as the energy of any molecular change. The discovery of fission enabled physicists to design experiments that would release such large amounts of energy. Unfortunately, in the context of the World War II, this idea was translated into creating atomic bombs capable of mass destruction.

Under the conditions of the war, the information about fission research and experiments became classified. One of the last openly published works on fission was written by the Danish physicist Niels Bohr and the Princeton physicist John Wheeler (1911–2008), entitled *The Mechanism of Nuclear Fission* [44].

The idea that nuclear fission could be used to create a bomb capable of mass destruction was of great concern to many scientists, but no government seemed increasingly interested in this idea until the beginning of the World War II. Troubled by the situation in fascist Germany, by Hitler's harsh anti-Semitic policy, and by his ambitions of territorial expansion, some scientists started to speak to their governments about this issue. One of the most active scientists in this respect was the Jewish physicist Leo Szilard, who had fled Germany like many other Jews, leaving behind everything. In the summer of 1939, he approached Albert Einstein, a fellow escapee from Germany, and convinced him to sign a letter he had written to the U.S. President F.D. Roosevelt [45]. The purpose of the letter was to inform the President about the possibility of neutron chain reaction and its potential application to weapons. It emphasized on the fact that the scientists in Nazi Germany were working on such a project. Despite the concerns of many great scientists, the government did not seem to be worried. It was not until after the United States had suffered the attack on Pearl Harbor and heard intelligence reports that Germany was working on a project to build a bomb, did the government deicide to launch the Manhattan Project. The World War II was declared only nine months after the discovery of nuclear fission by Lise Meitner and her former colleagues. Many of the scientists who worked on this project were Jewish and had been affected by Hitler's anti-Semitic policy (See *Appendix I*). They sincerely believed that their contributions aided the opposition to Hitler's extreme policy.

Fig. 14 Albert Einstein and Leo Szilard discussing the letter to President Roosevelt (1939)

The project's massive funding came on October 9, 1941, when President Roosevelt signed an executive order to begin an atomic program with the goal of creating an atomic bomb. The smaller programs prior to the Manhattan Project worked on theoretical ideas such as using the critical mass of Uranium and possible methods of separating Uranium isotopes. The two principle centers of research were located at Columbia University in New York and at the University of California in Berkeley, where the element Plutonium was discovered. Women scientists worked at both locations [46-48]. The so–called Uranium Committees were composed of scientists such as Lyman Briggs (1974–1964), Otto Robert Frisch, and Rudolf Peierls (1907–1955). The massive program established by President F.D. Roosevelt's order collected and used the results of the work done by these smaller committees. The Manhattan Project was headed by Major General Leslie Groves. Many women scientists and engineers were involved in the Manhattan Project and made important contributions. Their activities and presence were largely omitted from the official records and have been recognized only recently (See *Apendix II*) [46-48].

It was known by early 1942, that uranium existed in two naturally occurring isotopes, U-235 and U-238. Neutron bombardment of U-235 would produce an average of 2.5 neutrons and 200 MeV energy. Neutron bombardment of U-238 would produce U-239, which would emit an electron to produce Np-239. Np239 in turn would undergo beta decay to produce Pu-239, according to the following equations:

$$^{235}U_{92} + {}^{1}n_{0} \rightarrow \text{fission products} + (2.5)^{1}n_{0} + 200\ \text{MeV Energy}$$
$$^{238}U_{92} + {}^{1}n_{0} \rightarrow {}^{239}U_{92}$$
$$^{239}U_{92} \rightarrow {}^{239}Np_{93} + ß^{-1} \quad t_{1/2}=23.5\ \text{min.}$$
$$^{239}Np_{93} \rightarrow {}^{239}Pu_{94} + ß^{-1} \quad t_{1/2}=2.33\ \text{days}$$

Most importantly, for the future applications to the atomic bombs, Plutonium-239 is able to undergo fission as well and would produce energy by the same mechanism as the Uranium-235. A major challenge for both U-235 and Pu-239 was to separate them from the other products and reactants in the respective fission reactions.

In 1941, Robert Oppenheimer (1904–1967), an American–Jewish scientist, was brought into the atomic bomb project and was asked to calculate the amount of U-235 needed to sustain a chain reaction, known as its critical mass. He was appointed a chief scientist of the project in 1942. A location in Oak Ridge, Tennessee, was established to separate uranium isotopes and to create plutonium to be used in the bombs. The Oak Ridge site was just the fueling station for the upcoming assembly factory, which produced enriched Uranium–235 by the gaseous diffusion method. A second location was the Hanford Site in Richmond, Washington, where large nuclear reactors were built and plutonium was produced. The third site was the Los Alamos National Laboratory in New Mexico, where the nuclear weapons were engineered and designed.

Lawrence's lab in Berkeley was the first one to handle the problem of isotope separation and to successfully produce significant amounts of Uranium–235. In 1939 Lawrence had started the construction of a new giant 184-inch cyclotron. However, the World War II began before the new cyclotron could be finished. But the work on one of the key parts of the cyclotron, a giant 184-inch magnet, continued and was completed in 1942. In the summer of 1942 the magnet was used in a pilot plant to separate the two isotopes of natural uranium, Uranium-235 and Uranium-238. This resulted in the first significant amounts of Uranium-235 ever obtained. The 184-inch magnet remained in use at Berkeley until the end of the war and was providing information to Oak Ridge site of the Manhattan Project, where a large separation plant was built. [49].

A critically important step in the project was achieved by Enrico Fermi's group, which successfully demonstrated controlled chain reaction at the University of Chicago in December 1942. The University of Chicago had been selected as a research center consolidating the research related to an atomic bomb. To disguise the nature of the research, it was called the 'Met Lab'. The first nuclear reactor was called a pile or CP-1 (Chicago Pile 1), since they were built up of big piles of graphite and uranium blocks. The pile produced a small amount of Plutonium-239, in addition to access neutrons and energy. This was the world's first demonstration of controlled, self-sustaining nuclear chain reaction.

One of the women who worked on the calculations related to the piles was Katharine (Kay) Way (1902–1995), who analyzed the neutron flux from the early atomic piles to estimate if the neutron multiplication factor was sufficient for self-sustaining chain reaction [46]. She studied mathematics at Columbia University and, after received her B.S. in 1932, became the first Ph.D., student of the American theoretical physicist John Wheeler (1911–2008) at the University of North Carolina at Chappell Hill, where Wheeler taught before moving to Princeton University [46].

Another female physicist, who worked on the Manhattan Project was Leona Woods (Leona Marshall Libby). She had graduated with a Ph.D. in Molecular Spectroscopy from the University of Chicago, and participated in the work on CP-1. Leona Wood was the only female member in Fermi's group as shown in a photo taken on the fourth anniversary of the experiment (Fig. 16). She contributed to the construction of the boron trifluride detectors used to monitor the flux of neutrons from the piles and was present on December 2, 1942 when CP-1 went critical and produced the first self-sustained nuclear fission reaction [46]. After this successful experiment, the first reactor was dismantled and rebuilt at the Met Lab's Argonne Lab at Site A, outside Chicago. Leonna Woods Marshall continued working on the project CP-2 at Site A. When her husband John Marshall was sent to Hanford, she moved with him and worked on the construction of the plutonium production reactors there [46].

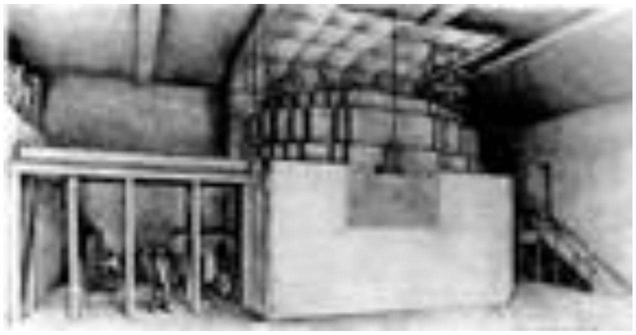

Fig. 15 The first controlled chain reaction, Chicago, Dec. 2, 1942. (Courtesy of the Argonne National Laboratory)

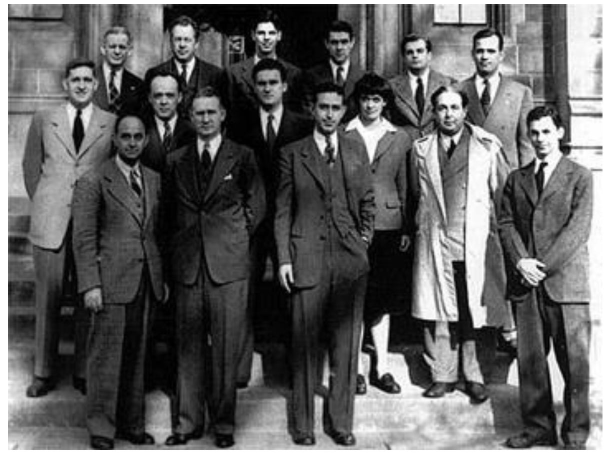

Fig. 16 The Chicago pile team in 1946. Leona Woods is the only woman in Fermi's group (in the middle row) [50]

Jane H. Hall was another physicist who worked at the Met Lab [47]. After she and her husband, the Manhattan Project physicist Theodore Hall, left the Met Lab and went to Hanford, she worked in reactor safety and health physics [46]. Later she went to Los Alamos, NM and became Associate Director, becoming one of the very few women who worked in management positions during the Manhattan Project [46, 48].

The challenges to produce controlled chain reaction had been resolved, yet the separation of Plutonium-239 from uranium and from the other radioactive fission products still remained. After the successful demonstration of the controlled chain reaction, President Franklyn Roosevelt approved building full-scale plants to produce both Uranium-235 and Plutonium-239, on December 28, 1942. This took place at the Oak Ridge site, which just served as a fueling station for the upcoming assembly factory.

Oppenheimer's main factory for designing and assembling the bombs was located in Los Alamos, New Mexico (Fig. 17). Los Alamos was the most secure location to work on the atomic bombs because it was near the New Mexico desert and distant from any major cities. In Los Alamos, the head scientist and engineers solved many issues ranging from the design of the bomb to the consequences of its detonation. The scientists came up with two types of bombs—one designed to contain Uranium and the other to contain Plutonium.

Fig. 17 Los Alamos National Laboratory, New Mexico. [51]

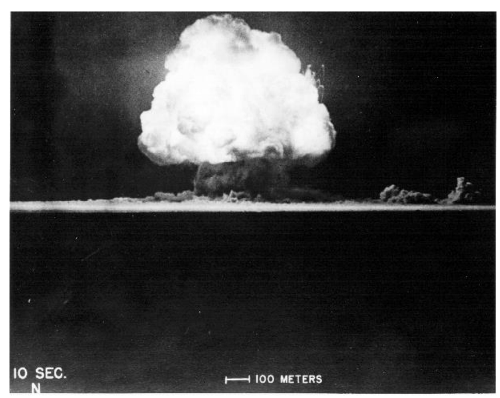

Fig. 18 First atomic bomb test, Trinity. [52]

The two types of bombs were named for their triggering mechanism, gun and implosion. The gun bomb used Uranium. The idea behind this bomb was to have a controlled explosion on one end of the bomb which drove one piece of fissionable material into the other side, creating the critical mass that started the chain reaction and released the maximum amount of energy. The implosion technique was fueled by Plutonium, which would be compressed by an explosion around the core mass. The compression squeezed the loosely packed Plutonium together, forming the critical mass. The implosion technique involved many difficulties. In order to release the desired amount of energy, the implosion process had to have just enough fission material to be consumed before it destroyed itself. Another difficulty lay in using the proper amount of material to reach critical mass. The leading physicist in the world solved both of these issues at the Los Alamos facility.

The first atomic bomb was tested near Los Alamos in the desert near Alamogordo, New Mexico (Fig. 18). The name of the bomb was *Trinity*, an implosion design. The explosion occurred on July 16, 1945. The scientist and generals were quoted for saying they were not prepared for the amount of destruction that occurred. The power of the bomb could be seen 100 miles away where windows were knocked out. *Trinity* left a crater in the desert about a half-mile wide. With this detonation, the world had entered the nuclear bomb era. At the time of the test Germany is already defeated.

Soon after the test, acting President Truman decided to unleash the new bomb on Japan in an effort to end the war. The first of two bombs, *Little Boy*, was dropped on Hiroshima, Japan, on August 6, 1945. The bomb was composed of Uranium-235 and was a gun trigger. The second bomb, *Fat Man*, was dropped on Nagasaki, Japan, on August 9, 1945. It was composed of Plutonium and was an implosion trigger.

5 Atomic Bomb Project in Japan: Conspiracy versus Facts

Japan was the only country that experienced the devastating impact of the first two atomic bombings. The country was defeated at the end of World War II after the two bombs detonated over Hiroshima and Nagasaki. Because of the vast amount of the energy released and the radiation created as a result of the nuclear fission reaction, the impacts exceeded anything else experienced by humans until then.

A number of publications claim that Japan also had a program dedicated to creating atomic bombs and would not have hesitated to use them had they won the nuclear research competition with the United States. Some sources even go so far as to claim that Japan had successfully tested an atomic bomb in North Korea and had their bomb ready one day after the second atomic bomb detonated over the city of Nagasaki. This section summarizes a number of publications regarding possible work on atomic bombs during World War II and attempts to clarify the difference between evidence supported academic work and speculations. To the best of our knowledge, the leading expert on Japan's nuclear history worldwide is Masakatsu Yamazaki, a nuclear physicist and Professor Emeritus of Tokyo Institute of Technology, whose most extensive research has been published in 2011 in a book, available only in Japanese [53]. The history professor Walter Grunden is the author of the most extensive English study of the nuclear research in Japan during World War II [54]. Critical readers should use caution in distinguishing between evidence based scholarly publications and sensation seeking journalism, studying the evidence carefully before making their own conclusions. The present section is an attempt to clarify the difference between myths and facts, conspiracy theories and actual events. According to several sources, Japan tried to develop a nuclear bomb but failed [55, 56]. Two of the leading proponents of the Japanese atomic bomb conspiracy are the authors Debora Shapley and Robert Wilcox. Shapley was published in the news section of *Science* in 1978 [57]; Wilcox authored *Japan's Secret War: Japan's Race Against Time to Build Its Own Atomic Bomb* [57]. Professor Walter Grunden expresses opposition to Shapley and Wilcox's view, criticizing the conspiracy theorists for their lack of solid evidence and contradiction with many other scholarly publications [57].

In 1982, several newspapers published an interview with the 83-year-old Colonel Toranosuke Kawashima (1897-1984), who was under orders by the Japanese Prime Minister Hideki Tojo (1884-1948) to build an atomic bomb during World War II. He made a statement about the Japanese atomic bomb program, which, he said, was initiated by Prime Minister Hideki Tojo in January of 1943. According to Kawashima, the program employed a dozen Japanese nuclear scientists, including the father of modern physics in Japan Yoshio Nishina. The program, however, was held back due to the lack of access to Uranium in Japan. To resolve the problem, Nishina asked the officers for two tons of Uranium ores. In response, the army sent a telegram to the Japanese ambassador in Berlin to request Uranium from Germany. In his statement, Colonel Kawashima, who was personally responsible for acquiring the Uranium, said that Hitler agreed to help and had sent a German submarine carrying two tons of Uranium, but the submarine was sunk by an Allied naval vessel and never reached Japan [59, 60]. This episode was publically discussed in *The Seattle Times* in 1997 by the late world-renowned nuclear physicist Herbert York, who participated in the development of the American atomic bomb as a young researcher. According to this article, the Uranium that was supposedly taken to Japan came from the present-day Czech Republic, where Germany had control over large deposits of Uranium [61]. However, the title of this article itself, "*Was Japan close to producing an a-bomb? Material sent by German U-boat, but no solid evidence yet found*," suggests that the previously mentioned publications are based merely on speculations.

The Making of the Atomic Bomb, a book written by Richard Rhodes, dedicates several paragraphs to the Japanese nuclear research [62]. Comparing the level of nuclear research in Germany and Japan, the book suggests that even though Japan had fewer qualified physicists than Germany, they were theoretically better prepared than them, partially due to the fact that many talented German scientists were forced to flee their country. According to Rhodes's book, Japan not only had physicists whose calculations were more accurate than those of Heisenberg's, but also was further along than Germany in its ability to purify Uranium. Like the German scientists, the Japanese were able to isolate only small amounts of Uranium for laboratory use, but not nearly enough for the making of an atomic bomb.

Wilcox's *Japan's Secret War,* a book unsupported by traceable evidence, suggests that Japan not only had its own version of the Manhattan Project but even made a bomb, which was completed on August 10, 1945, only a day after the second atomic bomb was dropped in Nagasaki [58]. According to the book, "just six days after Hiroshima, Japan tested its own atomic device on a small island 20 miles off the Korean coast! The sobering conclusion is that Japan may have been just weeks behind the U.S. in the race for the bomb" [58]. We share the opinion of the critics of this publication—that it lacks balance and objectivity [63].

A small fraction of the claims made by the speculation theorists are supported by scholars who are experts in the field [53, 54]. Yamazaki's Japanese publication confirms that the Japanese Army officially asked the leading nuclear physicist in Japan, Yoshio Nishina, to focus his research on nuclear fission, both in the interests of basic science as well as for the possibility of making an atomic bomb [53]. Indeed, after learning about the defeats of the Japanese Navy in 1942, Nishina spent some time on bomb related research [53,54]. However, his multiple efforts to extract a meaningful amount of Uranium 235 failed. Nishina officially announced the end of this project at an official meeting at RIKEN on May 15, 1945 [54]. This decision was also reported to the Japanese Army and, based on the report, the Army issued an internal report on June 28, 1945. The report declared that, after trying various methods and failing, they concluded that the extraction of Uranium 235 was impossible and that the situation must be the same in the Allied countries. Therefore, they discontinued the research on atomic bombs [54].

However, Nishina had to revise this conclusion only three months later. After the first atomic bomb destroyed Hiroshima, Nishina joined the study team of scientists who went to Hiroshima to evaluate the impact of the bomb. The team concluded that the bomb that dropped on Hiroshima must have been an atomic bomb based on the evidence at the impact site [54]. Nishina realized that he had misjudged the ability of the Allied countries to produce an atomic bomb. He felt such a load of responsibility for his conclusion that he considered committing *hara-kiri* (a form of suicide performed by cutting open one's own stomach).

Regarding the aftermath, what matters the most is not the details and the stages of the nuclear research, but the devastating impact of the atomic bombs [64]. Many of the survivors (Fig. 19) of the atomic bombs are still alive and willing to share their stories with people who are willing to listen [65]. John Hershey's book *Hiroshima* [66], considered the most important work of journalism in the 20th century, and Takashi Nagai's book *The Bells of Nagasaki* [67] both provide powerful details about the tragic events in Hiroshima and Nagasaki and show how these events impacted the personal lives of the people who survived the atomic bombings.

Dr. Takashi Nagai, a nuclear physicist, a doctor of radiology, and a great spiritual leader in Asia, suffered first-hand the impact of the plutonium bomb that dropped over Nagasaki on August 9, 1945. [67]. Before his death from radiation exposure, Takashi wrote 17 books and a report to Nagasaki University. In his account of the impact of the atomic bomb, he wrote about a discussion with the surviving members of his research group, all of whom had a great interest in and dedication to nuclear physics when the atomic bomb exploded over Nagasaki on August 9, 1945 [67]. This account reveals the knowledge that Japanese nuclear scientists had regarding worldwide research on nuclear physics, including that of Lawrence, Compton, Einstein, Bohr, Fermi, Chadwick, Joliot-Curies, Meitner, and Hahn. The researchers guessed that the type of atoms used in the bomb was Uranium. Their conversation reveals their awareness of where Uranium could be found, of the cyclotron in RIKEN, and of the discovery of fission (including the chain reaction and the role of the neutrons in it) as well as their confidence that Japan was not working on an atomic bomb.

After the war, Japan was left defeated and suffering from the impact of the two atomic bombs, and nuclear physics research itself took a fatal blow. The Allied Occupational Forces General Headquarters (GHQ) destroyed all four cyclotrons in Japan, including two in RIKEN, one in Osaka Imperial University, and one in Kyoto Imperial University. This was an unnecessary step since it was impossible for Japan to produce even one atomic bomb without having a certain amount of Uranium, a rare natural resource in Japan. On November 4, 1945, GHQ granted permission, with some limitations, to the request of Prof. Nishina to resume the cyclotron experiments [68].

Fig. 19 Hiroshima atomic bomb survivors suffering from burns and other injuries on the day of the explosion. About 2,270m from the hypocenter, 11 am, August 6 1945. Photo by Yoshito Matsushige

However, GHQ retracted its permission on November 24, and the U.S. Army destroyed the cyclotrons. That news shocked the American physicists and some of them, including Prof. Karl T. Compton, President of MIT, sent written protests to the President and to the Secretary of Defense. According to *The New York Times*, Dec. 1, 1945, Prof. Irvin Langmuir said at the Upper House that “You can’t gain atomic bombs from cyclotrons, you gain knowledge” [69-72].

6 Concluding Remarks

The discovery of nuclear fission was one of the greatest intellectual achievements within 20th century physics. Physics advanced exponentially after the discovery of the neutron. Such advancement eventually resulted in the discovery of nuclear power, which was achieved by putting together the work of the world’s most brilliant minds. Today, nuclear power is used in most countries in the world and in many space missions. The fundamental scientific contributions discussed in the present review led to the discovery of fission, which in turn led to the development and multiple applications of new interdisciplinary fields such as nuclear medicine, medical physics, radiology, radiobiology, and radiation oncology (Fig. 20). From the atomic bomb to the most recent submarine, the principles of nuclear physics play a key role in human lives, both in positive and in negative aspects. Unfortunately, under the conditions of World War II, this creativity of so many great minds resulted in destruction and disaster,

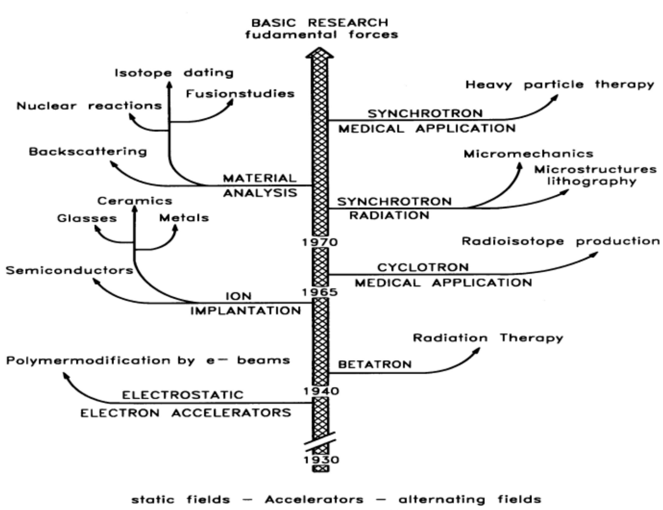

Fig. 20 Applications of Nuclear Physics and accelerators to basic and medical research [73]

a disturbing fact to physicists who are dedicated in their quest for truth. One might wonder if these brilliant scientists considered how their discoveries would be used. Should they be held responsible for the disastrous impact of the bombs dropped over Hiroshima and Nagasaki? Are physicists in control of their intellectual achievements? Questions about the responsibility of the physicists are frequently raised by the people at large. The present section sheds light on the degree of responsibility of the physicists involved in the fascinating fundamental research on the quest for truth and on the applications of their discovery. Below are some thoughts of scientists who worked on the fission related research.

Marie Curie, the only recipient of Nobel Prize in Physics (1903) and in Chemistry (1911), explained the motivation behind her research: “the search for the pure knowledge is one of the most important needs of mankind” [74]. She is also quoted for saying: “I am one of those who think like Nobel, that humanity will draw more good than evil from new discoveries” [75].

Francis Aston, the recipient of the 1922 Nobel Prize in Chemistry, addressed the responsibility of future scientists in the final paragraph of his Nobel Lecture, delivered in December 1922: “Should the research worker of the future discover some means of releasing this energy in a form which could be employed, the human race will have at its command powers beyond the dreams of scientific fiction; but the remote possibility must always be considered that the energy once liberated will be completely uncontrollable and by its intense violence detonate all neighboring substances” [31]. This was the first official warning to the world about the potential use of atomic energy.

Lisa Meitner, one of the major contributors to the discovery of fission, described her love for science like this: “Science makes people reach selflessly for truth and objectivity, it teaches people to accept reality with wonder and admiration, not to mention the deep awe and joy that the natural order of things brings to the true scientist” [19]. When Lise Meitner was asked to participate in a project that would apply fission to atomic bombs, she said,”I will have nothing to do with a bomb” [20].

Albert Einstein’s famous formula $E=mc^2$ is at the heart of the fission reaction, allowing scientists to calculate the released energy in any reaction. Einstein, however, derived it theoretically and didn’t think about applying it to weapons. Often his name is related to the atomic bomb because of the letter to the President that he signed out of fear that the German scientists under Hitler would make a bomb using the principle of nuclear fission. Later in his life, Einstein became a pacifist.

However, the Manhattan Project had ultimately been designed to create a bomb of mass destruction. Robert Oppenheimer himself expressed in 1947 his feeling of guilt, saying that “In some crude sense, which no vulgarity, no humour, no overstatement can quite extinguish, the physicists have known sin and this is a knowledge which they cannot lose” [76]. Many of the scientists who worked on the Manhattan Project were Jewish escapees from Germany who had suffered the anti-Semitic policy of Hitler *(Appendix I).* They sincerely believed that working on an American atomic bomb would prevent Hitler’s power from spreading. After Germany was defeated, many scientists didn’t see the necessity of using the atomic bombs at the end of the war. Few of the scientists at Los Alamos saw a need for a second bomb to be dropped on Nagasaki. Otto R. Frisch, one of the Jewish physicists who worked on the Manhattan Project, was reportedly disturbed when the bomb was dropped in Hiroshima. Many talented women physicist, chemists, biologists, mathematicians, and technicians contributed to different stages of the scientific discoveries, yet they were not given proper credit for their contributions in most of the publications on the topic. The present work is an attempt to do that. This is particularly important because even today, according to the most recent Global Report, the gender gap is still not bridged [77].

Some publications speculate about an atomic bomb program in Japan, although such speculation is not supported by evidence. The academic researchers with expertise on the subject provide details about preliminary atomic bomb research, but the research did not evolve into a large scale project due to the lack of Uranium resources in Japan. Regarding the aftermath of the impact of the atomic bombs, the stage of Japan’s nuclear research is irrelevant and cannot justify the dropping of the atomic bombs in Hiroshima and Nagasaki. Both Hiroshima and Nagasaki were destroyed beyond recognition and the radiation damage and ecological impact exceeded anything observed until then. In the words of Max Born from 1957, “Since the destruction of Nagasaki and Hiroshima the atom has become a spectre threatening us with annihilation.”

The images of destruction in the two destroyed cities are difficult to describe in words. The so-called A-Bomb Mound in the Peace Park in Hiroshima, is a grassy mound made from the ashes of 70,000 unknown victims of the bombing. A photograph of a little boy carrying his dead baby brother on his back and preparing to cremate him, was displayed for the first time in the Peace Museum in Hiroshima in 2013. No figure on a page of the present journal can give the reader a true feeling of the gravity of such tragedy. Only by crossing the distance to Hiroshima and Nagasaki to see the artifacts and hear the testimonies of the *hibakusha* (atomic bomb survivors) might one be able to relate to the experience of those who suffered the atomic bombing.

Regardless of one's point of view, the war, not science, is to be blamed for the damage and the destruction. The scientists served their countries while keeping high research standards.

These moments of discovery and the resulting impact of the atomic bombs require and deserve attention. We cannot afford to forget, and we cannot let the destructive power of another atomic bomb to be used against humanity.

7 Acknowledgements

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Appendix I: Some Jewish Scientists Involved in the Manhattan Project[3]

Jacob Beser	(American Jew)	Weapons firing and fusing
Hans Albrecht Bethe	(German born Jew)	Chief - Theoretical Division
Felix Bloch	(Swiss born Jew)	Worked under Hans Albrecht Bethe, performing nuclear fission research
David Bohm	(American Jew)	Performed theoretical calculations for the Calutrons at the Y-12 facility in Oak Ridge, used to electromagnetically enrich uranium for use in the bomb dropped on Hiroshima
Niels Bohr	(Danish born Jew)	Consultant to the Project
Gregory Breit	(Russian born Jew)	Predecessor of J. Robert Oppenheimer
James Chadwick	(British born Jew)	Chief - British Mission
Samuel T. Cohen	(American Jew)	Worked in the Efficiency Group
Albert Einstein	(German born Jew)	Consultant to the Project
James Franck	(German born Jew)	Director - Chemistry Group
Stan Frankel	(American Jew)	Theoretical Division
Otto Frisch	(German born Jew)	British Mission
Klaus Fuchs	(German born Jew)	Theoretical Division
Samuel Goudsmit	(Danish born Jew)	Scientific Head of the Alsos Mission
David Greenglass	(American Jew)	Manhattan Project Infiltration
Theodore Alvin Hall	(American Jew)	Youngest Scientist at Los Alamos
Morris Kolodney	(American Jew)	Manager - DP Site
George A. Koval	(American Jew)	Special Engineer Detachment
Nicholas Kürti	(Hungarian born Jew)	Worked with Franz Eugen Simon (German born Jew); developed a method of separating uranium 235 from raw uranium ore
J. Robert Oppenheimer	(American Jew)	Scientific Director - Project "Y"
Frank Oppenheimer	(American Jew)	Brother of and Assistant to J. Robert Oppenheimer
Rudolf Peierls	(German born Jew)	British Mission
George Placzek	(Moravian born Jew)	British Mission
Richard Phillips Feynman	(American Jew)	- Group Leader - Theoretical Division
Isidor Isaac Rabi	(Polish born Jew)	Consultant to the Project
Eugene Rabinowitch	(Russian born Jew)	Metallurgical Laboratory
Louis Rosen	(American Jew)	"Father" of the Los Alamos Neutron Science Center
Joseph Rotblat	(Polish born Jew)	Worked with James Chadwick
Emilio Gino Segrè	(Italian born Jew)	Group Leader
Louis Slotin	(Canadian born Jew)	Critical Testing - resulted in his accidental death
Leó Szilárd	(Hungarian born Jew)	Group Leader - Metallurgical Laboratory
Edward Teller	(Hungarian born Jew)	Thermonuclear Research
Stanislaw Ulam	(Hungarian born Jew)	Mathematician, developed the Monte Carlo method
Victor Weisskopf	(Austrian born Jew)	Theoretical Division
Alvin Martin Weinberg	(American Jew)	Theoretical Physics under Eugene [Paul] Wigner
Eugene [Paul] Wigner	(Hungarian born Jew)	Group Leader, Metallurgical Laboratory

[3] This partial list, including only the most important Jewish scientists who contributed to the Manhattan Project, was adopted from http://gblt.webs.com/Atomic_Bomb_Jewish_Invention.htm

Appendix II: Some Women Physicists and Chemists Involved in the Manhattan Project [4]

Elda Anderson	(Los Alamos/Oak Ridge)	fission measurements
Mary Langs Argo	(Los Alamos)	nuclear fusion calculations
Joan Hinton Engst	(Los Alamos)	reactor design, construction
Mary Rose Ford	(Oak Ridge)	health physics
Elizabeth Graves	(Los Alamos)	neutron scattering
Jane Hamilton Hall	(Met Lab/Hanford)	reactor supervisor
Helen Jupnik	(Princeton)	neutron absorption
Margaret Ramsey Keck	(Los Alamos)	explosives/medical physics
Leona Woods Marshall	(Met Lab/Hanford)	reactor design, detectors
Maria Goeppert Mayer	(Columbia Univ./Los Alamos)	opacity calculations
Rose Mooney-Slater	(Met Lab)	crystallography
Gertrud Nordheim	(Oak Ridge/Los Alamos)	neutron diffusion
Edith Quimby	(Columbia University)	medical physics
Jane Roberg	(Los Alamos)	fusion weapon calculations
Elizabeth Rona	(Oak Ridge)	Po-210 initiator prep
Lyda Speck	(Los Alamos)	neutron spectra
Leona Stewart	(Los Alamos)	experimentalist
Katharine Way	(Met Lab/Oak Ridge)	reactor design
Chien-Shiung Wu	(Columbia University)	xenon in reactors
Myrtle Batchelder	(Met Lab/Los Alamos)	analytical chemistry
Nathalie Baumbach	(Met Lab)	plutonium chemistry
Yvette Berry	(Hanford)	prep & analysis
Ethaline Cortelyou	(Met Lab)	plutonium chemistry
Marjorie Evans	(Met Lab)	plutonium chemistry
Hoylande Young Failey	(Met Lab)	plutonium chemistry
Rosellen B. Fortenberg	(Oak Ridge)	analytical chemistry
Margaret Foster		U and Th analysis
Kathleen Gavin	(Met lab)	plutonium chemistry
Nathalie M. Goldowski	(Met Lab/Hanford)	fuel cladding
Lottie Greiff	(Columbia University)	chemistry
Susan C. Herrick	(Columbia Univ/Oak Ridge)	uranium chemistry
Lilli Hornig	(Los Alamos)	Pu chemistry, explosives
Isabella L. Karle	(Met Lab)	transuranic chemistry
Margaret Melhase	(Met Lab)	co-discoverer of Cs137
Mary L. Miller	(Los Alamos)	supervised chemistry lab
Rose Mooney-Slater	(Met Lab)	crystallographer
Mary Nachtrieb	(Los Alamos)	Pu chemistry
Mary Holiat Newman	(Columbia Univ./Oak Ridge)	U isotope separation
Elaine L. Novey	(Argonne)	chemistry technician
Anne Perley	(Los Alamos)	biochemistry/radiation
Ada Kirkley Perry	(Oak Ridge)	analytical chemistry Y-12
Elizabeth Rona	(Oak Ridge)	Po-210 initiator prep
Roberta Shore	(Argonne/Oak Ridge)	chemistry
Marie Stuart	(Oak Ridge)	radiochemistry
Juanita Wagner	(Oak Ridge)	analytical chemistry
Ellen C. Weaver	(Oak Ridge)	fission fragment

[4] This partial list, including only the most important women scientists who contributed to the Manhattan Project, was adopted from Herzenberg C., Hyde Park Women in the Manhattan Project