On the History and Technology of the Atomic Bomb. The Commitment of the Scientists

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Abstract The development of the atomic bomb in the first half of the twentieth century marked a turning point in the history of nuclear science because it revealed the close relationships that exist among science, technology and society. In this paper the main discoveries that led to the scientific and technological development of the atomic bomb are presented together with the commitment of scientists who tried to avoid possible harmful uses of the results of their researches.

In this work a deep examination of the writings of some of these scientists is introduced, some of which are still unpublished, although already quoted by several authors, with the purpose to highlight the relevance of their position against the bomb to the present day. In this sense the content of the paper may appear as a novelty within the history of science and technology; even if it cannot be a unique story.

Keywords Atomic bomb · Soddy · Szilard · Rasetti · Oppenheimer · Commitment of the scientists

1 Introduction

It is generally believed among non-scientists that the invention of the atomic bomb took place in the United States of America during the Second World War and that it was made possible by the discovery of uranium fission, by Otto Hahn (1879–1968) and Fritz Strassmann (1902–1980), in Germany, in December of 1938. This isn't completely correct. The process that led to invention of the bomb was actually much longer, lasting about half a century, and was characterized by a series of discoveries of which the first and certainly the most important was that of the enormous amount of energy associated with natural radioactive phenomena made at the beginning

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R. Pisano (ed.), *A Bridge between Conceptual Frameworks,* History of Mechanism and Machine Science 27, DOI 10.1007/978-94-017-9645-3_7

of the twentieth century by Ernest Rutherford (1871–1937) and Frederick Soddy (1877–1956). Soddy was the first to pose the problem of the social significance of this discovery, even before Einstein formulated his famous law of energy.

As we shall see in the next paragraphs, in the 1930s there was a succession of discoveries: existence of the neutron, the radioactivity produced by alpha-particle bombardment, the neutron induced radioactivity, the properties of slow neutrons, nuclear fission, the nuclear chain reaction, until the invention of the atomic bomb.

Physicists immediately realized the great potentialities and possible applications of nuclear physics. But before the certainty that a bomb of unprecedented destructive power could actually be built, there were some scientists who undertook to avoid potentially harmful uses of science.

In this paper I want to emphasize the commitment of these individuals who tried by all means in their power to involve other scientists, scientific institutions and societies in their struggle.

Frederick Soddy, based on his personal experience, said that perhaps as they were constituted, scientific organizations were not suitable to deal with ethical issues (Soddy 1945, p. 9). Yet this work aims to demonstrate that the most reasonable way to address these issues is just internal debate within the scientific community.

2 The Discovery of Atomic Energy by Rutherford and Soddy

At the beginning of the twentieth century, at McGill University in Montreal, Rutherford and Soddy made important contributions to the study of radioactivity.

In 1901, Soddy brought his experience as a chemist to the study of gaseous emanation of radioactive thorium which had been observed by Rutherford a few years earlier. Soddy realized that thorium was transformed spontaneously in an inert gas of the argon family. This was the first, clear, experimental evidence of the direct formation of a chemical element known from another one.[1]

Their collaboration led quickly to the complete interpretation of radioactive phenomena as natural processes of spontaneous sub-atomic disintegration. Between 1902 and 1903, the two scientists published a series of articles describing the importance of the general theory of radioactivity with the laws of radioactive decay (Rutherford and Soddy 1902a, 1902b, 1903).

[1] [1]Rutherford won the Nobel Prize for Chemistry in 1908 “for his investigations into the disintegration of the elements and the chemistry of radioactive substances”, although the chemist of the team was Soddy. He gained due recognition only with the Nobel Prize in 1921 “for his contributions to our knowledge of the chemistry of radioactive substances and his investigations into the origin and nature of isotopes”. In 1913, in fact, he had found that certain elements exist in two or more forms with different atomic weights but they are chemically indistinguishable. Between 1911 and 1913, he had also formulated the Law of radioactive displacement, which refers to the fact that the emission of an α particle by an element moves it back two places in the periodic table, while the emission of a β particle situates it in one position forward. His naming to the Royal Swedish Academy of Sciences was proposed by Rutherford (and supported by Thomson), as if to repay the debt contract with Soddy on the occasion of the Nobel Prize in 1908.

As for the purposes of this study, the most relevant result obtained by the two scientists concerns their discovery of the huge amount of energy associated with radioactive phenomena. They, in fact, in 1903, estimated the total energy released during the radioactive decay of 1 g of radium, evaluating the kinetic energy of α particles emitted. They discovered that for a given mass, much more energy was emitted (up to a million times) than was produced in any known chemical reaction (Rutherford and Soddy 1903).[2]

In 1904 Ramsay and Soddy arrived at a more accurate estimate of this energy by multiplying the heat generated (per unit of time elapses) by the radioactive emanation from radium in a unit of time by the average life of emanation, which they measured. They found that the relation between the energy emitted by the radium emanation during its disintegration and the one released in the association of hydrogen and oxygen for the formation of water is, for the same weight, about 216,000 (Ramsay and Soddy 1904, p. 357).

The discovery of the immense amount of energy associated with atomic disintegration preceded, a few years, the famous formula $E = m \cdot c^2$ of special relativity. Einstein himself, in 1905, had suggested that his theory could perhaps be confirmed by "using bodies whose energy content is variable to a high degree (e.g. salts of radium)" (Einstein 1905, p. 174, line 19). Then he returned to this subject to express his doubts about the effective possibility of testing, in an experimental way, his theory because of the limits dictated by the technology of the time, unless other radioactive phenomena were discovered in which there was a greater mass fraction that would be transformed into energy (Einstein 1907, p. 288; 1910, p. 144). See also Pais (1982) pp. 148–149.

3 Soddy in the Face of the Risks and the Expectations of Atomic Energy

In 1903, Soddy returned to England and became adviser for and a commentator on the recent discoveries made together with Rutherford on radioactivity, putting particular emphasis on the inexhaustible energy associated with this phenomenon.

At the Bodleian Library, Oxford University, a document has been preserved that gives an account and the interpretative key of his speeches and articles of that period. It is a letter addressed to Harold Hartley, dated 22 May 1953, in which Soddy says:

> As I have indicated in these years one could not possibly have discussed radioactivity at all without reference to the hitherto completely unsuspected colossal store of energy latent in the atom and only knowable when the atom disintegrates.[3]

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[2] In March 1903, Pierre Curie (1859–1906) and Albert Laborde (1878–1968) had measured the heat developed in a Bunsen ice calorimeter from a known amount of radio in a defined time. They found enormous values of the order of 100 calories per hour for a single gram of radium (Curie and Laborde 1903). These authors, however, did not consider it possible that this heat was developed at the expense of the internal energy of the radium but they thought that it came from a source outside the atom, of unknown nature (on this topic see Soddy 1904b, Chap. XI entitled "The energy of radio-active change", pp. 165–170).

[3] Soddy (1953, f 282, 2, line 6).

In Contemporary Review, particularly in May of 1903, he used for the first time the term *atomic energy* in referring to the inexhaustible amount of energy stored in matter, and he asserted that radioactivity would have led to "alter our attitude towards inanimate matter", that it had to be considered as a vast reservoir of energy (Soddy 1903a, p. 720, line 10).

In his writings of that period he pointed out that the internal energy of the elements had to be really great because only a minimal fraction of it was released: the difference between the energy stored in the atom before and after its radioactive transformation was small (Soddy 1906). He pointed out, moreover, that, if 1 day scientists were able to accelerate the speed of radioactive transformations, it would be possible to solve problems related to the depletion of energy resources (Soddy 1903b). But also that human beings could create a bomb capable of destroying the whole world, if only they want to (Soddy 1904a).

The fundamental popular work, written in non-technical language by Soddy, was *The interpretation of radium*, 1909. It exposes the contents of six experimental lessons of popular character held at the University of Glasgow in 1908. The book had a wide circulation, including being translated also into Russian and to having two subsequent editions, in 1912 and in 1920, revised and updated with the advance of scientific knowledge.

In the first edition, in particular, Soddy underlines the possibility of catastrophes, consequences of the irresponsible use of atomic energy. On the whole, however, the volume expressed great hope in the potential of science and humanity. Thanks to atomic energy, scientists could explore distant worlds, make the desert habitable, and transform the whole planet into "one smiling Garden of Eden", freeing man from his daily needs and changing his relationship with nature (Soddy 1909, p. 244, line 17). Reading the 11th chapter of this book inspired Herbert George Wells (1866–1946) to write his novel *The world set free*[4] that in its turn would influence the choices of Leo Szilard (1898–1964) and other scientists against the atomic bomb.[5] In 1926, Soddy expressed his appreciation to Wells for "his customary brilliance and insight" that he had shown in analyzing the possible consequences of the discovery of atomic energy (Soddy 1926, p. 28, line 18).

The reading of the novel and even more the disasters of the First World War (with the transformation of many technological processes in devices of war) convinced Soddy to spend all his energies (as did several nuclear physicists many years after him) to warn humanity because

> the social effect of recent advances in physical science promises to be annihilating, unless, before it is too late, these arises an equal and compensating advance, of which there is at the present no sign, in the moral and spiritual forces of society[6]

[4] In this science fiction novel, H. G. Wells predicts, about 20 years in advance, the discovery of artificial radioactivity, the industrial use of atomic energy and a global conflict resulting from the use of "atomic bombs", with the devastation of the main cities of the planet (Wells 1914).

[5] See the 6th paragraph and Cioci (2008).

[6] Soddy (1915, p. 13, line 19).

Soddy tried to reform the Royal Society, transforming it into an organization engaged in functions similar to those that the BMA (British Medical Association) performed for doctors, who were required to utter the Hippocratic oath before they began to exercise their profession.

Soddy undertook to increase the democratic participation of Fellows in the life of the Society, proposing a series of measures including the possibility to elect the Council or new Fellows by postal vote (Soddy 1934). Moreover, he considered "that there should be a new system to make known to the public the achievements of scientists at the earliest possible moment"[7] in order to prevent, before it is too late, possible harmful uses of science.

Even later, he returned again to the crucial role to be played by the Society of specialists in making scientists responsible for the use of their discoveries and inventions (Soddy 1945, p. 9). Soddy advocated the establishment of a strong international authority, linking scientific institutions around the world and forcing scientists

> to obey a code of ethics drawn up for their protection and guidance, and requires from them an oath that they will not be a party to assisting in war work before allowing them to engage in scientific work, having adequate power to withhold the means for their doing so.[8]

4 The Discovery of Neutron-Induced Radioactivity

A study by Spencer Weart, former director of the Center for History of Physics, American Institute of Physics, showed that during the first decades of the 1900s, radium took almost the same proportion of space in printing as nuclear energy did in the 1960s (Weart 1982).

After the First World War and publication of The World Set Free, numerous short stories and novels were published in which was described the general destruction caused by new scientific weapons and in some cases also atomic ones.

In 1919, Rutherford performed the first artificial transmutation of the atom according to the nuclear reaction

$$^{14}N + \alpha \rightarrow {}^{17}O + p. \tag{1}$$

An alpha particle collides with a nitrogen atom knocking out a hydrogen nucleus—which Rutherford dubbed the proton in 1920—and changing the nitrogen in oxygen into the form of an oxygen isotope with mass number 17.

However, about 30 years had passed since discovery of the huge amount of energy associated with radioactive decay without having seen any considerable advances towards using macroscopic atomic energy. But in 1932 John Cockcroft (1897–1967) and Ernest Walton (1903–1995) split lithium in alpha particles, bom-

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[7] The Sydney Morning Herald (1935, f 124, line 43).

[8] Soddy (1949, p. 128, column 1, line 52). For the significant contribution made by Soddy to economics, linked to his commitment to the prevention of war, see Cioci (2009a).

barding it with high energy protons, and James Chadwick (1891–1974) discovered the neutron in that same year.

At the beginning of 1934, Irène Curie (1897–1956) and her husband Frédéric Joliot (1900–1958) discovered artificial radioactivity induced by alpha-particle bombardment: bombing, with alpha particles, boron or aluminum, they obtained respectively new isotopes of nitrogen and phosphorus that emitted positrons.

After the discovery of Curie and Joliot, Enrico Fermi (1901–1954) had the idea to use neutrons to induce radioactivity: neutrons, being neutral, would not have been repelled by the positive charge of the atomic nucleus and therefore they would have been more effective in producing nuclear reactions. In March of 1934, Fermi began to irradiate the known elements with neutrons using a radon-beryllium neutron source constituted by a glass tube containing beryllium powder and radon.

A few weeks later, also Franco Rasetti (1901–2001), Edoardo Amaldi (1908–1989), Emilio Segre (1905–1989) and the chemist Oscar D'Agostino (1901–1975) gave a valuable contribution, together with Fermi, to the systematic study and classification of the different mechanisms by which neutron-induced radioactivity, for different elements, took place (Fermi et al. 1934). In May of 1934, that interpretation of the case of uranium created many difficulties. The reaction products were elements whose atomic number was not included between that of lead and that of the same uranium. It was hypothesized that the irradiation of uranium with low-energy neutrons was to produce one or more elements in the periodic table that occupied successive positions and therefore called transuranic (Fermi 1934). Actually, the members of the Via Panisperna group (so called from the address of the Institute of physics, at University of Rome "La Sapienza", in Via Panisperna) had produced uranium fission without being aware of it.

In October 1934, after several months of work, "the Via Panisperna boys", who in the meantime had also seen the entrance of Bruno Pontecorvo (1913–1993), observed, interposing some hydrogenated means such as paraffin between the neutron source and a silver target, an amplification of the intensity of the activation. Contrary to what was assumed, this occurred as a consequence of the slowing down of neutrons caused by collisions with nuclei of hydrogen, since a slow neutron has a higher probability of being absorbed by a silver nucleus than a fast neutron is expected to do. Rome had become "the capital of the nuclear world". Aware of the possibility of industrial applications of the new discovery, Orso Maria Corbino (1876–1937) convinced the Roman physicists to apply for a patent in relation to their method of producing radioactive substances by bombardment with slow neutrons. Soon, however, Via Panisperna group dispersed.

5 Rasetti's Refusal to Participate in Researches for Military Use of Atomic Energy

In 1938, Fermi received the Nobel Prize for his "demonstrations of the existence of new radioactive elements produced by neutron irradiation, and for his related discovery of nuclear reactions brought about by slow neutrons". Straight from

Stockholm, Fermi left for the United States of America. The following year also Rasetti left Rome and moved to Canada and took over the Department of Physics of the nascent Faculty of Science and Engineering at the Catholic University of Laval in Quebec. Different choices had been made by the two physicists with respect to the creation of the atomic bomb. While Fermi gave an essential contribution to the Manhattan Project, Rasetti, in January 1943, was approached by Hans von Halban (1908–1964) and George Placzek (1905–1955) who proposed that he become a part of the group of French and English specialists who had moved from England to Montreal for security reasons (because of the constant bombing) and who wanted to build a nuclear pile, for military purposes, using heavy water as a moderator.[9]

Rasetti refused on grounds of morality. Not even the presence in Montreal of Bruno Pontecorvo, his old colleague in the group of Via Panisperna, convinced him to change his mind. He never regretted this choice.

In his biographical notes, Rasetti explained clearly his "opinion on the atom bomb question", since the renunciation of participating in the project of nuclear energy for military purposes marked his whole future scientific work:

> I was convinced that no good could ever come from new and more means of destruction [...][10]

His position was of great moral integrity, starting from consideration of the tragedies that were characterizing the performance of the Second World War and expressed his refusal to submit science to any degeneration:

> Evil as the Axis powers were, it was apparent that the other side was sinking to a similar moral (or rather immoral) level in the conduct of the war, witness the massacre of 200000 Japanese civilians at Hiroshima and Nagasaki.[11]

In this precious document is also reported a "stern judgment" formulated by Rasetti against those scientists "including Fermi" who made a different choice from his about the making of the atomic bomb (Rasetti 1958–1968, p. 11, line 10). This judgment has already been analyzed by several scholars.[12] In this work, I try to give an interpretation in terms of a confrontation inside the scientific community on ethical issues in relation to the discovery of nuclear energy and its use for military purposes.

[9] Heavy water was considered to be slow motion par excellence because deuterium has a light nucleus, suitable to subtract kinetic energy from neutrons, and being already formed by a neutron and a proton it was believed to be not "inclined" to absorb neutrons. The research started eventually in Montreal after the war with construction of the atomic pile ZEEP, the origin of the CANDU reactors.

[10] F. Rasetti (1958–1968, p. 11, line 2). Information about this document can be found in Amaldi (1990, p. 175, footnote 15). The document was widely quoted by Battimelli and De Maria in the "Preface" of Amaldi (1997) and by Maltese (2003).

[11] Ivi, line 4.

[12] Battimelli (2002), Maltese (2003). These authors reported Edoardo Amaldi's assessments; he considered the decision to work in the Manhattan Project as a necessary assumption of responsibility by scientists to prevent the world being conquered by the Nazis using nuclear weapons: "If I had found myself there (in front of this dramatic dilemma), after deep and painful considerations on which it was my moral duty of man asked to decide whether cooperate in the defense of democracies … or lock myself in my private life, doing nothing to fight the dictatorship, I would have eventually opted for the first solution" (Amaldi 1997, p. 98, line 32).

Rasetti's statements about his colleagues, particularly in regard to Enrico Fermi, should not be considered, in my opinion, as personal judgments of conviction: they were expressed mainly within the community of Italian physicists, so that if only Rasetti had wanted to, he could have expressed them with more visibility at the death of Fermi. Both in the article published in Science in 1955 and in that written in 1968 for the Celebration of the Accademia dei Lincei in honour of the great scientist who died prematurely, however, he praised his "ability to reach the summits of creative thought", his greatness both as a theoretical physicist and in the perfect "combination of a theorician and an experimenter", his carelessness of the "personal advantages" (Rasetti 1955, pp. 449–450), "his sense of duty, his unyielding spirit honesty" as well as the merit of having established "the tradition of integrity, scrupulous scientific seriousness, high-level research that reigns today in Italian physics." (Rasetti 1968, pp. 17–18). The esteem that had always bound him to his friend Fermi testifies that Rasetti did not intend to judge anyone but that he wanted only to emphasize his ethical choices (Cioci 2007, p. 213).

Among the various positions taken by the physicists of the Via Panisperna Group against the atomic bomb, we should emphasize the one assumed by Eoardo Amaldi. He was not as critical about Fermi as Rasetti, but he made important choices to avoid any nefarious use of the results of his research (Cioci 2009b, p. 56).

In the winter of 1940–1941, he was working, together with his collaborators, on the measurement of the cross section of fast neutrons of various energies against the nuclei of different atomic number and to the study of dependence of the cross section for fission on uranium energy of the neutrons incident. He become aware of the possible military applications of these studies. Then, "after extensive discussion," Amaldi and other Roman physicists decided to abandon the problem of fission and to engage in a general theme of research as far as possible from the previous one:

> we feared that being active and recognized experts on this topic could expose us to the invitation or coercion to work for the Axis powers to the development of military applications of nuclear fission.[13]

6 Leo Szilard and the Chain Reaction

Soon after the Joliot-Curie discovery of artificial radioactivity, Rutherford, on September 11, 1933, declared before the British Association for the Advancement of Science, in Leicester:

> The energy produced by the breaking down of the atom is a very poor kind of thing. Anyone who expects a source of power from the transformation of these atoms is talking moonshine.[14]

[13] Amaldi (1979, p. 199, column 2, line 13).

[14] Associated Press (1933, p. 1, line 18). A summary of the presentation at the British Association is published in the Times of September 12, 1933, p. 7 and of Nature, no. 132, pp. 432–433 (16 September 1933).

The reading of the report of Rutherford's speech in The Times gave birth to Szilard's interest and then to the idea of a practical method for using nuclear energy: an element that, "split by neutrons", emits two of them after having absorbed one, could sustain a nuclear chain reaction. On March 12, 1934, he presented a patent application (British patent application no. 7840) which included both the generation of radioactive elements by means of neutrons and the concept of a nuclear chain reaction (Szilard 1972, pp. 605–621).

In his memoirs, Szilard said he had read, in 1932, Wells's The World Set Free and that it made him realize the consequences that could have been derived from practical applications of nuclear energy. Thus he divided the patent into two parts, ensuring that the second (British Patent 630.726), relative to the chain reaction, would not become public domain when yielding the patent to the British Admiralty. This device allowed delay in publication of that part of the patent until 1949 (Szilard 1972, pp. 639–651).

In view of the possible significant applications, in 1936 he wrote to Fermi, Segre and Rutherford to ask them to participate in the formation of a sort of association in order to exercise a form of control on possible developments of their research through managing the patents granted relatively to it.[15] His attempts did not have the desired effect. According to Edoardo Amaldi

> Nothing came out of this proposal, mainly (I guess) because Fermi thought (in 1936) that the applications of our discovery were too remote.[16]

In December of 1938, the nuclear chemists Otto Hahn and Fritz Strassmann proved unequivocally the production of barium in the disintegration of uranium bombarded by neutrons (Hahn and Strassmann 1939). Lise Meitner (1878–1968) and her nephew Otto Frisch (1904–1979) interpreted the result of the experiment in terms of the atomic nucleus fission of uranium. In January 1939, they published two articles in Nature. In the first, the two scientists calculated that about 1/5 of the mass of a proton would be transformed into energy. For Einstein's law $E = m c^2$ this was equivalent to about 200 MeV, an energy much higher than that associated with radioactive phenomena known at the time (Meitner and Frisch 1939). In the second article, Frisch described the physical evidence obtained by him of the uranium fission into two fragments of nearly equal size, with high kinetic energy and electrical charge, which were revealed in an ionization chamber (Frisch 1939).

A complete theoretical description of the process was prepared by Bohr (Bohr 1939; Bohr and Wheeler 1939) who had already built a few years back a model of the nuclear compound system that described the capture of a neutron by the nucleus and the resulting nuclear transmutations (Bohr 1936; Bohr and Kalckar 1937).

The only question that remained open was whether neutrons were formed in the process of fission of uranium.

Szilard knew at once that this would happen. He, concerned about this forecast, tried to convince the researchers who were working on the problem—the two

[15] Szilard (1972, pp. 729–732; 1978, pp. 45–46).

[16] E. Amaldi (1984, p. 160, line 27).

groups at Columbia University in New York, the one formed by the same Szilard with Walter Henry Zinn (1906–2000) and that directed by Fermi, and the group in Paris that consisted of Joliot, von Halban and Kowarski—not to publish anything about it. Fermi decided that, if the majority had been opposed to the publication, even he would have abstained. In the end, researchers at Columbia University sent two items to the Physical Review, demanding that their publications be delayed until they had decided whether to keep these results secret or make them known (Zinn and Szilard 1939, dated April 15, received March 16; Anderson, Fermi and Hanstein 1939, dated April 15, received March 16). There was no way, however, to convince Joliot who published the results of his research in Nature (von Halban et al. 1939, dated March 18).

Only after each attempt to prevent the realization of monstrous means of destruction did Szilard propose to Einstein, in August 1939, the famous letter to the President of the United States of America, Franklin Delano Roosevelt (1882–1945), with which he recommended financial support and acceleration of atomic research: to ensure that Germany was not the only state in possession of the bomb.

Indeed, after the defeat of Hitler, Szilard tried in all possible ways to prevent nuclear weapons being used on Japan.

7 Oppenheimer and the Making of the Bomb

Einstein's letter to Roosevelt determined the allocation of only $ 6000 for research on uranium. The decision of the United States for a large-scale effort was made only after the news from England. Otto Frisch and Rudolph Pierls (1907–1995) had calculated that, to build a fission bomb based on a uranium isotope of mass 235 initiated by an impact with fast neutrons, a critical mass of only 5 kg[17] would have been sufficient to generate a self-sustaining chain reaction (compared to several tons necessary for uranium 238). This meant that an atomic bomb could be made by the end of the war. The two scientists prepared two memoranda (Frisch and Peierls 1940a, b)—the second of which was more technical—in March 1940 for the British government. These documents also hinted at the mechanism to detonate the bomb:

> a sphere should be made in two (or more) parts which are brought together first when the explosion is wanted. Once assembled, the bomb would explode within a second or less, since one [cosmic] neutron is sufficient to start the reaction[18]

In the summer of 1942, the U.S. government assigned to Colonel (later General) Leslie Groves (1896–1970) the task of realizing a project to create the first atomic bomb, known under the code name "Manhattan Project". Oppenheimer suggested to Groves that the development of the bomb was concentrated in a single laboratory

[17] The exact critical mass for uranium 235 is 52 kg. The critical mass for plutonium 239 is 10 Kg.

[18] Frisch and Peierls (1940b, p. 86, line 15).

> where people could talk freely with each other, where theoretical ideas and experimental findings could affect each other, where the waste and frustration and error of the many compartmentalized experimental studies could be eliminated, where we could begin to come to grips with chemical, metallurgical, engineering, and ordnance problems that had so far received no consideration[19]

Groves followed Oppenheimer's advice in the creation and location (at Los Alamos, New Mexico) of the laboratory and chose Oppenheimer himself as its director.

Meanwhile, December 2, 1942, the first controlled nuclear chain reaction took place under the stands of Stagg Field Stadium by the group of researchers from the University of Chicago under the direction of Fermi. While they had demonstrated that a chain reaction of uranium could be generated, they had also made manifest the impossibility (already known) of using natural uranium with a moderator, as occurs in an atomic pile, for the production of bombs of unprecedented power. As a matter of fact, the size would be too large for an explosive device (the equatorial axis of the pile was almost 4 m long) and "the thermal neutrons take so long (so many micro-seconds) to act that only a feeble explosion would result" (Smyth 1945, p. 209, line 23). Another (not secondary) effect of the reactions that occur in a stack is that part of ^{238}U absorbs a neutron in ^{239}U that with subsequent β decays can change into plutonium, extremely fissile material even if bombarded with fast neutrons.

The Manhattan project's success owed much to the leadership of Oppenheimer. Since March 1943, he attracted a first-class team of scientists and was able to delegate responsibilities and to trust his collaborators. Despite the problems of security and secrecy, Oppenheimer managed to keep free the flow of information and the in-depth discussions among scientists involved in the project.

During Oppenheimer's memorial session of the American Physical Society meeting held in Washington, D.C., in April 1967, Victor Weisskopf (1908–2002), speaking of the spirit of collaboration among scientists from different nations inspired by Oppenheimer, said that "he was to create at Los Alamos a new form of scientific life, … the new ways of big science, in nuclear physics and particle physics, have been inspired by the Los Alamos venture".[20]

For purposes of producing atomic explosive, however, one must consider the work done by several laboratories including the Metallurgical Laboratory at Chicago, the Clinton Laboratory at Oak Ridge, the Radiation Laboratory at Berkley, the Hanford Engineer Works at Richland, the Argonne Laboratory, the Jersey City laboratories for the separation of uranium isotopes U-235 from U-238 by electromagnetic and gaseous diffusion methods and for production and chemical separation of plutonium.

The number of people employed to build atomic bombs (nearly 130,000 including construction workers and military personnel) and the cost of the project ($ 2 billion in 1945) was the largest technological enterprise in the history of mankind (Jones 1985, p. 344).

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[19] United States Atomic Energy Commission (1971, p. 12, line 4).

[20] Weisskopf (1967, p. 40, column 1, line 19; 42, column 1, line 11).

On 16 July 1945 the first atomic bomb was tested at Alamogordo. It demonstrated the power of the new weapon. The official (censored) report on the development of the atomic bomb, written by Henry De Wolf Smyth (1898–1986) shortly after the war, reported that

> No man-made phenomenon of such tremendous power had ever occurred before. The lighting effects beggared description. The whole country was lighted by a searing light with the intensity many times that of the midday sun.[21]

Oppenheimer said, later, that when the bomb detonated, he became aware of the verse of the Bhagavad Gita "I am become Death, the destroyer of worlds" (Peierls 1974, p. 216, column 1, line 14).

8 The Frank Report and the Decision to Drop the Bomb on Japan

Once it became clear that Germany would not have been able to acquire the bomb by the end of the war, doubts about the meaning of their work began to spread among the scientists involved in the project.

Joseph Rotblat (1908–2005), a Polish-born physicist who had worked in England to research on the atomic bomb, had moved to Los Alamos in early 1944 where he got to work on the experimental study, using a cyclotron, of secondary effects of fast neutron irradiation with the fission products. He also participated in the restricted meetings with the coordinators of the project (Brown 2012, p. 47).

After learning from General Groves that by then "the real purpose in making the bomb was to subdue the Soviet" and "when it became evident, toward the end of 1944, that the Germans had abandoned their bomb project", the whole reason of his "being in Los Alamos ceased to be", and he got the "permission to leave and return to Britain".[22]

Leo Szilard, however, tried to stop the military use of the atomic bomb by the United States of America.

In March of 1945 he wrote a memorandum to President Roosevelt. Einstein enclosed a letter of introduction; this letter was dated 25 March 1945 (Szilard 1978, pp. 205–207). Szilard's Memorandum drew the attention of the President to the consequences that the use of the bombs over Japan would engender, such as the arms race that would follow and the dangers that the United States would have to face due to a possible nuclear war. A copy of the letter was sent to Mrs. Roosevelt asking for an appointment with her husband, but this never took place because the President died April 12, 1945.

Subsequently Szilard had the opportunity to present, without success, his memorandum (rewritten with greater care for the occasion) to James Byrnes, who had the

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[21] Smyth (1945, p. 254, line 16).

[22] Rotblat (1985, p. 18, line 22).

confidence of President Truman and who would become Secretary of State (Szilard 1978, pp. 196–204).

He promoted, among the scientists who participated in the Manhattan Project, and on moral grounds alone, a petition against the use of the bomb against Japan (Szilard 1978, p. 211).

Szilard also made a contribution to the proposal made by James Franck (1882–1964). A Nobel Prize-winner, together with Gustav Ludwig Hertz (1887–1975) "for their discovery of the laws governing the impact of an electron upon an atom", and senior physicist in the Metallurgy Laboratory of Chicago, he had been made aware of the social responsibility of scientists after participating in the First World War in a German program for development of chemical weapons. He agreed to participate in the atomic bomb project in 1942, with the promise by Arthur Holly Compton (1892–1962) that, when the time had come for a decision on the use of the bomb, he would have had the opportunity to present his views to high-level politicians.

Franck was chairman of the Committee of Compton's Metallurgical Laboratory in Chicago on Social and Political Implications of the atomic bomb that included also Donald J. Hughes (1915–1960), James Joseph Nickson (1915–1985), Eugene Rabinowitch (1901–1973), Glenn Theodore Seaborg (1912–1999) and Leo Szilard. In June 1945 they prepared a memorandum known as the Franck Report for Secretary of War Stimson which proposed the use of the bomb on an uninhabited island before the representatives of all nations.

The motivations of the Chicago group, to limit the military use of the bomb, were based on the impact it would have had on the international and post-war situation, providing as fundamental objective "an international agreement on the prevention of nuclear warfare". From this point of view, the use of atomic weapons could easily destroy all the future possibilities of reaching an agreement, because it would be extremely difficult to persuade the world that a nation which had used such a weapon of mass destruction, could then be trusted in its proclaimed desire to abolish these weapons, by means of an international agreement.[23]

The memorandum was submitted to the Interim Commission of the War Department composed of Arthur H. Compton, Ernest O. Lawrence (1901–1958), Enrico Fermi and J. Robert Oppenheimer. They argued that a demonstration on an uninhabited island would not have been effective, and that the only way in which the atomic bomb could be used to end the war was to use it on a military objective in a densely populated area.

The four scientists were told that it was impossible to cancel or postpone the planned invasion of Japan, certainly very costly in terms of human lives, if Japan would not surrender in advance as a consequence of being told about the bomb. They knew nothing of attempts by the Japanese government to enter into negotiations for peace, which could have led to a diplomatic solution of the conflict.

On 6 August 1945, the uranium bomb was dropped on Hiroshima: 140,000 of its citizens were killed in a year and 200,000 in 5 years. Three days later the plutonium bomb was dropped on Nagasaki, 70,000 people died before the year was out and more than 70,000 died in the next 5 years as a result of radiation (Rhodes 1986, p. 734, 740–742).

[23] Committee on Social and Political Implications (1946, p. 3, column 3, line 34).

9 The Commitment to Peace by Robert Oppenheimer

Philip Morrison (1915–2005) and Robert Serber (1909–1997) went to Hiroshima at the beginning of September 1945 to study the effects of nuclear weapons. They reported to the Los Alamos scientists the terrible suffering endured by the civilian population. As the days passed, revulsion grew for what had been done, even by those who believed that the successful end of the war was the justification for the bombing.

On April 16, 1954, interviewed by Robert Robb, when asked if he had scruples about the fact that 70,000 civilians were killed or injured by dropping the bomb on Japan, Oppenheimer said: "Terrible ones" (United States Atomic Energy Commission 1971, p. 235, line 61).

Oppenheimer, in 1947, during a conference at the Massachusetts Institute of Technology (MIT) in Cambridge entitled "Physics in the Contemporary World", declared that "the physicists felt a peculiarly intimate responsibility for suggesting, for supporting, and in the end, in large measure, for achieving the realization of atomic weapons", so they "have known sin, and this is a knowledge which they cannot lose".[24]

Much is written about this opinion expressed by Oppenheimer and his repentance after Hiroshima. According to Alice Kimball Smith, who edited the account of the commitment to peace of atomic scientists between 1945 and 1947[25] and published a remarkable collection of letters and memories of Oppenheimer,[26] it expresses more "an intensely personal experience of the reality of evil […] and not a feeling of guilt in the ordinary sense" (Smith 1971, p. 77, line 25).

Many years later, in the face of representations, even theatrical ones (Kipphardt 1964), which gave Oppenheimer as a broken man for what he had done, the scientist wrote that

> My principle remaining disgust with Kipphardt's text is the long and totally improvised final speech I am supposed to have made […] My own feelings about responsibility and guilt have always had to do with the present. and so far in this life that has been more than enough to occupy me.[27]

The awareness of the committed evil generated in Oppenheimer a new attitude. Even while waiting for news of the capitulation of Japan after the bombing of Nagasaki, Oppenheimer worked on the final report on post-war planning that the Interim Committee's Scientific Panel was preparing for the Secretary of War. In the report that Oppenheimer brought to Washington to submit to Secretary Stimson, it is pos-

[24] Oppenheimer (1948, p. 66, line 45).

[25] The account of A. K. Smith is entitled "A peril and a Hope" by a famous expression of Oppenheimer according to which nuclear weapons would constitute a danger and a hope for humanity because given the power of these terrible means of destruction humankind would have to give up war to settle international disputes and would have to create a united world under the law and humanity.

[26] Smith and Weiner (1980).

[27] Oppenheimer (1966, line 20).

sible to grasp what would be his next commitment to peace, so that "all steps be taken, all necessary international arrangements be made, to this one end"(Smith and Weiner 1980, p. 294, line 31).

Oppenheimer then gave up the direction of Los Alamos to devote himself to teaching, to the social implications of atomic energy and to the project for its international control.

In 1946 he was the only atomic scientist who took part in drafting the "Acheson Lilienthal Report", developed under the auspices of the State Department after the first resolution of the General Assembly of the United Nations, held in London in January 1946, which advocated the elimination from national arsenals of nuclear weapons and of all weapons of mass destruction. Central to the proposal was the recommendation to set up an International Atomic Development Authority, to assist the United Nations,

> with exclusive jurisdiction to conduct all intrinsically dangerous operations in the field…. The international agency would also maintain inspection facilities to assure that illicit operations were not occurring[28]

Oppenheimer foreshadowed thus the birth of the International Atomic Energy Agency (IAEA).[29]

Oppenheimers greatest contribution to peace and to disarmament was undoubtedly his opposition to the hydrogen bomb.

After the explosion of the first Russian atomic bomb, in August 1949, the Commission for Atomic Energy of the United States of America convened a special session of the General Advisory Committee chaired by Oppenheimer to discuss what should be the U.S. response to the "aggressive" policy of the Soviet Union and in particular in order to express its opinion about the realization of a super bomb, a nuclear bomb (based on the fusion of hydrogen) about a 1000 times more powerful than the bombs of Hiroshima and Nagasaki.

The Committee members observed that

> once the problem of initiation has been solved, there is no limit to the explosive power of the bomb itself except that imposed by requirements of delivery. This is because one can continue to add deuterium—an essentially cheap material—to make larger and larger explosions[30]

They then were unanimous in recommending that the development of the bomb must somehow be avoided, since its use "carries much further than the atomic bomb itself the policy of exterminating civilian populations".[31]

The majority of the Committee, with Oppenheimer, believed that "this should be an unqualified commitment", while the minority, by Fermi and Isidor Isaac Rabi

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[28] Lilienthal et al. (1946, p. 24, line 15).

[29] For further arguments in favour of this conclusion see Cioci (2004).

[30] General Advisory Committee (1949, p. 155, line 39).

[31] Ivi, line 21.

(1898–1988), felt that this commitment "should be made conditional on the response of the Soviet government to a proposal to renounce such development".[32]

After the decision taken by President Harry S. Truman (1884–1972), dated January 31, 1950, to begin a program of development of the hydrogen bomb, Oppenheimer, invited by Teller, refused to move to Los Alamos to work on the project for the construction of the super bomb (United States Atomic Energy Commission 1971, p. 232)

From April to May of 1954, Oppenheimer had to stand trial because of some contacts he had had at the beginning of the 1930s and 1940s with the Communists, but also because in 1949 he had opposed the development program of the hydrogen bomb. Oppenheimer was accused of having slowed down, with his influence on American scientists, the effort that was to lead to development of the bomb (United States Atomic Energy Commission 1971, p. 1011). The trial ended with suspension of his security clearance, the authorization for access to secret information.

Oppenheimer was fully rehabilitated in 1963, when President Lyndon Jonson gave him the "Enrico Fermi Award", the greatest honor that the U.S. government can bestow for outstanding service in the field of nuclear energy. The proposal was in fact approved by John F. Kennedy shortly before his assassination, recognizing that a great injustice had been done against Oppenehimer, who died a few years later, on February 18, 1967.

10 Conclusion. The Moral Responsibility of the Scientist

The experiences of scientists presented in this work indicate an example to follow. They have questioned the possible consequences of their findings, have discussed and have compared their views with those of their colleagues, expressing their concerns within the scientific community. They have tried to delay the publication of research results or even to change their field of study for not carrying out, in a particular historical moment next to the war, terrible means of destruction. This has provided a model of behavior also for other branches of science.[33]

In some topical cases, the scientists have expressed their fears to political institutions and to the public. It is what Einstein and Szilard did when they wrote the letter to the President of the United States of America. Roosevelt then recommended financial support and the acceleration of atomic research for fear that the research on uranium fission could lead to creation of a Nazi atomic bomb.

Later, Einstein promoted shortly before his death, together with Bertrand A. W. Russell (1872–1970), the publication in London in 1955, of an Appeal for Abolition of War (known as the Russell-Einstein Manifesto), almost a spiritual testament, in which he informed the authorities in the world, and through them the scientists and

[32] Ibidem, 156, line 6.

[33] See Capuozzo and Cioci (2010).

the public, that nuclear "weapons threaten the continued existence of mankind" (Russell and Einstein 1955, p. 25, column 5, line 57). It was then hoped that the "scientists should assemble in conference to appraise the perils that have arisen as a result of the development of weapons of mass destruction, and to discuss a resolution in the spirit of the appended draft" (Russell and Einstein 1955, p. 25, column 1, line 62). See also Butcher (2005).

The Manifesto was signed shortly by thousands of scientists around the world and was the basis for the emergence in 1957 of the Pugwash Conferences on Science and World Affairs, which took place at the Canadian village of Pugwash, where scientists met from around the world to respond to the call made by Einstein and Russell.

Unfortunately, while on one hand, scientists informed civil society, on the other they continued to do their "duty" in military laboratories.[34]

This position, in which the man of science can often be found, refers to the distinction, which Einstein also does, of the "two roles of the intellectual worker: his role as scientist or man of letters, and his role as citizen" (Hinshaw 1949, p. 652, line 27). Only on the basis of this differentiation could a scientist preserve his or her own methodological objectivity in their scientific activity, which requires no showing of concern for value judgments that are of a very subjective nature and often deal with social issues.

According to the philosopher Hans Jonas (1903–1993), who had been engaged in the construction, in a pluralistic society, of an ethic of responsibility in favor of future generations (Jonas 1984), it is important to reconsider the question of so-called "freedom from values" of science, because leaving out of consideration the value of the object of knowledge allows a degree of freedom in treating and manipulating it without any limits and respect. Jonas, in his essay "On Technology, Medicine and Ethics" about the practice of the responsibility principle, cites precisely the experience of Oppenheimer as a starting point for a renewal of scientific practice (Jonas 1997, p. 55).

Oppenheimer in fact solves the problem in an original way, synthesizing the task of the scientist and that of the citizen, by opposing, in institutional settings, construction of the hydrogen bomb and refusing to move to Los Alamos to work on it.

There is a substantial difference between informing people about the risks connected with the results of scientific research and simply objecting to them. In the second action the scientist assigns values to the science in which he participates and he becomes a sign of hope for humanity.

The position of Oppenheimer, the most advanced, has been isolated. Following disapproval by the Commission for Atomic Energy of the United States of America, scientists preferred the attitude of Einstein, certainly less uncomfortable but perhaps the time is ripe for it to resume the position of Oppenheimer (Cioci 2004, p. 143).

[34] E.g. see: Teller (1950).

Acknowledgments I thank Professor Giovanni Battimelli, Referent for Documents and Sources for the History of Physics, Department of Physics, University “La Sapienza” of Rome, who helped me in the consultation of the Edoardo Amaldi Archives.

My special thanks is addressed to Colin Harris, Superintendent of the Special Collections Reading Rooms, for his help in finding the unpublished writings of Frederick Soddy, to Dr. Chris Fletcher, Keeper of Special Collections, and to the Bodleian Library, Oxford University, which owns them, for permission given on the basis of ‘non-exclusive rights’ to quote and to paraphrase them.

I am grateful to Bonnie Coles for helping me in the examination and retrieval of the writings of Robert Oppenheimer at the Manuscript Division of the Library of Congress (USA).

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