Nuclear power

Summer 1942 in Chicago

by B. Goldschmidt*

On 2 December 1942 the first man-made nuclear reactor went critical. The nuclear age was born. In his recently completed "political history of nuclear energy+" M. Goldschmidt traces the whole story of the nuclear age from the discovery of fission to the present day. In the extract from his book printed below, M. Goldschmidt tells of his personal involvement in the US nuclear research programme and of his contact with the workers at the University of Chicago; he reminds us that Fermi's achievement, historic as it was, was not the first chain reaction to take place on earth.

As a representative of the British, as well as the only Frenchman to take part in the US programme, though only for the few months from July to October 1942, I had the good fortune to follow its spectacular development in Chicago.

My particular field was the chemistry of radioactive elements as during the five years preceding the war I had worked in the Radium Institute, where Marie Curie had engaged me in 1933 (the year before her death) as her personal assistant.

After being dismissed at the end of 1940 as assistant at the Paris Faculty of Science (under the anti-Semitic laws then introduced by the Vichy government that among other things prohibited Jews from teaching), I had succeeded in leaving France for the United States in the spring of 1941.

Shortly after my arrival in New York, Enrico Fermi and Leo Szilard called me and suggested that I join their team at Columbia University, where I would devote myself to the problems of producing very pure uranium.

Throughout the summer of 1941 I awaited my assignment to Columbia; Szilard always assuring me that it was imminent, the delay being due to no more than the formalities of security clearance. But when the decision finally came in October, it was negative.

Fermi and Szilard broke the news to me. They had themselves managed, at last, to obtain greater government support for their work, but on the condition that they recruit no more foreigners. They were thus forced to abandon their offer for me to join them, an offer made still more difficult because Washington at that time did not recognize the Free French forces. The Free French, therefore, proposed my services to British scientific research so that I could join the Cambridge group led by Hans Halban and Lew Kowarski.

While awaiting the outcome of this proposal, I worked for several months at the New York Cancer Hospital, where the first tests were being made of internal radiotherapy using artificial radioisotopes. From there I went to Canada as a consultant at the radium and uranium extraction plant at Port Hope, Ontario.

Then, at the end of June 1942, I was called to Washington by the British embassy, where I learned that instead of going as I had expected to join Halban's team in Cambridge, I was to be sent, on behalf of the British, to Chicago to learn about the chemistry of the new element, plutonium.

A group had been set up at the University of Chicago since the spring of 1942, under the direction of the physicist Compton and was known by the code name "Metallurgical Project". Compton had been asked to bring into the group, among others, the New York team of Fermi and Szilard and the unit recruited by Glenn Seaborg, who had been responsible for the discovery of plutonium. The new combined group was assigned a double task: to determine whether a chain reaction could be achieved with natural uranium and graphite, and at the same time, to try to develop a chemical method for extraction of the plutonium produced in such a reaction.

I arrived in Chicago in July 1942, where I was to spend nearly four fascinating months. I was received by Compton himself, one of the most respected scientists in the States. He explained that, as a representative of the British team, I would find all doors open to me.

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+ *The Atomic Complex* – A Worldwide Political History of Nuclear Energy, by Bertrand Goldschmidt. Published by the American Nuclear Society, La Grange Park, Illinois, USA (1982). This is revised and updated from the original French edition *Le Complexe Atomique* – Histoire politique de l'énergie nucléaire. Published by Librairie Arthème Fayard, 75 rue des Saints-Pères, F-75006 Paris, France (1980).

The West Stands of Stagg Field at the University of Chicago. The team led by Enrico Fermi constructed the world's first nuclear reactor inside this building. At 3.25 pm on 2 December 1942, a cadmium-plated control rod was withdrawn from the reactor and the first man-made self-sustaining nuclear chain reaction was initiated. (Photo: Argonne National Laboratory)

However, he asked me to voluntarily restrict my work to the area of my special competence, namely, chemistry. Then, to my great surprise, he told me that among the many secrets I would learn, the chemical behaviour of plutonium was no less important than the actual discovery of that element had been. In fact, it was then correctly believed that the Germans had no cyclotron powerful enough to enable them to discover and isolate the new element, which had been found by Seaborg to have chemical properties different from what might have been expected.

Fermi and Szilard also gave me a most friendly welcome. They were very amused to find me at last inside the inner sanctum of the American project, under the dual banner of the Free French forces and British scientific research.

At the time of my arrival in Chicago, there were already more than 100 scientists at work in various laboratories of the university. There was an excellent atmosphere within this young and enthusiastic group; they knew their objective was a weapon that, if successful, would have a destructive power beyond all comparison with armaments of the past. Moral scuples had been overcome by the fascination of the research and by the haunting fear that the Germans were following the same path, and were even possibly ahead. The timetable then envisaged, which was miraculously adhered to, foresaw that a bomb would be achieved within three years.

Fermi was responsible for producing the chain reaction. In the greatest secrecy, beneath the stands of the university football stadium, a structure of graphite and natural uranium was being assembled. Because it was built by piling up tens of thousands of graphite blocks, in some of which cavities had been made and filled with uranium oxide or metal, it became known as an "atomic pile". (The term "reactor" came later.)

The chemists were from time to time allowed into this mysterious place, all shining with graphite powder. There they saw a bizarre cubic structure, black and glistening and several yards in each dimension, being built by men covered from head to foot in black powder. The sight of the experiment was highly moving, for we knew that the outcome of the war, and therefore the destiny of the world could perhaps depend on it.

The nineteenth layer of graphite photographed during the construction of the Fermi Pile. Slugs of uranium oxide may be seen in layer 18 which is partly uncovered. (Photo: Argonne National Laboratory)

According to calculations, when the structure reached about a 7-metre cube, critical size would be achieved and the chain reaction would progressively begin – slowly, because the graphite would slow down the neutrons and increase the time between succeeding generations of fissions and because "safety rods" of cadmium, a material that absorbs neutrons, had been arranged so that they could be pushed into the pile as required to prevent the reaction from getting out of control.

Accordingly, a system of natural uranium and graphite (the essential elements of the Chicago pile) has a critical mass as in the case of a bomb. But there are two fundamental differences. The first is that, with natural uranium, tons are needed before the critical mass is obtained, as opposed to the few kilograms required in the cases of uranium-235 or plutonium. The second difference is that, because the neutrons are slowed down, the production of their successive generations takes place much less rapidly than in the bomb. It is this aspect that makes the pile controllable.

A natural uranium atomic pile is also a true "alchemy machine", for as the uranium-235 is gradually consumed in fission, a quantity of plutonium is produced approximately equivalent to that of the uranium-235 that has been used up.*

Now, while the separation of the two isotopes of uranium is extremely difficult, that of plutonium from uranium is relatively easy, except that the latter separation is complicated in practice by the intense radioactivity of the fission products that are present.

This complex development of a chemical process for plutonium extraction was the objective of Seaborg's team to which I was assigned. We all worked in a single large room, previously used by chemistry students for their laboratory training. Some 10 small groups, each comprised of two or three scientists, were studying various possible methods of separation, using trace quantities of plutonium that were insufficient to be weighed but detectable by their radioactivity. Working with Seaborg's deputy Isadore Perlman, my job was to identify the principal long-lived fission elements that

* For each gram of uranium-235 consumed, slightly less than a gram of plutonium is produced, together with some 20 000 kilowatt-hours of energy.

must be separated from plutonium during its extraction. It was the golden age of this new chemistry and we quickly discovered some new radioelements – isotopes of then unfamiliar elements – that were to represent an important part of the radioactive wastes from the operation of future nuclear power reactors.

On 20 August 1942, during one of the weekly meetings of the Metallurgical Project researchers (meetings at which the numbers of participants grew at a rate worthy of a chain reaction), Seaborg got up to announce that on that very day a substance transmuted by man had actually been seen for the first time: a miniscule quantity – a few micrograms – of a pink-coloured plutonium compound. Edward Teller, another brilliant scientist of Hungarian origin who headed the theoretical physics group and was later to become "father of the H-bomb", asked what the compound was. Seaborg replied that he was not allowed to say, so strictly compartmented was our knowledge as a precaution against leakage.

The chemical data obtained from the separation of a quarter of a milligram of the element in September were the basis of a most remarkable feat of technical and industrial achievement. Less than three years later, kilogram quantities of plutonium were to be extracted in a fascinating plant, remotely controlled through thick concrete walls protecting the operators from lethal irradiations.

A few months after this first fraction of a milligram of plutonium had been isolated, another vitally important event took place in Chicago. On 2 December 1942, a truly historic date in the atomic era, Fermi's pile reached its critical size and the chain reaction was initiated in this strange structure of uranium (6 tons of metal and 50 tons of oxide) and graphite (400 tons).

Slowly withdrawing the cadmium rods caused a growing rise in radioactivity and in the neutron flux in the pile. Within a few minutes, after an energy release of less than one watt, the reaction had to be slowed down to keep the level of radioactivity from becoming dangerous for the operators.

Following several days of running at powers of a fraction of a watt, Ferm's pile had to be shut down; otherwise the radiation would have become dangerous even for passers-by and for people living across the road from the football stadium. This first pile, built by successive approximations and for purely experimental purposes, had not been equipped with protective shielding. It had been by no means certain that it would work, and in any case it had never been envisaged as a permanent, or even semi-permanent, installation.

Nearly four years after Joliot-Curie and his team had beaten that of Fermi by a single week in the discovery of secondary neutrons from fission, the Italian scientist took his brilliant revenge. But it is probable, had it not been for the invasions of France and Norway, that Joliot-Curie and his co-workers would have won this second race also, achieving a chain reaction with uranium and heavy water.

Compton, who was present throughout the whole of the 2 December operation – termed the "divergence" of this first atomic pile – telephoned Conant in Washington to report the success. He said simply "you will be interest to learn that the Italian navigator has landed in the New World." At the same moment when the German advances had for the first time been halted, before Alexandria in the Egyptian desert and before Stalingrad in the icy Russian steppes, a successful experiment had opened for mankind the door to a new world full of hopes and threats, the world of modern alchemy.

Thirty years later, in the laboratories of the French Atomic Energy Commission, a detailed analysis by French scientists of uranium deposits from the country of Gabon in Africa was to prove beyond a doubt that a chain reaction had already taken place in nature.

Because uranium-235 is a radioactive isotope more unstable than uranium-238, as one goes back in prehistory it is found that natural uranium then was more "enriched" than it is today. When the mineral deposits in the Gabonese mine at Oklo were being formed two billion years ago, the amount of uranium-235 in the mixture at the time was five to six times greater than today, the concentration being about the same as that now used in ordinary (light) water-moderated nuclear power reactors, the most common type in current operation.

At that time, our planet was about two-thirds its present age, the African and American continents were joined together, and the most advanced living organisms on the earth's surface were the monocellular blue algae. Thus, conditions were physically favourable, given an appropriate concentration of uranium (as at Oklo), for a chain reaction to start in the sedimentary deposits each time there was an incursion of water. Evidence has been found of several natural piles of this type in the prehistory of the area, all within a few miles of each other. They must have been active over thousands of years, their operating cycles "controlled" by water evaporation due to the heat they generated, leading to an interruption of the nuclear reaction until a renewed penetration of water.