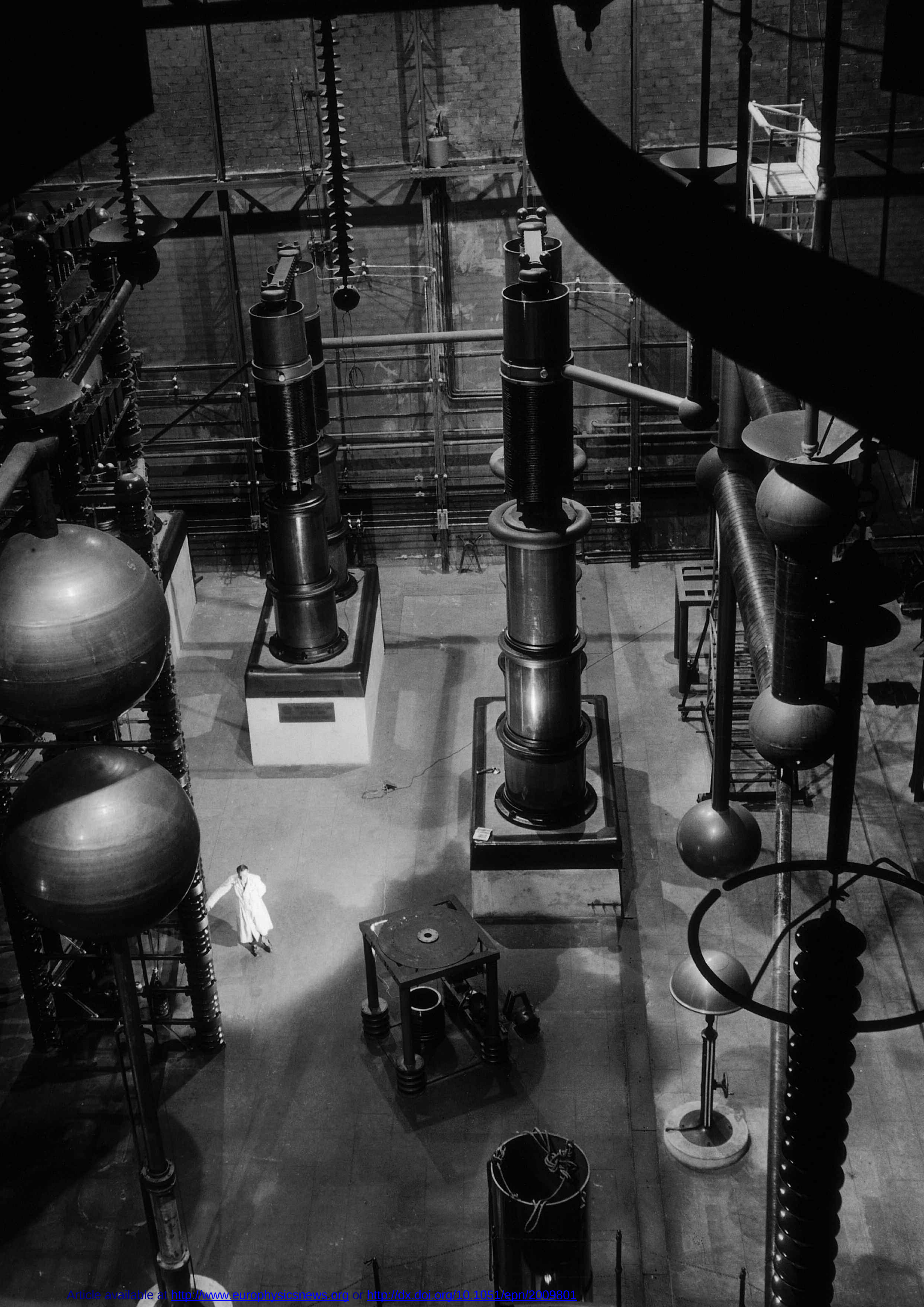

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FRÉDÉRIC JOLIOT-CURIE AND THE FIRST FRENCH ATOMIC REACTOR

Half a century ago Frédéric Joliot (1900-1958) passed away. With his wife, Irène Joliot-Curie, he had discovered artificial radioactivity in 1934, for which they were awarded the Nobel prize in chemistry in 1935. This led ultimately to the start-up, under his leadership, of the first French nuclear reactor ZOÉ, in 1948.

Frédéric Joliot was born in Paris on March 19th, 1900. At the top of his year when completing his engineering school, the *École municipale de physique et chimie industrielles*, he is introduced by Paul Langevin, its director for education, to Marie Curie who immediately recruits him as personal assistant at her laboratory at the *Institut du Radium* (Radium Institute). Irène Curie, daughter of Marie and Pierre, is in charge of showing him around the laboratory. The two young people will get married in 1926 and will jointly undertake a series of experiments in the field of radioactivity.

Discovery of artificial radioactivity

In 1930, in Berlin, W. Bothe and H. Becker note that the bombardment of beryllium with alpha particles produces a very penetrating non identified radiation. In Paris, Frédéric and Irène produce small very intense sources of polonium, an alpha emitter. At the beginning of 1932, they observe that the penetrating radiation is able to eject recoil protons out of sheets of hydrogenated substances. This will be the starting point for James Chadwick who, one month later, at Cambridge, discovers that the unknown radiation consists of "neutrons".

Following up their experiments, Frédéric and Irène discover, in January 1934, "artificial radioactivity", that is the production of radioactive isotopes of stable elements by nuclear reactions in other elements (for instance radioactive phosphorus formed in aluminum). This is a remarkable generalization of natural radioactivity with multiple applications, in particular in biology. This discovery brought the two young scientists the Nobel Prize in chemistry of 1935. On their return from Stockholm, at a banquet given in their honour, Paul Langevin proposes to call both "Joliot-Curie" from then on.

◄ The "laboratoire de synthèse atomique d'Ivry", summer 1942

Immediately, in Rome, Enrico Fermi and his team decide to produce, if possible, radioactive isotopes of all available chemical elements, using neutrons, which are able to penetrate in the heaviest nuclei. They observe in uranium irradiated by neutrons what they believe to be isotopes of "transuranic" elements, nuclei heavier than uranium. The torch is handed over to Otto Hahn, Lise Meitner and Fritz Strassmann in Berlin; in their publications these scientists indicate that they had identified several series of transuranic isotopes. Early 1938 in Paris, Irène Joliot-Curie and Paul Savitch open a new way for studying this problem.

Fission, chain reaction and international background

In July 1938, following the *Anschluss*, Lise Meitner, having Austrian nationality and Jewish origin, is forced to flee from Germany, taking refuge in Sweden. Hahn and Strassmann resume their chemical separations in order to examine with still more care whether some of the transuranic isotopes would not actually be isotopes of radium. Just before Christmas of 1938, to their great surprise, they

▼ FIG. 1: Irène and Frédéric Joliot-Curie in their laboratory at the Radium Institute.

▲ **FIG. 2:** From left to right: F. Joliot, H. Halban and L. Kowarski (adjusting a pulse amplifier) at the laboratoire de chimie nucléaire of the Collège de France.

▼ **FIG. 3:** F. Joliot (with raincoat) and L. Kowarski (to the right) in front of the blockhouses of the Châtillon fort in 1946.

dicover that these radionuclides are not isotopes of radium but isotopes of barium, a much lighter element; uranium nuclei would thus have "burst" under the action of the bombarding neutrons. Their results are published early January 1939. Alerted by Otto Hahn, Lise Meitner, with her nephew Otto Frisch, provide a physical explanation of the phenomenon, to which Frisch will give the name of "fission"; they publish this explanation in February.
Professor at the *Collège de France* in Paris, Joliot immediately seizes this problem. He realizes, like a few of his colleagues in other countries, that fission must release a considerable amount of energy. This observation leads him at once to an experiment on the recoil nuclei, providing a physical proof of fission (end of January, 1939). A cloud chamber picture provides additional confirmation. He thinks that fission must be accompanied by new neutrons, which would thus open the possibility of a chain reaction. He then forms a team with Hans Halban and Lew Kowarski in order to check experimentally that new neutrons are actually emitted, and, after that, to measure their energy and establish their number. The results which they obtain are very encouraging.

The team of the Collège de France is in competition with a team at Columbia University in New York, led by Fermi and joined by Leo Szilard. The French team is in general ahead by one to three weeks; Francis Perrin is asked to join in order to compute the dimensions of an energy producing device. On May 1st, 2nd and 3rd, the team takes out three patents on behalf of the *Caisse nationale de la Recherche scientifique* (father of the present CNRS). Immediately afterwards F. Joliot travels to Brussels to propose an industrial collaboration to the *Union minière du Haut-Katanga*, a company which holds the most important uranium mines. A memorandum of understanding is signed and a draft agreement is prepared. The Union minière places a total of 8 tons of uranium oxide at the disposal of the French team, which carries on its work at the Laboratory of atomic synthesis at Ivry, in the southern suburbs of Paris. In a few weeks, F. Joliot has shifted from basic science to applied science. In the United States, N. Bohr and J.A. Wheeler show that uranium-235, the less abundant isotope of natural uranium, is responsible for the fission by slow neutrons.
The war breaks out on September 1st, 1939. Work goes on, but the results are no longer published; a sealed letter is deposited at the Academy of sciences. Frédéric Joliot is received by Raoul Dautry, the new Minister for armament, and explains to him the aims of the ongoing work. Slow neutrons are more efficient for producing fission; the team uses a hydrogenous medium ("moderator") for slowing down the neutrons. However they realize that, in order to obtain a divergent chain reaction, moderator and uranium must be separated and form a heterogeneous device. They also realize that ordinary hydrogen absorbs neutrons too efficiently and therefore want to use deuterium as a moderator. Consequently, they must obtain heavy water which, at that time, is only prepared at Rjukan in Norway. On the basis of a report by Joliot, Dautry decides to send lieutenant Jacques Allier, as head of a commando, on a secret mission to Norway to get the precious product. The operation unfolds successfully at the beginning of March 1940, bringing 167 liters of heavy water to France.
Two new patents are taken out on April 30th and May 1st, 1940. However, soon after that the German invasion of France begins. Halban, Kowarski, the heavy water and a large part of the equipment are withdrawn to Clermont-Ferrand, joined by F. Joliot just before the Wehrmacht marches into Paris. The situation has become dramatic. The three physicists take the heavy water to Bordeaux. At Joliot's request, Halban and Kowarski, with an official travel warrant, embark for England on June 17th, on board the "Broompark", carrying the stock of heavy water and the documents corresponding to the last results obtained by the team. F. Joliot decides to stay in France. The uranium, transported to Morocco, is hidden in a closed-down mine

gallery during the entire war. Upon arrival in London, Halban and Kowarski draw up the summary and the conclusions of the last work of the team; they end with the following sentence : *"Two ways are recommended for the production of energy : the method of slow neutrons with a little enrichment in uranium-235; or the hope that the capture of neutrons by uranium-238 leads after all to a new fissionable nucleus [1])."*

Frédéric Joliot, having returned to Paris, faces up to the situation. He finds his laboratory at the Collège de France occupied by the Germans, but under the authority of a friendly physicist, Wolfgang Gentner, an "elder" of the Institut du Radium. Gentner will protect him efficaciously when Joliot gets actively involved in the Resistance movement. The physicist undertakes research in collaboration with biologists on the use of radioactive isotopes in biology.

After the war : the Department of atomic energy (CEA) and ZOÉ

At the Liberation, in August 1944, Joliot is appointed Director general of the National Center for Scientific Research (CNRS). He gradually learns about what has been achieved in the United States during the war, and in particular the starting up of the first atomic pile (nuclear reactor) in Chicago, under the leadership of Fermi, in December 1942. Joliot has two conversations with General de Gaulle, president of the provisional government: in November 1944, and, together with Pierre Auger, in May 1945. The idea of a French organization especially devoted to atomic energy (nuclear energy) is dawning. After the atomic bombs on Hiroshima and Nagasaki in August 1945, de Gaulle has an 'ordinance' adopted in October establishing the CEA (Commissariat à l'énergie atomique); the text had been prepared by F. Joliot and R. Dautry. On January 3rd 1946, de Gaulle appoints Frédéric Joliot to be "Haut-commissaire" and Raoul Dautry to be general Administrator of the CEA.

F. Joliot immediately launches a systematic search for uranium ore in France. Three years afterwards, in February 1949, he was to describe the programme of the new organization in the following way,: *"We started almost from scratch as far as equipment was concerned, and we had to create everything; but the special ordinance which established the CEA had been taken with a view to make our task easier. We have immediately foreseen three stages in the development of atomic energy, and the first of these comprised the construction of a heavy water uranium pile, of low power, together with all the subsidiary constructions this included."*

Under the enthusiastic impetus of Frédéric Joliot and the direction of Lew Kowarski back from Canada, the pile ZOÉ (for Zero power, uranium Oxyde and heavy Water) is built at the fort of Châtillon in Fontenay-aux-Roses. For that achievement the CEA has at its disposal the results obtained by the team of the Collège de France in 1939-1940, the uranium brought back from Morocco, the agreements concluded with Norway for heavy water, the knowledge brought by the French scientists returning from Canada (Kowarski, Goldschmidt, Guéron and Auger) and parts of the Smyth report publicized by the American authorities as early as August 1945 (*Review of Modern Physics*, October 1945). The work is proceeding fast. The uranium is processed at the Le Bouchet factory, south of Paris. On December 15th of 1948, ZOÉ, the first French atomic reactor, begins operating. It will supply artificial radioactive isotopes for biological applications, allow the training of technicians and the development of materials necessary for the construction of medium power reactors. Its external installation has been preserved and one can visit it by appointment.■

▼ FIG. 4: Frédéric Joliot (on the left) and Lew Kowarski (on the right) accompanying the President of the Republic, Vincent Auriol (center), at the inauguration of ZOÉ in December 1948.

About the author

Pierre Radvanyi is a nuclear physicist, active in history of science; he is honorary director of research at the CNRS. After a Ph.D., directed by F. Joliot-Curie, on radioactivity by electron capture at the Collège de France, he worked with the Orsay synchrocyclotron, the Saclay linear electron accelerator and the Saturne synchrotron. He has been deputy director of *Laboratoire national Saturne* (1978-1985).

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note

[1] This will actually be plutonium 239, discovered in Berkeley in 1940/1941.