



DISTINGUISHED

NUCLEAR PIONEERS—1972

FRÉDÉRIC AND IRÈNE

JOLIOT-CURIE

The choice of Frédéric and Irène Joliot-Curie as Distinguished Nuclear Pioneers for 1972 by the Society of Nuclear Medicine is one of the best that could be made because their discovery of artificial radioactivity was not only a great step forward in the development of nuclear physics but has also led directly to the possibility of obtaining radioactive isotopes of practically all the chemical elements—those radioisotopes which are now so widely used in medical research or practice, and without which nuclear medicine could not exist.

Frédéric Joliot was born in Paris on March 19, 1900. His father, Henri Joliot, having participated in the uprising of the Commune of Paris in 1871, had been obliged to spend several years in Belgium. When he returned after the amnesty, he settled in Paris where he became a well-to-do tradesman. He married Emilie Roederer, of Alsatian origins, in 1879. Frédéric was the youngest of their six children. Raised in a nonreligious family, he never attended any church. He spent seven years as a boarder at the Lycée Lakanal near Paris, and after the death of his father, two years at the Ecole Primaire Supérieure Lavoisier in Paris. There he prepared for the Ecole de Physique et de Chimie Industrielle de la Ville de Paris to which he was admitted in 1920. During the three years of studies in this well-known engineering school where a large part of the curriculum is devoted to laboratory work, Joliot discovered basic science and scientific research. He was

there under the guidance of his principal teacher, the great physicist Paul Langevin, who was the first to recognize Joliot's exceptional gifts and who had a decisive influence on him, not only in the field of science but also in leading him toward socialism and pacifism. Joliot graduated first in his class, and after 15 months of military service, he might have started a brilliant career as an engineer in industry. But following the advice of Paul Langevin he became a personal assistant to Marie Curie who paid him on a grant from the Rockefeller Foundation.

Thus Frédéric Joliot started his scientific career in the spring of 1925 at the Institut du Radium of the University of Paris under the guidance of Marie Curie. His first research concerned a new method of studying the electrolytic deposition of radioelements, especially of polonium. This work, in which he displayed great skill in handling difficult techniques, led him on to the study of the electrical properties of very thin metallic films, which later proved of some practical importance. In 1930 he received the degree of doctor in physical science for a thesis on the electrochemical properties of polonium.

From the time he began to work at the Institut du Radium, Frédéric Joliot had been brought into contact with Marie Curie's eldest daughter, Irène, who was already a qualified researcher having just received the degree of doctor in physical science. He was soon attracted by her exceptional personality, completely different from his own. They were

married in 1926 and began to collaborate on some experiments. They first published a paper together in 1928, but it was not until 1931 that they started the close collaboration which, uniting their complementary qualities, led them, within four years, to the discovery of artificial radioactivity and the joint award of the Nobel Prize.

Irène Curie was born in Paris on September 12, 1897. She was the daughter of Pierre and Marie Curie, the discoverers of radium. Pierre Curie was already a well-known physicist when he married in 1895, at the age of 36, a brilliant Polish student, Marie Skłodowska. This marriage led to a constant collaboration between two exceptionally gifted scientists who had both decided to dedicate their life to basic research. Their joint effort culminated in the discovery of radium hardly more than a year after the birth of Irène, their first child. Since her mother spent most of her time in the laboratory, the childhood of Irène would have been very lonely if her grandfather, Eugène Curie, had not come to live with Pierre and Marie in 1898. Eugène Curie, a medical doctor, had imperiled his life by attending the wounded on the barricades during the popular uprisings in Paris in 1848 and in 1871 during the Commune. Until his death in 1910, he had a great influence on the development of Irène's character and personality. It was to him that Irène owed her unqualified atheism and her bent to the liberal socialism to which she remained faithful all her life.

Irène did not go to school until she was 12 years old, but her mother supervised her early scientific education, and for two years Irène enjoyed the privilege of attending lessons in a teaching cooperative established by Marie Curie and some of her colleagues for their own children. Marie Curie taught physics, Paul Langevin mathematics, and Jean Perrin chemistry. After that, Irène went to the Collège Sévigné, a private school pioneering in teaching methods. She passed the baccalauréat just before the outbreak of the first World War. During the following six years, she studied at the Sorbonne, passing the examinations leading to a licence in physics and mathematics. While pursuing her studies at the University, Irène served many months during the war as an army nurse, assisting her mother in setting up equipment for radiography of the wounded; at the age of 18, she had sole responsibility for installing and starting the operation of a radiographic unit in an Anglo-Canadian hospital, a few miles from the front in Flanders.

After the end of the war, Irène Curie was appointed assistant at the Institut du Radium, of which her mother was the director, and soon she began scientific research in radioactivity. Her first impor-

tant investigation was on the straggling (fluctuation of range) of alpha particles, deduced from the accurate measurement of the range of a large number of alpha rays emitted by a thin layer of polonium whose tracks in a Wilson cloud chamber were photographed. This work was presented in her doctoral thesis in 1925. After her marriage to Frédéric Joliot in 1926, she continued for a few years to work alone most of her time on some studies in the field of what may be called classical radioactivity.

The real collaboration between Frédéric and Irène Joliot-Curie (this double name came into use much later) started in 1931 and was based on the use of several new instruments, some of which were specially constructed under the supervision of Frédéric and following his design, notably a large cloud chamber that could operate at various pressures and in a strong magnetic field) allowing the determination of the energy of electronic rays (beta rays) and, as it turned out to be important, their electrical sign. They also prepared together an exceptionally strong source of polonium, the largest ever prepared, with a high surface density of activity. This preparation could be done because of a large stock of radium D patiently accumulated at the Institut du Radium by Marie Curie, but it was both difficult and dangerous because of the high toxicity of polonium, and it required considerable experimental skill and a detailed knowledge of radiochemistry.

They first used this very strong source of alpha rays to follow up the recent discovery by the German physicists Bothe and Becker of an extremely penetrating radiation emitted by boron or beryllium bombarded by alpha particles. Displaying much



imagination in their experiments, they soon made the quite unexpected discovery that this new radiation, assumed to be very energetic gamma rays, had the property when passing through a substance containing hydrogen like paraffin or water of ejecting in the forward direction high-energy protons. On reading the publication, dated January 18, 1932, of this striking discovery, James Chadwick immediately recognized that the projection of energetic protons could not be due to any gamma radiation but must result from collisions of fast-moving heavy neutral particles, the long-thought-of-neutrons, and less than one month later he published some complementary evidence of his interpretation. But obviously the discovery made by the Joliot-Curies was the essential and decisive step which led to the discovery of the neutron.

While continuing to study the emission of neutrons in varied nuclear reactions, the Joliot-Curies made important contributions concerning positive electrons, whose existence and properties had been predicted by Dirac and which had been recently discovered in cosmic radiation by Carl Anderson. In the spring of 1933, they discovered that some of the light elements emitting neutrons when bombarded by alpha particles, also emit positive electrons. But it was not until the early days of 1934 that Frédéric Joliot fortuitously observed that, whereas the emission of neutrons ceased as soon as the alpha-ray source was taken away, the emission of positive electrons continued for several minutes. In collaboration with his wife, he was able within a few days to prove that the delayed emission of positrons decayed exponentially with time, as does the emission of ordinary negative electrons by a natural beta radioactive element. It appeared that the creation of such radioactive atoms could only result from the capture of the incident alpha particle followed by the ejection of the observed neutron. The new radioelement should thus be an isotope of phosphorus, in the case of aluminum, and of nitrogen, in the case of boron. Using with dexterity the extremely sensitive methods of radiochemistry, the Joliot-Curies successfully demonstrated, in less than two weeks, that this was indeed the case.

These experiments provided the first chemical proof of induced transmutations and showed the possibility of artificially creating radioisotopes of known stable elements. This remarkable discovery of what has been called artificial radioactivity was recognized the following year (1935) by the award of the Nobel Prize for Chemistry jointly to Irène Curie and Frédéric Joliot for "their synthesis of new radioactive elements".

The fame coming with the Nobel Prize brought

them new responsibilities and separated their careers.

Frédéric Joliot, who had lived since 1931 on a research stipend from the recently created Caisse Nationale de la Recherche Scientifique, was elected in 1937 professor at the Collège de France. For nearly two years he devoted his energy to equip his new laboratory with particle accelerators which were replacing radioactive sources for the study of nuclear reactions.

Irène Joliot-Curie was for a few months in 1936 a member in Léon Blum's Popular Front government, as a secretary of state responsible for the national organization of scientific research. She was then elected assistant professor at the Sorbonne and resumed her research work in the laboratory of the Institut du Radium. It was during the following year that she did her most remarkable work, quite independently of any collaboration with her husband. Taking advantage of her great experience in radiochemistry, she sought to unravel the complex phenomena which result from bombarding uranium with neutrons. In collaboration with the Yugoslav physicist, P. Slavic, she showed that, among the many different radioisotopes formed by the neutron irradiation, one had chemical properties very similar to those of lanthanum, an element situated in the middle, not near the end, of the Mendeleev classification. A fortuitous complication prevented her from discovering that this radioelement was indeed an isotope of lanthanum, but it was on following up these experiments of Irène Joliot-Curie that Otto Hahn discovered, in December 1938, the fission of uranium by neutrons.

Within a few days after the publication of this discovery of fission, established by Hahn on chemical evidence, Frédéric Joliot by a simple and elegant experiment demonstrated the explosive character of the bipartition of uranium nuclei by neutrons (which was proved independently and nearly simultaneously by O. Frisch in Copenhagen). Pursuing the study of this phenomenon, Frédéric Joliot was uncontestedly the first, in collaboration with H. Halban and L. Kowarski, to prove that the fission of a uranium atom by one slow neutron is accompanied (or followed) by an emission of several fast neutrons. It was then possible, as Joliot immediately did, to consider the development, like that of an avalanche, of divergent chain reactions in which a fast increasing number of uranium atoms would undergo fissions linked by neutrons. With the added collaboration of Francis Perrin, the conditions in which such divergent nuclear chain reactions could develop were soon determined. It was shown that it would be necessary to associate with uranium a substance containing light atoms and absorbing very few slow neutrons

to slow down the fast neutrons emitted by the fission process, and that the best moderator (term adopted much later) would be heavy water. It was also shown that large quantities of uranium and moderator would be needed. For these reasons Joliot, who had obtained six tons of uranium oxide from the Belgian Congo, ordered from Norway the only sizable stock of heavy water then existing in the world. This heavy water, nearly two tons, arrived safely in Paris in spite of the outbreak of the Second World War but too late before the invasion of France to do any experiment with it there. Both Frédéric and Irène Joliot-Curie decided to remain in France with most of the researchers in their laboratories, but Joliot directed Halban and Kowarski to carry the precious heavy water with them to England and to continue there the investigations of the French group. All work on chain reactions in uranium stopped when the German military authorities took over Joliot's laboratory. While continuing research in pure nuclear physics and working with one of his biologist colleagues on some applications of radioiodine in physiology, Frédéric Joliot became increasingly involved in dangerous resistance activities. In the spring of 1944 he had to go into hiding with the help of militant Communists. It is during this period that he joined the then clandestine Communist party.

Immediately after the liberation of Paris in the summer of 1944, Frédéric Joliot was appointed Director of the Centre National de la Recherche Scientifique and for about one year he devoted his activity to the reorganization of scientific research in France. After the explosions of the first atomic bombs, Joliot recommended to General de Gaulle, head of the provisional Government, that a special and powerful organization be set up to resume the work on nuclear energy which had been interrupted in 1940. Following this advice the Government created the "Commissariat à l'Énergie Atomique" under the direction of Joliot as High Commissioner, responsible for all scientific and technical activities, and of an Administrator-General, responsible for administration and finance. On the board of Directors were Irène Joliot-Curie, Francis Perrin, and Pierre Auger. Under the inspiring direction of Joliot, in spite of all the industrial difficulties resulting from the long German occupation, much work was quickly done and France's first atomic pile came into operation in December 1948. The next step was the creation of a major nuclear research center near Saclay some ten miles south of Paris, in which Joliot directed the construction of a much more powerful atomic pile, of a large cyclotron, and other accelerators, and of many laboratories.

In 1950 Frédéric Joliot was dismissed from the

post of High Commissioner for political reasons and was succeeded by Francis Perrin. In the following years Joliot once again gave most of his time to the direction of his laboratory at the Collège de France, but feeling that he ought to dedicate his best efforts to what seemed to him the most effective struggle against the threat of an atomic war, he became very active in the Communist-dominated World Organization of the Peace Partisans.

In 1946 Irène Joliot-Curie was appointed professor at the Sorbonne and director of the Institut du Radium created for her mother some 30 years before. There she continued her personal experimental research, working most of the time in the small laboratory in which she had conducted all her own research in radiochemistry. After 1950, she devoted an increasing effort to the creation of new laboratories for the Radium Institute at Orsay, in the southern suburbs of Paris. Also during these years she was very active in women's pacifist movements but never became a member of any political party. She died in March 1956 at the age of 58, a victim, like her mother, of an acute leukemia resulting undoubtedly from excessive irradiation by x- and gamma rays to which she had been exposed over many years, when their dangers were not yet recognized.

The death of his wife was a great shock to Frédéric Joliot who had at that time hardly recovered from a serious attack of viral hepatitis. He was appointed to succeed her as director of the Institut du Radium and took over with ardor the task of supervising its relocation in the newly built laboratories at Orsay, but his health remained precarious. He died in August 1958, after an operation following an internal hemorrhage. At his state funeral a large crowd paid homage to the great scientist and the great pacifist he had been.

During his life Frédéric Joliot was honored by many academic distinctions. He was a member of the Académie des Sciences and of the Académie de Médecine, a foreign member of the Royal Society of London, the Academy of Sciences of the USSR, and of several other Academies. He was also doctor *honoris causa* of many universities.

Frédéric and Irène Joliot-Curie had two children who have both become distinguished scientists. Their daughter, Hélène, born in 1927, is a nuclear physicist, and their son, Pierre, born in 1932, a biophysicist. Hélène has married one of Langevin's grandsons, Michel, a nuclear physicist like herself, thus uniting the families of the two great physicists, Marie Curie and Paul Langevin, who had the most important influence in molding the scientific personalities of Irène and Frédéric.