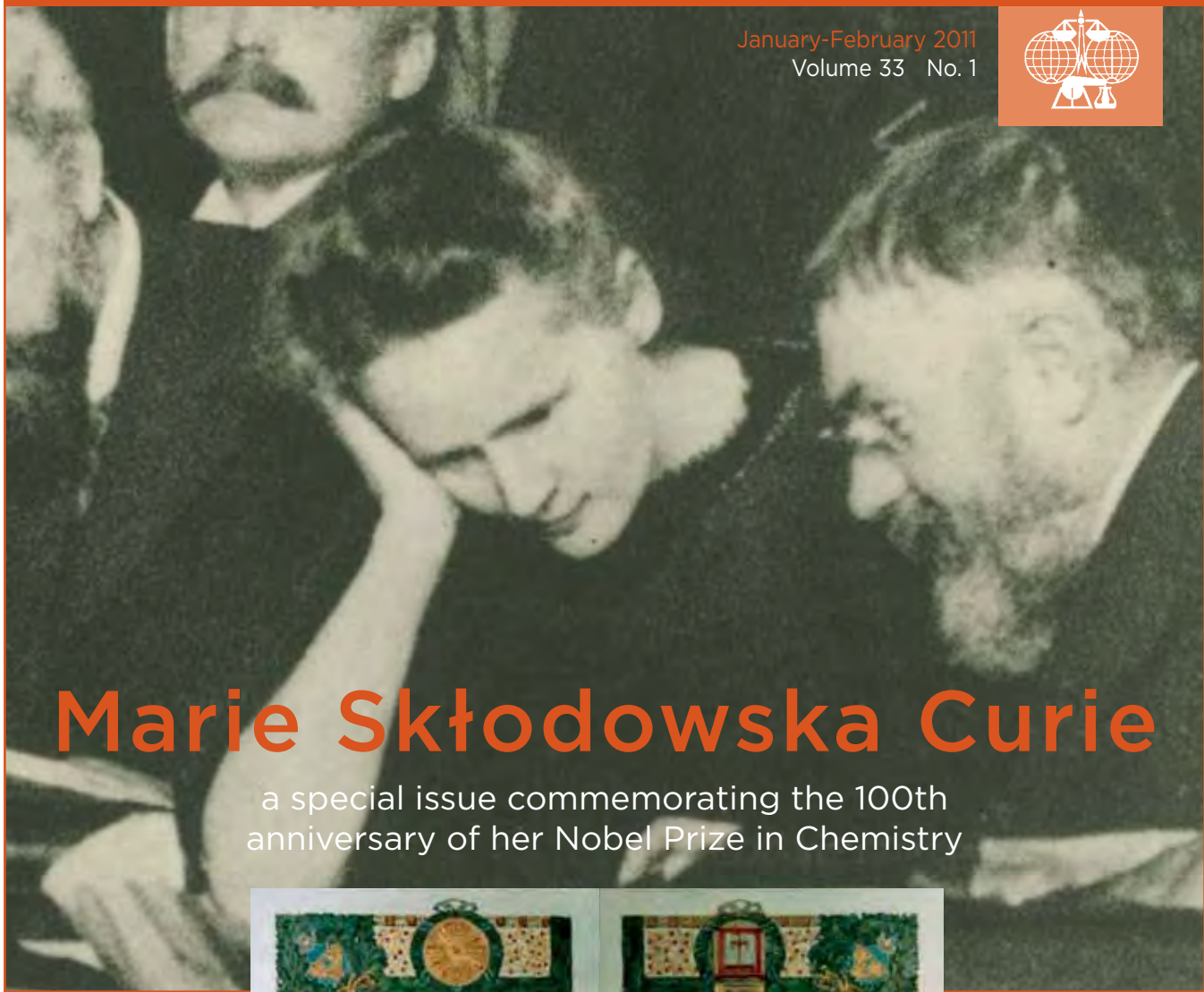


The News Magazine of the  
International Union of Pure and  
Applied Chemistry (IUPAC)

# CHEMISTRY

## International

January-February 2011  
Volume 33 No. 1



# Marie Skłodowska Curie

a special issue commemorating the 100th  
anniversary of her Nobel Prize in Chemistry



**IYC 2011**  
International Year of  
CHEMISTRY



# From the Editor

## CHEMISTRY International

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International Union of Pure and  
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## Special

As we embark on the International Year of Chemistry, it is hard to imagine a more fitting symbol of chemistry's potential, power, and peril than Madame Marie Skłodowska Curie. For this one pathbreaking woman embodies all of the goals of our year-long celebration of chemistry. Her story illustrates *the role of chemistry in meeting world needs*, it can help *encourage interest in chemistry among young people*, and can *generate enthusiasm for the creative future of chemistry*. And, quite obviously, in Marie Curie we have an *opportunity to celebrate the contributions of women to science* and to *highlight the benefits of international scientific collaboration*.

In preparing this special issue of *Chemistry International* devoted entirely to Marie Curie, guests editors Robert Guillaumont, Jerzy Kroh, Stanislaw Penczek, and Jean-Pierre Vairon made a point of celebrating not only her scientific achievements, but also the person and the woman. These articles demonstrate how one of the most extraordinary scientists was a most amazing person as well—from overseeing mobile X-ray units during World War I to raising a family to creating a whole new field of medicine to pursuing international peace.

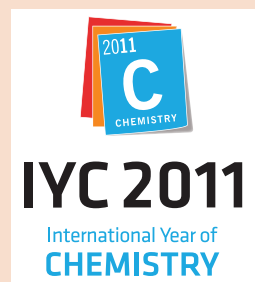
I think that Marie Curie would approve of the IYC motto, *Chemistry—our life, our future*, since it would be as fitting in her lifetime as it is today. Her future is our history and this issue is an invitation to consider the ways she used chemistry to contribute to the well-being of humankind.

Much has been written about Marie Curie, so we simply hope this special issue will add a spark of motivation for celebrating IYC.

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The upper image on the cover is of Marie Curie conferring with Henri Poincaré at the First Solvay Conference in 1911. The lower image is of the Nobel Prize in Chemistry diploma awarded to Curie in 1911.





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by Guest Editors Robert Guillaumont, Jerzy Kroh, Stanislaw Penczek,  
and Jean-Pierre Vairon

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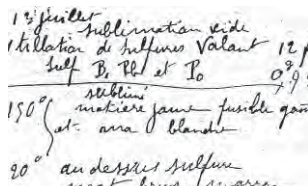
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## Preface

# Celebrating One Hundred Years

by Guest Editors Robert Guillaumont,  
Jerzy Kroh, Stanislaw Penczek, and  
Jean-Pierre Vairon

When the United Nations declared that 2011 would be the International Year of Chemistry, it did so in part because the year 2011 coincided with the 100th anniversary of the Nobel Prize in Chemistry awarded to Madame Marie Curie—an opportunity to celebrate the contributions of women to science. With this in mind, IUPAC has devoted this special issue of *Chemistry International* devoted entirely to Marie Curie. Produced under the direction of a French-Polish editorial board, the issue explores the impact of Marie Curie's discoveries and personality on the development of modern chemistry, physics, and nuclear medicine. The closely linked contributions to this issue merge the scientific and personal aspects of Marie Curie—the scientist and the woman—to offer a new perspective on her unique life.

In addition to the eminent specialists who contributed articles, this issue features two authors with firsthand knowledge of Marie Curie. We are very much grateful to Hélène Langevin-Joliot, granddaughter of Marie and Pierre Curie, who kindly agreed to coauthor the first article. In addition, we are thankful for the contributions from guest editor Jerzy Kroh, a former student of one of Marie Curie's coworkers—in essence a grandson-through-science of Marie Curie.

Let us point out, in a few words, why Marie Curie is so closely tied to the International Year of Chemistry.

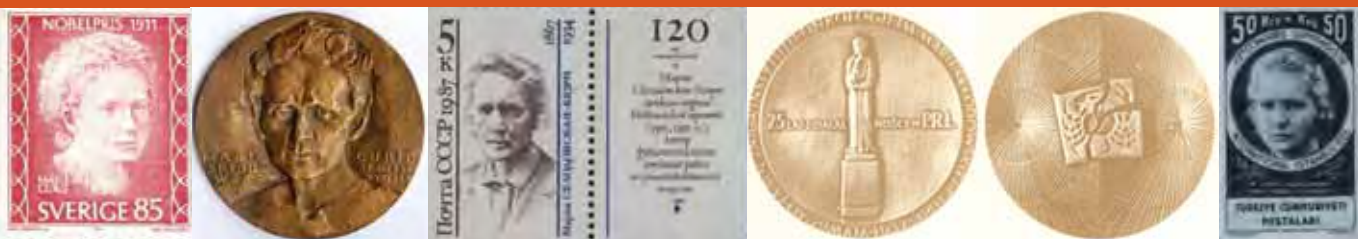
**Marie Curie is a legendary figure of science.** She received the highest scientific recognition for her work twice: being awarded the Nobel Prize in 1903 and 1911. The first time, she shared the third-ever Nobel Prize in Physics with Henri Becquerel and Pierre Curie; half to Henri Becquerel for “the discovery of the spontaneous radioactivity” and half to Pierre and Marie Curie for “their joint researches on the radiation phenomena

discovered by Henri Becquerel.” It is notable that in these statements that the word “radioactivity” is associated with the name of Henri Becquerel since the word was coined by Marie Curie in her doctorate, which was presented at the Sorbonne in 1903. Pierre and Marie Curie had already announced, five years earlier, the discovery of the elements polonium and radium. But physicists and chemists were still disputing the existence of “radioactivity” and the chemists on the Nobel Prize jury refused to mention the word “radium” in the heading of a Nobel Prize in Physics. In 1911 Marie Curie was awarded the Nobel Prize in Chemistry for “her services to the advancement of chemistry by the discovery of the elements polonium and radium, by the isolation of radium, and the study of the nature and compounds of this remarkable element.” Her scientific stature was now at the level of her friends Jean Perrin, Paul Langevin, Henri Poincaré, Albert Einstein, and many others who renewed the sciences of physics and chemistry at the beginning of the 20th century.



**Marie Curie was the first woman to win the Nobel Prize in Chemistry.** Curie received a thorough education in chemistry in Poland before graduating with degrees in physics and mathematics from the La Sorbonne, Paris, in 1893 and 1894. A year before attending the Sorbonne in Paris, she worked in the laboratory of the Warsaw Museum of Industry and Agriculture, which was headed by Professor Józef Jerzy Boguski, a former assistant of Dymitri Ivanovich Mendeleev in St. Petersburg. In this lab, she learned qualitative and quantitative chemical analysis, studied the chemistry of minerals, and gained practice in various chemical procedures. In Poland, Curie also studied with Napoleon Milicer (a pupil of Robert Bunsen) and Ludwik Kossakowski. She wrote, “If Professor N. Milicer and his assistant lecturer, Dr. L. Kossakowski, hadn't given me a sound grasp of analysis in Warsaw, I would have never separated out radium.”

In Paris, Curie promptly became acquainted with the state of the art of the 1895 fundamentals of chemistry, mainly analytical chemistry, working with Gustave Bémont, chef de travaux at the Ecole Municipale de Physique et Chimie de la ville de Paris. Clearly, Pierre and Marie were already au fait in radiation physics and



the measurement of radioactivity. From her 1911 Nobel Lecture, it is clear that by mastering both chemistry and radioactivity, she pioneered the concept of chemistry based on the “atom.” Marie Curie’s Nobel lecture summarized the state of the art of this “new science” she created, today known as radiochemistry. This could be described as the sunrise for a new school of thought in chemistry, and in science in general, centered upon the atom. In this context, it is worth noting that Pierre and Marie Curie’s daughter, Irène, and her husband, Frédéric Joliot, discovered artificial radioactivity. They were awarded the Nobel Prize in 1935 for this discovery, one year after Marie Curie passed away.

**Marie Curie is one of the most important women in human history.** *The Encyclopaedia Britannica’s* list of “300 Women Who Changed the World” rightly includes Marie Curie. Clearly, she is someone who helped change the course of science, but she also helped change the course of women in society. Faced with a male-dominated world—in particular, a male-centered academia and press—she still managed to advance farther in science than any woman before her. In the media frenzy surrounding her accomplishments, she overcame discrimination on the part of numerous prestigious academic institutions that refused to fully recognize her scientific achievements. Françoise Giroud’s biography, *Marie Curie: A Life*, explores this aspect of her life and career and emphasizes her role as a feminist precursor. Today, although inequalities still linger, the opportunities available to women in science have grown steadily since Curie’s heroic achievements. In fact, in 2009, for the first time three women received Nobel prizes in the sciences—nearly a century after the two-time Nobel Prize winner was barred from France’s science academy.

In addition to helping advance the rights of women, Marie Curie had a major impact on society through her establishment of Institutes of Radium in France and Poland, providing them with large specimens of radium. During World War I she helped improve treatment to soldiers in France (together with her young daughter) by providing them with X-rays out of a small army of cars called “Petites Curie” (Little Curies).

A great deal has been already said, written, and disseminated about Marie Curie. Of the many Marie Curie biographies, the one written by Marie Curie’s daughter Eve is particularly popular; it is often a reference text for students, especially in Poland (E. Curie 1937). Marie

Curie’s name is inseparable from that of radium, the most popularized chemical element among all others during the first half of the 20th century. Around the world, her name has also become attached to numerous international scientific programs, research institutions, universities, high schools, streets, and more. Her image appears on many medals, stamps, and currency. Her ashes, along with Pierre Curie’s, are in the French Pantheon, the greatest tribute paid by France to its most renowned citizens.

We are convinced, as guest editors, that this issue of *Chemistry International* will help illuminate the life and career of Marie Curie. In addition, we hope it proves inspirational to young scientists everywhere. The legacy of Curie is that talent, combined with perseverance and hard work, can lead to exceptional results.

The following quotes from Marie Curie capture the essence of the woman and her unique contributions. “Nothing in life is to be feared. It is only to be understood.” And then, in her Nobel Lecture, she modestly stated that “In the case of radium, isolation was completely successful but required several years of unremitting effort.” Obviously, her colleague Albert Einstein was correct when he said “Marie Curie is, of all celebrated beings, the one whom fame has not spoiled.” 🍷

**Robert Guillaumont** is an honorary professor of chemistry at the University of Paris-Sud, Orsay; a member of the French Academy of Sciences; and president of the French National Committee of Chemistry. His research field in radiochemistry focused mainly on tracer scale chemistry and on thermodynamics of actinide chemistry. He is a member of several committees on radwaste management.

**Jerzy Kroh** is a full member of the Polish Academy of Sciences, honorary member of the Royal Society of Edinburgh, doctor honoris causa of four universities (Glasgow, Leeds, Pavia, Lodz), exRector of Lodz Technical University, author and coauthor of 400 scientific papers, and founder of the radiation chemistry school in Lodz, Poland.

**Stanislaw Penczek** is a professor of polymer chemistry at the Polish Academy of Sciences and is a member of the Academy. He is also an honorary professor of the Jagiellonian University (Krakow), Doctor h.c. of the University Pierre et Marie Curie (Paris), and Dr h.c. of the Russian Academy of Sciences. He is a foreign member of the German (Nord Rheinische) Academy of Sciences and a member of the IUPAC Bureau.

**Jean-Pierre Vairon** is emeritus professor of chemistry at the University Pierre et Marie Curie, Paris; a member of the French National Committee of Chemistry; coordinator of the 2011-Marie Skłodowska-Curie Nobel prize celebration; and Dr. h.c. of the Russian Academy of Sci. and honorary member of the Polish Chemical Society.

# Marie Curie and Her Time

by *Hélène Langevin-Joliot*

**M**arie Curie (1867–1934) belongs to that exclusive group of women whose worldwide recognition and fame have endured for a century or more. She was indeed one of the major agents of the scientific revolution which allowed experimental investigation to extend beyond the macroscopic world. Her work placed the first stone in the foundation of a new discipline: radiochemistry. And Curie's achievements are even more remarkable since they occurred in the field of science, an intellectual activity traditionally forbidden to women. However, these accomplishments alone don't seem to fully explain the near mythic status of Marie Curie today. One hundred years ago, she was often considered to be just an assistant to her husband. Perhaps the reason her name still resonates is because of the compelling story of her life and her intriguing personality.

## The Most Beautiful Discovery of Pierre Curie

The story of the young Maria Skłodowska leaving her native Poland to pursue upper-level studies in Paris sounds like something out of a novel. At that point, however, Maria's future was far from written.

"I keep a sort of hope that I shall not disappear completely into nothingness," she wrote to a friend, three years before leaving Warsaw for Paris. In the fall of 1891, she registered at the Sorbonne and from then on until her successes in physics and mathematics, she spent days, evenings, and even nights in the attic where she studied. She wrote to her brother: "We must believe that we are gifted for something, and that thing at whatever cost must be attained."

Marie Skłodowska and Pierre Curie had apparently ruled out love and marriage for themselves when they first met in 1894. At the time, Marie thought

her duty was to teach in Poland. Eventually, Pierre found the words to overcome her hesitations: "It would be a fine thing, in which I hardly dare believe

to pass our lives near each other hypnotized by our dreams, your patriotic dream, our humanitarian dream, and our scientific dream."

Frederick Soddy wrote about Marie that she was "the most beautiful discovery of Pierre Curie." Of course, it might also be said that Pierre Curie was "the most beautiful discovery of Marie Skłodowska." It is difficult to imagine more contrasting personalities than those of Pierre and of Marie. In spite of that, or because of that, they complemented each other astonishingly well. Pierre was as dreamy as Marie was organized. At the same time, they shared similar ideas about family and society.



*In this iconic photograph of participants at the Fifth Solvay Conference in 1927, Marie Curie is third from the left in the front row.*

## A Woman Scientist in a Male-Dominated Society

The discoveries of polonium and radium in 1898 are, no doubt, a cornerstone of Marie Curie's celebrity nowadays. However, this article focuses not on her research, but on Curie herself and the important people in her life. It should be noted that a century ago, it would have been exceptionally difficult for a woman to be recognized for scientific achievement—by the academic community, let alone by the public—without the encouragement and support of a father, a husband, or a brother. It is worthwhile to point out the importance for Curie's scientific future of the seemingly simple act of placing only her signature on the April 1898 note to the French Academy of Science. Although even today this might seem presumptuous for someone who was still only a Ph.D. student, the fact that her signature alone appeared on that note would later prove significant in recognizing her contribution towards the discovery of polonium and radium.

Marie Curie had begun working on her Ph.D. thesis on Becquerel's rays a few weeks after the birth of her



*A July 1895 wedding photo of Pierre and Marie. They first met in 1894.*

first daughter Irène. She measured the radiation with an apparatus using a piezoelectric Quartz that had been set up by Pierre Curie. The experimental program was mainly hers; in particular, the crucial decision to investigate minerals and to compare the activity of the natural chalcocite she was studying to that of an artificial one. However, she was a Ph.D. student and she benefited from Pierre's help and advice since they had already started to work together. The tradition, still practiced today, would have been for the "supervising" physicist to also sign the note. Clearly, Pierre thought it important for her to sign it alone. For the other two papers that they published that year, in July and December, announcing the discovery of Polonium and Radium, they both signed their names. In 1903, they shared with Henri Becquerel the Nobel Prize in physics.

The opening of the Nobel Prize Committee's archives brought to light an astonishing story about the 1903 Nobel Prize in Physics. In Stockholm, the committee for physics at first considered naming only Becquerel and Pierre Curie as recipients of the Nobel Prize, following the suggestion of the French Academy of Sciences. Thankfully, Pierre was privately informed by a Swedish colleague of the impending decision. He immediately protested and Marie was added as a prize recipient. Ironically, because the prize did not refer to the discovery of radium, it left the door open for her to win a second Nobel Prize in 1911, this time for chemistry. And with that, Curie became the first celebrated woman scientist in the world.

*...the fact that her signature alone appeared on that note would later prove significant...*

After the Nobel Prize of 1903, journalists focused on the dilapidated shed where Marie, with Pierre's help, had successfully separated pure radium. Marie described this period as "her killing work" in a letter to her sister. However, she protested later against the glorification of their poor working conditions, insisting they would have reached their goal much faster if the conditions had been better. Today, the symbol of the discovery of radium is not Pierre and Marie Curie with their electrometric set up at the School for Industrial Physics and Chemistry in 1898. It is a sketch of Marie Curie at a cauldron handling a heavy bar and mixing boiling matter. The picture illustrates her efforts to separate pure radium, an important result of her the-

sis and a major step for her second Nobel Prize. As a result, unfortunately, Pierre and Marie's work in common in 1898 is blurred.

## Losing Pierre

Marie and Pierre enjoyed their family life with Pierre's father, the young Irène, and their second daughter, Eve, and their time with close friends. Although they spent days and many evenings at the laboratory, but they managed to stop working on weekends and holidays. The Curies believed that it was quite important to let their children benefit from the countryside.

Tragically, this happy period of Marie's life was cut short on 19 April 1906, when Pierre was hit by a horse-drawn carriage on the streets of Paris and died instantly. This terrible loss would remain with Marie for the rest of her life. For years, she could not speak of Pierre to her children. On the other hand, she refused a national pension offered to her after Pierre's death. The French academic authorities, strongly upset by the sudden death of Pierre Curie, quickly made the historic decision to put Marie in charge of Pierre's lectures and the laboratory. This simple act swept away for the first time traditions excluding women from high-level education positions and opened the door for other women.

Marie Curie's first lecture at the Sorbonne on 5 November 1906 was celebrated in newspapers as a victory for feminism. Yet, Marie, depressed at the time, did not think of it as a victory. She was writing despaired "letters to Pierre" in her private diary. She couldn't forget the circumstances that led to her promotion, noting that "some fools congratulated me." Articles described Marie as modest and simple as she demonstrated the blue light of radium at the lecture, and then left, indifferent to the applause.

Curie did not exhibit some of the typical "feminine" qualities of the time. She was deeply convinced that women and men were equal in their potential intel-



*Pierre and Marie Curie on their honeymoon, 1895.*

## Marie Curie and Her Time

lectual capabilities. In this sense, she thought of her nomination for the Nobel Prize as a “normal” decision. She was, however, by no means a militant of feminist ideas. In many respects, she was a woman of her time, albeit one with an exceptional personality. Of her husband, Marie wrote: “Pierre Curie had devoted his life to his scientific dream, he needed a companion who could live the same dream as him.”

*“Pierre Curie had devoted his life to his scientific dream, he needed a companion who could live the same dream as him.”*

### Through Hardship and Success

In addition to spending time with her children, resuming her research on radium’s chemical properties provided the best comfort for Marie. She worked hard to prepare her lectures, which extended far beyond radioactivity subjects. She also was now at the head of a small laboratory, which she fought to expand so it would fit more researchers. In 1912, she was finally successful in this effort as construction of the Radium Institute began. This was especially rewarding for Marie Curie as the previous year had been one of hardship,

even if also of success. In 1911, she fell one vote shy in the competition for a seat at the French Academy of Science. The “Institut de France,” which gathers the five French Academies, had publicly expressed the desire to maintain its male status quo. Prior to the vote, the press and religious fanatics had waged a campaign against Marie for being a feminist, anticlerical, and a free thinker. Her supposed “affair” with the physi-

cist Paul Langevin had broken out in the papers in the fall, at the moment they were both attending the first



*Marie Curie with daughters Eve (left) and Irène, 1908.*

meeting of the prestigious Solvay Council of physics. However, in November 1911 she was informed that she would be awarded the Nobel Prize in Chemistry.

Marie attended the Nobel ceremony in December 1911. After weeks of nervous tension, she entered a period of deep depression. Her health greatly deteriorated and a kidney operation was urgently needed. Summer holidays in Great Britain with Herta Ayrton, a fellow scientist, helped her to recover. She never applied again to the French Academy of Sciences. Later, the Academy of Medicine offered her membership in recognition of the role of radium in cancer therapy. She accepted.

### Marie Curie’s Impact on Medicine

The mythical status of Marie Curie among the general public probably has more to do with the medical use of radium than with her role in opening the atomic age. Pierre and Marie Curie had taken no patent for the procedure of radium separation, a decision which added to their reputation as disinterested scientists working for the benefit of humanity.

Marie Curie’s most direct collaboration with the medical profession did not involve the use of radium but of X-rays during the First World War. The military health service was unprepared for the huge demand for X-ray diagnoses. Curie helped set up X-ray stations in several hospitals and created dozens of radiological cars that could operate near the battlefield. She helped on the scene, examining the wounded



*Prof. Władysław Skłodowski and his daughters (from left) Maria, Bronia, and Helena in an 1890 photograph.*



## Marie Curie and Her Time

to better understand how X-rays could be used, and she organized radiology training for nurses. Marie's abilities in analysis, decision making, and organization proved quite helpful in this endeavor. The whole experience helped to strengthen her self-confidence and diplomacy skills, both of which would serve her well in the years that followed.

In 1921, she contributed to the creation of the Curie Foundation for Radium Therapy and X-Radiotherapy. Marie, a powerful and dynamic director, successfully developed the new Radium Institute to make it one of the most important laboratories for radioactivity in the world.

### A Leading Person

Among the many events that contributed to the public status of Marie Curie, one cannot overlook the visit paid by Mrs. Brown Meloney, an editor of a women's magazine in the USA. This dynamic woman organized a successful subscription campaign among American women to offer 1 gram of radium to Marie Curie. Local and national newspapers followed every detail of the campaign, which involved a nationwide tour in 1921 by Marie Curie of numerous universities and a final stop at the White House to meet President Warren G. Harding.

Marie Curie attained such a celebrity status in the USA that shortly after her death, a book editor asked Eve Curie to write a biography of her mother: *Madame Curie* turned out to be a best seller in many languages all over the world.

Marie's journey to America showed her that her prestige could be used for projects of general interest. Thereafter, she supported Jean Perrin in his campaign for fundamental research in France. She would even publicly state her support for a woman's right to vote.

*“Mankind's effort toward its greatest aspirations is imperfect as everything which is human.”*

She also spent more of her time attending conferences and visiting other countries to promote scientific cooperation. As vice president of the International Committee for Intellectual Cooperation, she pleaded for the creation of international fellowships so that

gifted young men and women would not have to give up research work because of a lack of university positions. She also spoke out against the idea of a “failure of science.” “Mankind's effort toward its greatest aspirations is imperfect as everything which is human,” she said. “It has often been turned off its direction by forces of national egoism and social regression.”

### Beyond the Myth

One admires how Marie Curie devoted her life to science. She had commented: “I have given a great deal of time to science because I wanted to, because I loved research.” Shortly before her death, she defended her love of research against alarms and doubts expressed about the future of science and culture: “I am among those who think that science has great beauty. A scientist in his laboratory is not only a technician: he is also a child placed before natural phenomena, which impressed him like a fairy tale. We should not allow it to be believed that all scientific progresses can be reduced to mechanism . . . neither do I believe that the spirit of adventure runs any risk of disappearing in our world. If I see anything vital around me, it is precisely that spirit of adventure, which seems indestructible and is akin to curiosity.”

Marie Curie's life is an outstanding example of how science can be a human adventure. 🏆



*Maria Skłodowska (left) and her sister Bronia.*

Hélène Langevin-Joliot, granddaughter of Pierre and Marie Curie, is director of research emeritus at the National Center for Scientific Research, nuclear physicist at the Institute for Nuclear Physics, and president of the Rationalist Union.

# A Biographical Sketch

**M**aria Salomea Skłodowska was born in Warsaw, Poland, on 7 November 1867 as the fifth child of Władysław and Bronisława (née Boguska) Skłodowski.\* Her father was a teacher of physics and mathematics and her mother was the headmistress of a prestigious school for girls. Maria's parents raised her in a very patriotic atmosphere, even though Poland did not exist then as an independent country and Warsaw was under Russian occupation. Maria wrote, "Our father . . . used to translate foreign poems into Polish. On Saturdays we gathered to listen to him reading the masterpieces of Polish poetry and prose, we enjoyed these evenings immensely. . . ."

Maria suffered much under Russian oppression in her school days, but finally graduated from the state school with a gold medal at the age of 16. Since the Skłodowski family was very poor, Maria attempted to earn a living through private tutoring as her eldest sister Bronisława had done. On the other hand, the two teenagers attended lectures of the so-called "floating university" secretly organized in Warsaw. Maria wrote later, "I belonged to those young Poles who believed that the only hope for our nation was in a great effort to develop our intellectual and moral strength."

In the second half of the nineteenth century, higher education in the Russian empire was not open to women. Thus, Maria made a pact with her sister that would enable them to achieve their common aim to study in Paris. Maria would provide financial help to Bronia for her medical studies in Paris, which Bronia

\* In the Polish language the family name of women may have the ending "ska," whereas the male members of the family may have names ending with "ski."



*Maria Skłodowska's father, Władysław, and mother Bronisława.*

would later repay by helping Maria move to Paris to study. Maria had to undertake work as a governess with several families in turn. The most important of these jobs was at the Żórawski estate at Szczuki, less than 100 km north of Warsaw, where she organized a secret Polish primary school for the children of local peasants. She also fell in love for the first time, with the handsome Kazimierz Żórawski, but his parents did not want to hear about any plans for marriage.

Maria came back to Warsaw and spent one year with her father, giving lessons again. She spent her evenings working at the laboratory of the Warsaw Museum of Industry and Agriculture, learning qualitative and quantitative chemical analysis, the chemistry of minerals, and gaining practice in various procedures. Maria wrote, "I developed there my taste for experimental research during these first trials." Maria left Poland for Paris in October 1891.

Maria Skłodowska was 24 when she registered as Marie Skłodowska at the Sorbonne to pursue a master's degree in physics. She soon discovered she was not as well prepared for university studies as she had thought. The scientific material was challenging and she needed more practice in French to fully understand the lectures. She first lived with her sister and brother in law, Casimir Dluski, and then decided to rent a room much nearer to the Sorbonne: "I am working a thousand time as hard as at the beginning of my stay." She became haunted by her studies, neglecting her health and not eating enough, up to the point of fainting. Her favorite subject to study was physics.

In June 1893, the result of her labors exceeded her own expectations: she had the highest score in the master's examination. Thanks to the efforts of a comrade, Miss Dydynska, the "Alexandrovitch Scholarship"



*Maria's parents with teachers at the school for girls.*

was given to Marie, allowing her to study for another year in Paris. She received the second highest score in the master's examination in mathematics in 1894. That same year she met Pierre Curie.

Marie had been awarded a small grant to perform a systematic study of the magnetic properties of different kinds of tempered steels. A Polish professor, J. Wierusz-Kowalski, suggested that Marie meet Pierre

Curie whom he thought could provide good advice on her research. Years before, Pierre had discovered piezoelectricity with his brother Jacques. He had later formulated symmetry laws in physics. More recently, he had developed extremely difficult experiments on magnetic properties as a function of temperature and established the well-known Curie law.

The first time that Marie and Pierre met, it was clear that they had much in common. Their first conversation became a scientific dialogue, with Marie discussing her research problems and Pierre explaining his own research. This was quite striking for a man who had written in his diary many years before that "women of genius are rare." Pierre wanted to see Marie again. She explained that she would leave France the next summer, and that her duty was to settle in her homeland as a teacher. Eventually, she changed her mind and they were married on 26 July 1895.

The young couple rented a small flat in Paris, very near the school for physics and chemistry where Pierre Curie was a professor and had his laboratory. Marie was allowed to work at the school, an exceptional decision at the time. There, she finished her study of steel's magnetic properties.

In the meantime, she prepared for the national competitive examination for teaching positions at secondary schools for girls. She never applied for a position.



*The Tschechoslovak Medal of 1967 commemorating the 100th anniversary of Marie Curie's birth. The inscription, in Latin, evokes Jachymov (Joachimstal) as the place from which the uranium ore for the Curies came.*

Instead, a few weeks after the birth of her first daughter in September 1897, she decided to prepare a thesis on the new radiation discovered by Henri Becquerel.

The spontaneous emission of radiation by uranium was a weak but very puzzling phenomenon. Marie would use a quantitative approach to go further than Becquerel's results: the precise measurement of electric charges produced by uranic rays in a primitive ionization chamber. This work was made possible by the extreme sensitivity of a piezoelectric quartz apparatus developed by Pierre.

The story of the discovery of polonium and radium is summarized in the three notes that Marie and Pierre sent to the French Academy of Sciences in 1898. The note published in April by Marie alone underlined a decisive result: two uranium minerals, found to be more active than uranium itself, may contain an unknown element. The second note (in July on polonium) was

published with Pierre and the third (in December on radium) was published with Pierre and Gustave Bémont. In their research, polonium and radium were observed as traces among other elements. Marie then focused, with Pierre's help, on the separation of pure radium and the measurement of its atomic mass.

On 25 June 1903, she defended her thesis at the Sorbonne: "Researches on Radioactive Substances." The thesis was soon published and translated into several languages. That same year, Pierre and Marie Curie shared with Henri Becquerel the Nobel Prize in Physics for their research on radioactivity. In the meantime, Marie had been chosen to give lectures

two times a week at the well-known École Normale Supérieure de Sèvres, an appointment that provided her with a small salary.



*Stamp block from the Republic of Guinea, 2001, showing Marie Curie in her laboratory. Note: the dates of birth and death are erroneously those of Pierre Curie.*

## A Biographical Sketch

The Nobel Prize money undoubtedly eased the couple's financial situation. The prize also stimulated the authorities to nominate Pierre Curie as a full professor at the Sorbonne. As a consequence, Marie was appointed as Pierre's assistant (chief of work); her first official position. The thunderous notoriety which followed the Nobel Prize was, on the other hand, disruptive as it interfered with the research plans of the couple and their family life as well. "One would like to dig into the ground somewhere to find a little peace," Marie wrote to her brother.

Family life was quite important for Marie, in spite of her deep involvement in scientific research. The needs and progress of her children, Irène and second daughter Eve, born in December 1904, were a constant preoccupation. She had remained close to her family in Poland and was actively interested in everything concerning her motherland. A holiday stay with Pierre at Zakopane in the Polish Tatra mountains in 1899 was a happy occasion that brought together all of her family. Marie's sister and brother-in law, the Dulskis, had established a sanatorium in Zakopane. Later, Marie would send her daughters there for summer vacations and join them and her family for a short time in 1911. The two girls learned to speak and write her native language of Polish, but Marie deliberately raised them following French traditions.

*Family life was quite important for Marie, in spite of her deep involvement in scientific research.*

At the beginning of 1906, Marie's life seemed to have reached a happy equilibrium. She performed experiments about one or another question raised by controversial results published in the rapidly developing field of radioactivity. When the weather was fine, she used to spend a few days in the countryside near Paris with Pierre and the children. On Thursday 19 April, Pierre attended a meeting with other professors, but without Marie. It was raining when he left and as

he crossed a street without noticing a heavy horse-drawn wagon he was run over and killed. Marie would never completely overcome the sudden catastrophe.

When the French government offered Marie an annual pension as Pierre's widow, she refused, stating that she was only 38 and could work. What she really desired was a laboratory to continue her research.

Marie's future as a scientist was at risk after Pierre's death. At the insistence of fellow professors, the council of the Faculty of Science finally decided to confer Pierre's chair to her along with the directorship of the laboratory. She was appointed two years later as a full professor. She soon resumed her work at the laboratory, focusing on radiochemical

research, calibration of radium sources, and the preparation of the first radium standard.

*Marie's future as a scientist was at risk after Pierre's death.*

Marie was awarded the Nobel Prize in Chemistry in 1911 for the discovery of radium and polonium. This important event occurred as she underwent a dramatic period in her life. Her supposed affair with her colleague Paul Langevin had turned into a scandal with the publication of correspondence that they claimed, in vain, had been falsified. The French authorities were shaken enough by the campaign against Marie that they pushed for her to resign. A delegation from the Warsaw Scientific Society, headed by the famous Polish writer and Nobel Prize winner Henryk Sienkiewicz, visited Marie in Paris. They asked her to return to Warsaw and continue her research there. She refused. However, in 1913 she accepted the position of honorary director of the Radiological Laboratory in Warsaw and was admitted as an honorary member of the Warsaw Scientific Society, although she remained in Paris.

Her own laboratory, in rue Cuvier, was not large enough for the increasing number of scientists interested in the new field of radioactivity. The "fight for a laboratory" came to fruition in 1912 with the con-



*A Polish stationery postcard of 1938. This version was meant for foreign mail and thus has inscriptions in Polish and French (a similar postcard for inland mail has inscriptions only in Polish).*

## A Biographical Sketch



*Marie Curie (left), shown here with the Joliot-Curies and their young children.*

struction of the Radium Institute. The first part of the laboratory was nearly finished when the war broke out in 1914. During the four years of the war, Marie's main preoccupation was organizing radiology and radiotherapy services for military hospitals.

With the war over, the Radium Institute slowly resumed its research in a country ruined by the war. In 1921, Marie Mattingly Meloney, the editor of a women's

magazine in the United States, organized a subscription campaign among American women in order to offer one gram of radium to Marie Curie on her visit to the States. Marie's subsequent visit culminated with a reception at the White House with President Warren G. Harding. She came back from her travels with additional funds, equipment, and radioactive products for the Radium Institute.

At the same time, the Curie Foundation was created. Marie strongly supported the medical use of X-rays and radium radiation to treat cancer. She became a very active vice president in the International Committee on Intellectual Cooperation created by the League of Nations. Since Poland had become a free nation again, she visited with her family on different occasions. The last time was in 1932 when she took part, as honorary director, in the opening ceremony of the Warsaw Radium Institute. She donated to the Institute the gram of radium bought with the money collected in the States in 1929 via a second subscription campaign.



the States in 1929 via a second subscription campaign.

Irène, Marie's eldest daughter, became her closest assistant. And then, when Irène married Frédéric Joliot, she got another assistant and before long became a happy grandmother. She used to spend summer holidays partly with the family on the coast of Brittany, partly in the south of France. In her later years, Curie managed the Radium Institute and pursued her own research. In January 1934, her daughter and son-in-law discovered artificial radioactivity. It was a last joy for Marie, who died six months later. A few months following her death, the Nobel Prize in Chemistry was awarded to the Joliot-Curie couple "in recognition of their synthesis of new radioactive elements." 🏆

This biographical sketch was compiled by Héliène Langevin-Joliot and Jerzy Kroh.



*In this photograph taken by Ms. Lipkowska, her husband, Prof. Lipkowski (president of the Committee of Chemistry of the Polish Academy of Science) stands under a mural of Marie Curie in Warsaw. The large letters read "I was born in Warsaw." The smaller print says, among other things, that "Whenever she was giving a talk she started by saying 'I was born in Warsaw.'"*

# An Inspiring Laboratory Director

## Marie Curie and Women in Science

by Soraya Boudia

**“It** is a woman who is now in charge of research and of numerous applications relating to radioactivity . . . Helping her and sharing the same work, is a whole staff of women doctors and university graduates.” This is how a female French journalist described Marie Curie’s laboratory in 1927, underlining the large number of women to be found working in a single scientific research laboratory that was also run by a woman (Geestelink 1927). It is interesting to look back at the large number of female researchers who worked with Marie Curie, and consider her role in inspiring and encouraging women to embrace a scientific career despite the difficulties and prejudices of the time.

### Marie Curie, A Woman at the Head of an Interdisciplinary Institute

Following Pierre Curie’s death, by force of circumstance, Marie Curie took over as director of their laboratory in rue Cuvier. She henceforth played an increasingly important role in the French and international scientific communities. Along with other French scientists, she supported a policy for the development of scientific research and looked for ways both to develop her laboratory and to recruit more researchers. In 1908, the Pasteur Institute and the University of Paris decided to build a new multidisciplinary institute

for research and for applications of radioactivity; it was called the Institut du Radium (Radium Institute) and had two sections, one devoted to physical and chemical studies (the Curie Pavilion, directed by Marie Curie), and the other concentrating on biological and medical applications (the Pasteur Pavilion, run by Claudius Regaud).

*Curie’s laboratory . . . was at the heart of a scientific, industrial, instrumental, and medical network.*

The Institut du Radium was completed in 1914, but not until after the First World War was it able to operate under normal conditions. During the 1920s it was one of the four main laboratories dominating the domain of radioactivity research, along with the Cavendish Laboratory in Cambridge, directed by Ernest Rutherford, the Institut für Radiumforschung in Vienna, directed by Stefan Meyer, and the Kaiser Wilhelm Institut für Chemie in Berlin, under the direction of Otto Hahn and Lise Meitner. In this domain, there were different ideas, concepts, and experimental practices concerning the application of radioactive elements. Each institute had its own approach. For instance, Rutherford’s collaborators had at first concentrated mainly on the study of physical radioactive changes and on the mechanisms of disintegration of radioactive elements. Then they began to progressively study atomic structure (Hughes 2002). In Berlin, the researchers specialized in the identification of new radioactive elements and in the physical study of their emissions. At Curie’s laboratory, part of the work was devoted to the study of the physical and chemical properties of radioactive elements, with particular focus on the development of different applications for these elements, such as in the field of medicine and in industrial production.

So it was its numerous different activities that made Curie’s laboratory stand out from the crowd; it was at the heart of a scientific, industrial, instrumental, and medical network (Boudia 2001). The Curies had begun to build this network together, but it was Marie’s impetus which allowed it to grow. The project to cover different areas of radioactivity stemmed from her decision to specialize in the purification and study of radioactive substances. For researchers in radioactivity, getting hold of radioactive substances was a constant concern. There was a profound lack of many



*The Radium Institute in Paris, completed in 1914.*

radio-elements on the market and industrial production was difficult to set up. Those which were produced were extremely expensive, often well beyond the means of laboratories. Furthermore, their state of purification was often below the quality required by the research teams. The Curie laboratory helped to develop and adapt chemical treatments for each mineral type. Its researchers made instruments which were specially adapted to industrial needs and to mineral prospecting. The large amount of correspondence between the laboratory and its factories bears witness to the extensive circulation of personnel, radioactive substances, and instruments. Marie Curie was also in regular contact with factories abroad, such as St. Joachimstal in Pittsburgh, Pennsylvania, USA, and with the Union Minière du Haut Katanga (Belgium at that time).

Marie Curie's strategy for acquiring and purifying radioactive sources was not only a legitimate one; it was also effective. It allowed her laboratory to position itself in the world of radioactivity research as the leader in the preparation of radioactive sources, in terms of both quantity and quality. It also enabled it to become the reference for radioactivity metrology. Indeed, in 1910, an international commission made up of leading radioactivity researchers adopted the curie, suggested by Marie Curie and André Debierne, as the international unit of measurement for radioactivity and tasked Marie with establishing an international radium standard which would serve to calibrate different radioactive sources for both research and radioactivity applications.

## The Women in the Curie Laboratory

In the large laboratory that she had succeeded in building, Marie Curie made considerable room for women. Between 1904 (when the laboratory was created in rue Cuvier) and 1934 (the year of Marie Curie's death), 47 women worked there as researchers. Information about these women, from the archives in the Curie Museum in Paris, although fragmented, nevertheless provides us with a certain amount of information about them and their work. Regarding geographical origin (see table, page 14), the data shows that 15 (perhaps 19) of the women came from France and 25 from abroad. For the remainder, some doubt still remains. More than a quarter came from eastern

Europe, Poland, and Russia in particular. A significant group came from Scandinavian countries (the first being Norwegian Ellen Gleditsch and Swede Eva Ramstedt). When they arrived at the laboratory, nine women held doctorate degrees (in physics or chemistry and one in medicine). Ten others had science, physics, or chemistry degrees (two or three of these later went on to complete doctorates), four were teachers who had qualified at the École Normale de Jeunes Filles de Sèvres (where Marie Curie had taught between 1900 and 1904), two were engineers, and at least one had a degree in pharmacy.



*Marie Curie with her daughter Irène and other researchers in her laboratory at the Edith Cavell Hospital in 1914.*

*In the two years immediately after the war there was a large majority of women at the laboratory.*

The place and role of women in the laboratory changed over time. The First World War saw a break both in the number and in the composition and status of the women. The cramped premises at rue Cuvier restricted the number of researchers. Of the 58 who worked at the laboratory between 1904 and 1914, 10 were women. The majority of them were foreigners (6 out of 10). All of them, with the exception of Ellen Gleditsch, remained for one or two years. They either had grants from their home countries or else worked for free. After the war, the laboratory's female population grew. In the two years immediately after the war there was a large majority of women at the laboratory, with their number later stabilizing at around 30 percent. When the laboratory moved to the new Institut du Radium, it was able to hold a larger number of researchers, with a regular turnover in personnel. Marie Curie "made do," finding intermediary and tem-

## An Inspiring Laboratory Director

porary solutions which required constant renegotiation with the administration and with manufacturers.

As of 1907, the Curie laboratory had at its disposal a number of specific grants (the Carnegie-Curie grants) which were given to a certain number of researchers—between two and six per year. For several years, about one-third of the personnel was essentially working for free. After the war, the number of grants increased. In addition to the Carnegie-Curie grants, were added the Commercy, Rockefeller, Rothschild, and Lazard grants, named after their patrons. Toward the end of the 1920s, the Caisse des Recherches Scientifiques and the Caisse Nationale des Sciences provided significant funding. While several women benefited from these grants and funds, they did so in a smaller proportion than their male counterparts (between 1920 and 1934, women obtained less than 20 percent of the grants). Women probably encountered the same difficulties as foreigners from certain geographical zones (eastern European countries in particular).



*Irène Joliot-Curie and husband Frédéric Joliot in their laboratory at the Radium Institute, 1935.*

Institutional resistance to the professional integration of women could be seen in the virtual absence of regular positions: aside from Irène Curie, no woman

### The Women in Marie Curie's Laboratory: Where They Came from and How Long They Stayed

Name	Stay in Curie Lab	Geographic origin
Brooks, Harriet	1906–1907	Canada
Gleditsch, Ellen	1907–1912 ; 1919–1920, short stays in 1924–1926	Norway
Blanquies, Lucie	1908–1910	France
Leslie, May Sybill	1909–1911	UK
Ramstedt, Eva	1910–1911	Sweden
Szmidt, Jadwiga	1910–1911	Russia
Gotz, Iren	1911–1912	Hungary
Wrangell	1911–1912	
Veil, Suzanne	1912–1914	France
Ascouart	1913–1914	France
Molinier, Madeleine Née Monin	1917–1921	France
Cotelle, Sonia Née Slobodkine	1919–1945	Poland
Galabert, Renée	1919–1933	France
Holwech, Randi	1919–1920	Norway
Joliot Curie, Irène	1919–1956	France
Klein, Marthe	1919–1920	France
Maracineanu, Stefania	1919–1920	Romania
Weil, Jeanne Samuel	1922–1925	France
Chamie, Catherine	1919–1920	Russia
Lattes, Jeanne Samuel	1921–1949	France
Brunschvicg, Weill Adrienne	1921–1928	France
Weinbach, Lucienne	1923–1926	France
Garcynska, Janine	1923–1924	Poland

Name	Stay in Curie Lab	Geographic origin
Wisner	1924–1925	France ?
Dedichen, Sonja	1924–1925	Norway
Dorabalska, Alicja	1925–1926	Poland
Gourvitch, R.	1925–1927	Lithuania
Pilorget, Germaine	1928–1930	Switzerland ?
Montel, Eliane	1925–1927	France
Rona, Elisabeth	1925–1926	(Hungary), Vienna
Larche	1926–1931	France ?
Waldbauer-Patton, I. Jocelyn	1926	Canada
Leblanc, Marthe	1927–1929	France ?
Pompei, Angèle	1927–1928	France
Archinard, Isabelle	1928–1932	Suisse
Perey, Marguerite	1928–1937	France
Grabianka, Seweryn	1929–1934	Poland
Korvezee, A.	1929–1941	Netherlands
Lub Willy, A.	1930–1931	Netherlands
Marques, Branca Edmée	1930–1933	Portugal
Wibratte, Marie-Henriette	1931–1934	France
Macaigne, R.	1931–1936	France ?
Manteuffel, I.	1931–1933	Poland
Prebil, Alice	1932–1934	Yugoslavia
Baschwitz-Levy, A.	1932–1933	
Blau, Marietta	1932–1933	Austria
Emmanuel Zavizziano, Hélène	1933–1939	Greece



## Marie Curie and Women in Science

held the position of assistant. Generally speaking, the lack of funding made it very hard to bring young scientists into science faculties, but a relatively permanent group of researchers was formed and was able to ensure continuity at the laboratory. This group comprised 10 or so personnel, half of whom were women: Marie, Irène Curie, Catherine Chamié (Syro-Russian), Sonia Cotelte (Polish, née Slobodkine), and Renée Galabert. The last two had degrees in chemistry and




*Marie Curie and four of her students (sometime between 1910 and 1914, U.S. Library of Congress).*

joined the laboratory in 1919. Sonia Cotelte specialized in the preparation of radioactive sources. In 1926, she was appointed to a position which was created as part of a “special framework” for the Curie laboratory by the science faculties. Renée Galabert quickly took over the management of the measurements department. She left the laboratory in 1933 to take up a post as technical director at a radioactive elements factory. Catherine Chamié completed a doctorate in physics at the University of Geneva in 1913, and continued her scientific work as a mathematics assistant at the University of Odessa. She joined the laboratory in 1921, and then benefited from several grants before being compensated from the funds of the measurements department. These women had real scientific careers, similar to those of other researchers at the Curie laboratory.

The work done by these women was a reflection of the laboratory’s various activities. Many of them worked in physics and chemistry, studying, for example, the characteristics of radioactive elements and their radiation and determining procedures for chemical treatments or for methods of measurement. They were particularly involved in two areas: the preparation of radioactive sources and certification (metrology). Numerous women were specialists in what was later to be called radiochemistry. This was true of the Curies, mother and daughter, and Ellen Gleditsch, Sonia Cotelte, and Marguerite Perey. This was not an

occupation reserved for women however: Bertram Boltwood at Yale and the two Nobel Prize winners Otto Hahn in Berlin and Otto Hönigschmit in Vienna won acclaim as radiochemists. In addition, the laboratory’s measurements department was usually run by women. Created in 1911, this department acted as a national metrological institution in the field of radioactivity. Its activity focused on the calibration and certification of sources. Sonia Cotelte, Renée Galabert, and Catherine Chamié were all in charge of this department at some point. In other laboratories (UK, USA, Germany, and Austria), metrology was run by men.

The example of the Curie laboratory demonstrates the variety of jobs held by women in the field of radioactivity. It is clear that these women were not simply given the most repetitive and boring tasks, with the real research roles given to men. (e.g., in astronomy, women were employed to sort through thousands of negatives, a task deemed to require qualities proper to women—patience and perseverance.) Their significant presence is probably the result of several factors. Marie Curie was a role model for many young women who aspired to careers in science. She was not a feminist (few female scientists in France were), nor did she develop any policies in favor of women, but she did represent an example to follow. Furthermore, the field of radioactivity sciences was an emerging one; it was not particularly institutionalized, and as it offered few career opportunities, it was initially more accessible to women. 

Proportion of Women in Marie Curie's Laboratory	
Year	Rate of Women
1904–1905	1/9 (11.4%)
1905–1906	1/8 (12.5%)
1906–1907	2/10 (20%)
1907–1908	2/11 (18.2%)
1908–1909	3/18 (16.7%)
1909–1910	4/18 (22.2%)
1910–1911	5/22 (22.7%)
1911–1912	4/20 (20%)
1912–1913	2/15 (13.3%)
1913–1914	3/15 (20%)
1919–1920	9/14 (64.3%)
1920–1921	10/19 (52.6%)
1921–1922	5/14 (35.7%)
1922–1923	7/28 (25%)
1923–1924	9/31 (29%)
1924–1925	12/35 (34.2%)
1925–1926	14/37 (37.8%)
1926–1927	11/31 (35.5%)
1927–1928	10/31 (32.2%)
1928–1929	10/33 (30.3%)
1929–1930	11/37 (29.7%)
1930–1931	12/44 (27.3%)
1931–1932	14/43 (32.5%)
1932–1933	16/53 (30.2%)
1933–1934	13/47 (27.7%)

Soraya Boudia is an associate professor in Science and Technology Studies at the University of Strasbourg. She was the director of the Curie Museum in Paris from 1999 to 2003. She published several papers on the history of radioactivity and on the international regulation of radiation risks. She is preparing a new book on the history of the radiation low doses.

# Marie Curie's Relations with the United States

by George B. Kauffman

**I**n a magnificent gesture of magnanimity Marie and Pierre Curie had decided not to patent their most famous discovery—radium—or its medical applications. According to Marie:

“The price of radium is very high since it is found in minerals in very small quantities, and the profits of its manufacture have been great, as this substance is used to cure a number of diseases. So it is a fortune which we have sacrificed in renouncing the exploitation of our discovery, a fortune that could, after us, have gone to our children. But what is even more to be considered is the objective of our many friends, who have argued, not without reason, that if we had guaranteed our rights, we could have had the financial means of founding a satisfactory Institute of Radium, without experiencing any of the difficulties that have been such a handicap to both of us, and are still a handicap to me. Yet, I still believe that we have done right.” (National Bureau of Standards 1921)

The Curies' decision to forego a patent would ultimately lead Marie to visit the United States twice—once in 1921 and again in 1929, both times in search of funds for her work. In the spring of 1920, Marie



*Marie Curie (left) with President Warren G. Harding at the White House, 20 May 1921 (U.S. Library of Congress).*

Mattingly Meloney a small, dynamic, trailblazing journalist and editor, known to all as “Missy,” finally succeeded in obtaining an interview with Marie in her Paris laboratory. Despite Marie's disdain for the media and their differences in temperament, the two women became close friends for the rest of their lives (Meloney 1921).

When Missy asked Marie how she could help her, Marie told her that she had no radium for research. The Radium Institute had no money for equipment, and the entire supply of radium (1 gram) was used in the institute's biological section to provide radon tubes for cancer therapy. The United States had the world's most plentiful supply—50 grams.

Instead of merely getting a story for her magazine Missy decided to use her influence, contacts, and clout to give a gram of radium, which cost about USD 120 000, to Marie. She became chair of the Marie Curie Radium Fund and asked prominent New York doctors to join the fund's board. Marie was highly respected among them because during the war she had educated numerous American physicians at her Radium Institute. One of the prime movers behind the fundraising was Robert Abbe, M.D., who had visited the Curies in Paris as early as 1902 and was the first American doctor to use radium to treat cancer and other diseases. Prominent women who joined the board included Mrs. John D. Rockefeller and Mrs. Calvin Coolidge. The advisory committee of scientists included the president of the American Medical Association and leading representatives from the Rockefeller Foundation and Harvard, Cornell, and Columbia Universities.

Missy employed the pages of *The Delineator* (“A Journal of Fashion, Culture, and Fine Arts”), the foremost women's magazine in the United States, which she edited, to solicit small donations from many American women to contribute to the fund. American physicians also made sure that the money for the radium was raised, but also generated additional funds to provide Marie with a modern and well-equipped laboratory.

On 3 May 1921 the Marie Curie Radium Fund Committee awarded a contract to the Standard Chemical Company of Pittsburgh, Pennsylvania, USA, for the gram of radium, with the price reduced to



*Marie Curie (center) at the Radium Refining Plant of the Standard Chemical Company, Pittsburgh, Pennsylvania, USA (National Bureau of Standards, 1921).*

USD 100 000 in her honor. The radium was later presented to Marie at the White House in Washington, D.C., on 20 May 1921. According to *The New York Times* ("To Supply Curie Radium," 4 May 1921), three other firms bid on the contract.

Missy had convinced Marie to travel to the United States on a whirlwind tour which involved numerous receptions and long receiving lines to accept the gift. Accompanied by her daughters, Irène (Adloff and Kauffman 2006) and Eve (Kauffman and Adloff 2009), Marie arrived in New York City aboard the *Olympia* on 11 May 1921, her first trans-Atlantic trip.

A large crowd, including 26 photographers, met the Curies at the dock, which was decorated with the flags of the United States, Poland, and France. Missy had publicized the event by writing about Marie and her work in *The Delineator* and providing advance information to her newspaper colleagues (Quinn 1995). She protected Marie, who was in fragile health, from the press' excessive inquisitiveness. Irène and Eve took over many of the functions expected of their mother. It was not until this trip that Irène (age 23) and Eve (age 16) realized their mother's global fame (E. Curie 1937).

On 12 May, *The New York Times* described the Curies' arrival in a front-page article, "Mme. Curie Plans to End All Cancers," which it retracted the next day, "Radium Not a Cure for Every Cancer," stating that radium was a specific therapy for many but not all cancers. Both articles detailed Marie's itinerary for the rest of her trip.

On 17 May, Marie was honored at New York City's American Museum of Natural History. On 18 May at Carnegie Hall, 3500 representatives of almost every major women's college on the Eastern seaboard, the

largest meeting of American college women, honored Marie with the Ellen Richards Memorial Prize of USD 2000. This event was also the launch of a movement to advance disarmament and prevent war.

Marie and her daughters visited numerous women's colleges, among them Smith, Vassar, Bryn Mawr, Radcliffe, Wellesley, Simmons, and the Women's Medical College in Philadelphia. She received honorary degrees from the Universities of Pennsylvania, Pittsburgh, and Chicago as well as Columbia, Northwestern, and Yale Universities. She spent considerable time in Pittsburgh, conversing with scientists and engineers at the Standard Chemical Company, the American manufacturer of radium. The Curies visited the Grand Canyon and Colorado, where carnotite,  $K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$ , the ore that was the source of American radium, was mined. They visited Niagara Falls, where university women from Toronto, Canada, honored her. In nearby Buffalo, New York, she was made an honorary member of the Buffalo Society of Natural Sciences and visited the Gratwick Cancer Center (now Roswell Park).

The highlight of Marie's trip took place on the afternoon of 20 May, when she was received in the East Room of the White House in the presence of more than 100 eminent scientists and diplomats from Poland and France. She is said to have worn the same black dress that she wore when she received both her Nobel Prizes.

President Warren G. Harding presented her with a deed inscribed on a scroll tied with red, white, and blue ribbons and gave her a small, elaborate golden key to open the polished, lead-lined, ribbon-draped, steel box within a mahogany box containing the gram

## Marie Curie's Relations with the United States



*From left: Marie Mattingly ("Missy") Meloney with Irène, Marie, and Eve Curie as they arrive in New York City on 12 May 1921 (U.S. Library of Congress).*

of radium, in 10 small tubes, weighing a total of 125 pounds. The radium had been kept at the Bureau of Standards where it had been tested and where it remained until just before Marie's departure from New York City. President Harding is said to have also given her a "Certificate for Radioactive Material" submitted for measurement and certification to the National Bureau of Standards signed by National Bureau of Standards Director Samuel W. Stratton. A facsimile key, which was given as a souvenir to Mrs. Harding, had been prepared in case the radium might not be ready in time for the presentation. The mahogany box is on display at the museum of the Institut du Radium (Mould 1998). A plaque attached to the container reads:

"Presented by the President of the United States on behalf of the women of America to Madame Marie Skłodowska Curie in recognition of her transcendent service to science and to humanity in the discovery of radium." (Mould 1998)

President Harding welcomed Marie on behalf of the American people, calling her the "adopted daughter of France" and the "native-born daughter of Poland":

"I have been commissioned to present to you this little phial of radium. To you we owe our knowl-

edge and possession of it, and so to you we give it, confident that in your possession it will be the means further to unveil the fascinating secrets of nature, to widen the field of useful knowledge, to alleviate suffering among the children of man. Take it to use as your wisdom shall direct and your purpose of service shall incline you. Be sure that we esteem it but a small earnest of the sentiments for which it stands. It betokens the affection of one great people for another. It will remind you of the love of a grateful people for yourself; and it will testify in the useful work to which you devote it, the reverence of mankind for one of its foremost benefactors and most beloved of women" (Harding, papers of, 1888–1923).

In the next day's issue of the *Washington Post*, Constance Drexel reported the event in a front-page article (Drexel 1921) and quoted from President Harding's remarks:

"The zeal, ambition, and unswerving purpose of a lofty career could not bar you from splendidly doing all the plain but worthy tasks which fall to every woman's lot."

On the day before the presentation, when the deed for the radium was given to Marie to review, she objected that it made her the sole owner of the radium, with her daughters as heirs. She insisted that the deed be changed so that the radium would pass from her to the laboratory rather than to her family so that it would be available to other researchers. On the afternoon before the presentation a lawyer rewrote the deed (E. Curie 1937). On June 25 Marie and her daughters left New York with the radium, mesothorium, and thousands of dollars to finance the Radium Institute.

Marie visited the United States for her second and last time in 1929, but compared with her 1921 visit, it was short and not well publicized. During the 1920s she and her older sister Bronislawa ("Bronya"), a physician, were responsible for building the Radium Institute (now the Marie Skłodowska Curie Institute of Oncology) in her hometown of Warsaw, which was similar to the institute in Paris. The financial situation in post-World War I Poland was even more acute than in France. Poland had just attained its independence as the Second Polish Republic in 1918, and Marie not only

# Marie Curie's Relations with the United States


called upon the population to donate funds for the founding of the institute but also contributed some of the money from her first trip to America to “rent” radium for Warsaw scientists.

In 1928 in Paris, Marie asked Missy Meloney if the American people could provide funds for another gram of radium for the Polish Radium Institute. Missy, who was now editor of the *Sunday Magazine* of the *New York Herald Tribune*, began to organize a second trip, but cautioned Marie that since her last visit Americans had become politically “small-minded,” “isolationist,” and less magnanimous. Newly elected President Herbert Hoover, who had been a member of the Marie Curie Radium Fund Committee of 1921 and had met Marie during her first visit, invited Marie, at Missy’s behest, to stay at the White House, an unprecedented “first” (No foreigner had ever been so privileged).

On 15 October 1929, Marie, whose sight was failing, arrived in New York City, where she was the guest of honor at the American Society for the Control of Cancer (now the American Cancer Society). Her remarks were broadcast on the radio. On 21 October she was honored at the 50th anniversary celebration of Thomas Edison’s invention of the electric light bulb in Dearborn, Michigan; President Hoover spoke at the event. On 23 October she visited the General Electric Company in Schenectady, New York; the plant was closed in honor of her visit. On 25–26 October she visited St. Lawrence University, in Canton, New York, where she dedicated the Hepburn Science Building and received an honorary D.Sc. Degree, on which occasion Charles Chelsea Gaines, the oldest faculty member, composed and recited a sonnet in her honor.

On 30 October, at the building of the National Academy of Sciences and National Research Council, President Hoover presented Marie with a USD 500 000 bank draft. Nations had been permitted to enter bids, and Belgium won with the bid (half the price of a gram of radium in 1921) based on reduced costs of commercial production from ore deposits in Katanga, Belgian Congo. The event was overshadowed by the stock market crash (“Black Thursday,” 24 October, followed by “Black Tuesday,” 29 October), reports of which filled the newspapers and ushered in the Great Depression.

Responding to President Hoover, Marie declared:

“In accepting this precious gift, which will hasten the opening of the Radium institute in Warsaw, I offer you, and all my American friends, my most profound thanks. My laboratory in Paris will keep in close relation to the Warsaw Institute, and I will like to remember the American gifts of radium to me as a symbol of endearing friendship bridging your country to France and Poland.” (Ham 2002) 

George B. Kauffman, professor of chemistry emeritus at California State University, Fresno and Guggenheim Fellow, is a frequent contributor to the scientific and historical literature and the recipient of numerous national and international awards. He was a research student of Marguerite Perey, who was an assistant of Marie Curie and the discoverer of francium. He succeeded Perey as the chair of nuclear chemistry, was a member of the IUPAC Commission on Radiochemistry and Nuclear Techniques, and acted as an expert in radiochemistry for the IAEA.



The “Certificate for Radioactive Material” submitted for measurement and certification to the National Bureau of Standards and signed by Director Samuel W. Stratton.

# A Short History of Polonium and Radium

by Jean-Pierre Adloff

In 1897 at the age of 30, Maria Skłodowska, who had married Pierre Curie in 1895, concluded her studies at the Sorbonne in Paris and was thinking of a subject for a thesis. X-rays, discovered by Wilhelm Conrad Röntgen in 1895, were still a topical question, but had lost the charm of novelty. On the other hand, the uranic rays, discovered in 1896 by Henri Becquerel, raised a puzzling problem. Uranium compounds and minerals appeared to maintain an undiminished ability to blacken a photographic plate over a period of several months. What was the source of this inexhaustible energy that apparently violated the Carnot principle that energy can be transformed but never be created or destroyed? Pierre Curie, already a famous physicist for his work on magnetism and crystal symmetry, had a feeling that the phenomenon was quite extraordinary, and he helped his wife reach a decision in her choice of thesis topic. Marie Curie, in a biography of Pierre Curie, confirmed, “we felt the investigation of the phenomenon very attractive, so much the more so as the topic was quite new and required no bibliographical research.”

After initial excitement, interest in the new rays had faded rapidly. One reason was the proliferation of false or doubtful observations of radiation similar to uranic rays in a variety of substances. The topic was moribund when Marie Curie entered the scene. However, within eight months in 1898 she discovered two elements, polonium and radium, founding a new scientific field—radioactivity. This

short history of the discoveries is retraced from three laboratory notebooks in which one can distinguish the writings of Pierre and Marie (Adloff 1998) and from three notes published in the *Comptes Rendus de l'Académie des Sciences (C.R. Acad. Sci. Paris)*.

In addition to blackening a photographic plate, uranic rays rendered air conductive for electricity. This later property was much more amenable to quantitative measurement. Becquerel had used electroscopes, but the measurements were unreliable. At this point, little progress would have been made without the genius of Pierre Curie. In 1880, together with his brother Jacques, he had discovered piezoelectricity (i.e., the production of electric charges when pressure is applied to hemihedral crystals such as quartz). He invented a device by which the charges produced by uranium in an ionization chamber were compensated for by opposite charges in known amounts produced by applying a weight to a leaf of quartz. The compensation was followed by a second invention, the quadrant electrometer. The emission of

uranic rays could now be quantified from the weight and the time required for compensation of the charges produced in the ionization chamber.



An illustration from *Vanity Fair* magazine, 1904 (Library of Congress).



The “Curie Laboratory”: left, chemistry bench; right, ionization chamber and electrometer.

## Marie Curie's First Publication: 12 April 1898

Marie Curie's strategy is clearly expressed in her first note published on 12 April 1898 in the *Comptes Rendus de l'Académie des Sciences*: "I have searched [to see] if substances other than uranium compounds render air conducting for electricity" (Curie, M. 1898). Beginning on 11 February 1898, she tested all samples at hand or borrowed from various collections, including a large number of rocks and minerals, taking the activity of metallic uranium as a reference. She found that all compounds and minerals that contained uranium were active and that pitchblende, a massive variety of uraninite from the Joachimsthal mine in Austria, as well as chalcocite, a natural uranium phosphate, were more active than metallic uranium itself. Marie Curie noted, "This fact is quite remarkable and suggests that these minerals may contain an element much more active than uranium." Her hypothesis was immediately confirmed: "I have prepared chalcocite with pure products; this artificial chalcocite is not more active than other uranium salts." She then concluded that an unknown element exists only in the uraniumiferous minerals that are more active than uranium. At this stage, the hunt for the supposed element became a matter of paramount importance and urgency. Pierre Curie was fascinated by Marie's findings: On 18 March he abandoned his own research projects and joined his wife in the venture.

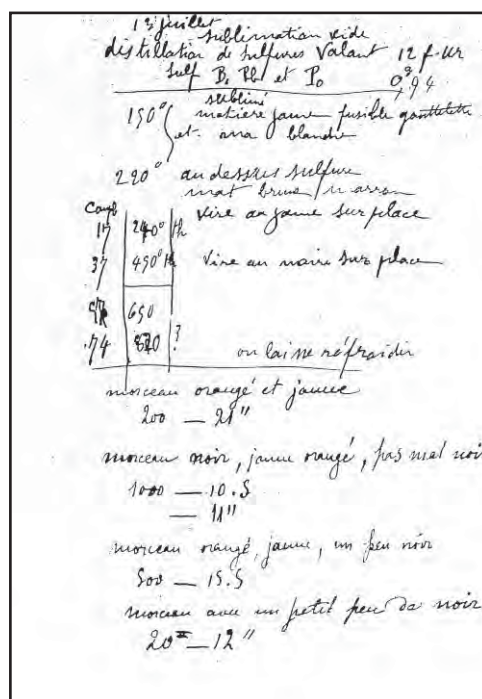
In the course of the systematic search of Becquerel rays, Marie Curie also discovered, on 24 February, that thorium compounds were also active. However, the German physicist Gerhardt Schmidt had observed the emission several weeks earlier.

## The Discovery of Polonium: 18 July 1898

The research on uranic rays now turned from physics to chemistry. It became necessary to separate and identify a substance whose chemical properties were unknown. However, the hypothetical element could be followed by tracing its radioactivity. Marie Curie explained the process: "The method we have used is a new one for chemical research based on radioactivity. It consists of separations performed with the ordinary procedures of analytical chemistry and in the measurement of the radioactivity of all compounds separated. In this way, one can recognize the

chemical character of the radioactive element sought; the latter is concentrated in fractions which become increasingly radioactive in the course of the separation." Neither Marie nor Pierre were chemists, so they were assisted by Gustave Bémont, who was in charge of practical training for students at the Parisian Ecole Municipale de Physique et Chimie Industrielle.

On 14 April, the trio began research on pitchblende, which was two and a half times more active than uranium. Several procedures were used in parallel runs by precipitations with various reagents and sublimations of solid deposits, whereby the active substance accompanied primarily bismuth, from which it could be progressively separated. On 27 June, Marie Curie precipitated sulfides from a solution containing lead, bismuth, and the active substance. She underlined the result in her notebook: the solid was 300 times more active than uranium. On 18 July, Pierre Curie obtained a deposit 400 times more active than uranium. The Curies carefully verified that "compounds of all elements, including those of the rarest substances were not active."



First mention of polonium, "Po" in the laboratory notebook of Pierre and Marie Curie, 13 July 1898.

## A Short History of Polonium and Radium

On 18 July 1898, Pierre and Marie Curie wrote to the *Comptes Rendus de l'Académie des Sciences*, "On a new radio-active substance contained in pitchblende." "We believe that the substance we recovered from pitchblende contains a heretofore unknown element, similar to bismuth in its analytical properties. If the existence of this new metal is confirmed, we propose that it be named polonium in honor of the native land of one of us" (P. Curie and M. Curie 1998). The symbol Po, written by Pierre Curie, appears in the notebook on 13 July. The name polonium had a provocative significance because Poland had disappeared as a state in 1795, being divided between Prussia, Russia, and the Austrian Empire.

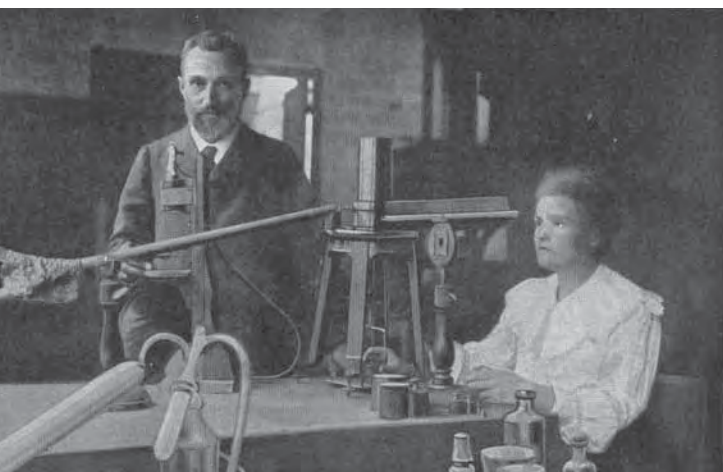
*... we propose that it be named  
polonium in honor of the native  
land of one of us.*

The publication signed both by Pierre Curie (as first author) and Marie Curie, was based on experiments performed from 9 April to 16 July. The title is historic: It proclaims that the search for the element more active than uranium was successful, and the word *radio-active* appears for the first time (The Curies

dropped the hyphen the following year). The announcement of a new element that remained invisible and was identified solely on the basis of its emission of "uranic rays" was unique in the history of chemistry. It was customary that no such claim was considered valid until a pure substance had been isolated, the atomic weight of the element had been determined, and its spectral lines had been measured. Eugène Demarçay, a recognized authority in spectroscopy, examined the spectrum of the new element, but to the Curies' disappointment he could not distinguish any new characteristic lines. The authors admitted, "This fact does not favor the idea of the existence of a new metal."

The isolation of polonium from uranium had been accomplished although the Curies were unaware of the relationship between the two elements. They considered the entire material as a mixture. They knew nothing of radioactive decay. In this sense it was purely a matter of chance since the experiments were performed within three months, a relatively short time with respect to the 138-day half-life of polonium.

It was only a few years later that the authors noticed with astonishment and great perplexity that polonium was progressively disappearing, still unaware of its half-life. They were preoccupied with the authenticity of polonium for several years, and with their customary honesty they did not hide their doubts. In 1899, Marie Curie still raised the question: "Is polonium, which exhibits the lines of bismuth, really a new element or simply bismuth activated by the radium contained in pitchblende?" The doubt persisted for several years (Adloff 2007). Eventually, in 1910 Marie Curie and André Debierne separated from several tons of residues of uranium ores a final product that weighed 2 mg and contained about 0.1 mg of polonium. The spark spectrum of this sample revealed for the first time a few lines characteristic of the element. The position of polonium in the periodic table was not assigned by the discoverers, but the new element could obviously be placed to the right of bismuth as "eka-tellurium," with atomic number 84.



*Pierre and Marie Curie handling the electrometer.*



## A Short History of Polonium and Radium

The note in the *Comptes Rendus* concluded the short story of polonium for several years. Marie Curie maintained a strong sense of ownership for the element, which she defended with considerable emotion and vehemence. In a sense she was correct: the subsequent discoveries of the atomic nucleus, artificial radioactivity, and fission were all performed with her polonium.

*Marie Curie maintained a strong sense of ownership for the element [polonium], which she defended with considerable emotion and vehemence.*

### The Discovery of Radium: 26 December 1898


The Curies laboratory notebook has no record from July to 11 November. The Curies suspected the presence of a further radioactive element in the pitchblende, which behaved like “nearly pure barium.” Their hypothesis was confirmed in three steps. First, they verified that “normal” barium was inactive. Second, they found that a radioactive substance could be concentrated by fractional crystallization from barium chloride contained in pitchblende. They pursued this operation until the activity of the chlorides was 900 times greater than that of uranium. Their third and last argument was decisive. This time the spectroscopic analysis was successful. Demarçay observed in the spectrum of radioactive barium chloride several lines that could not be assigned to any known element and whose intensity increased with the radioactivity. The Curies concluded, “We think this is a very serious

reason to believe that the new radioactive substance contains a new element to which we propose to give the name radium.” They added, “the new radioactive substance very likely contains a large amount of barium, nevertheless, the radioactivity of radium must be enormous.” The name, “radium,” followed by a question mark appears in the notebook on 18 November.

At that time, the authors had used up their supply of pitchblende and were aware that vast amounts or raw material would be necessary in order to prepare “visible,” or at least much larger quantities of, the two new elements. In December 1898, the Austrian government offered the Curies a first batch of 100 kg of uranium-free residue from the treatment of the Joachimsthal pitchblende. The authors acknowledged that “this shipment will greatly facilitate our research.”

The determination of the atomic mass of radium became an obsession for Marie Curie. On 21 July 1902, she obtained the value  $225 \pm 1$  (now known to be 226.0254) on a self-luminous sample of 0.120 g of radium chloride with a radium barium ratio of  $10^6$ , which was one million times more active than uranium.

With the foregoing discovery of polonium, the Curies had oddly enough begun with the most difficult part of the work. In its own right, radium had outstanding advantages: its half-life is 1600 years; its concentration in the ores was about 5000 times greater than that of polonium; it is a true analog of barium, from which it can be separated; and it could be readily assigned its place in the periodic table.

On 12 June 1903, Marie presented her thesis, “Researches on Radioactive Substances,” at the Sorbonne. Later that year she shared the Nobel Prize in Physics with Pierre Curie and Henry Antoine Becquerel. 

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# Chemistry after the Discoveries of Polonium and Radium

by Robert Guillaumont and Bernd Grambow

**T**he experimental chemistry of elements, substances which cannot be decomposed and which combine in fixed ratios, was developed by Antoine Lavoisier. Around 1805–1808, following John Dalton’s work, a basic scientific concept emerged which held that each chemical element was ultimately composed of hard, solid particles (atoms) of specific, invariable mass (atomic weight), and that all substances were composed of such atoms. The atoms were too small to measure their weight directly, but relative atomic weights could be determined starting with hydrogen as the lightest one. However, the theory of atomism in chemistry was accepted with difficulty.

Significant advances were achieved by Dmitri Mendeleev in 1869 and Julius Lothar Meyer in 1870 in ranking the nearly 60 known chemical elements according to a periodic law, linking relative atomic weights of the elements to their chemical properties. Mendeleev developed a chart showing that homologue elements have large differences in atomic weights and different elements of similar atomic weight exhibit large differences in properties. With a limited number of empty places in the chart, Mendeleev predicted the existence of yet-undiscovered elements, such as eka-aluminium and eka-silicium, and their expected properties. A final proof of the validity of the Mendeleev concept was the discovery of the elements gallium in

1875, scandium in 1879, and germanium in 1886. In 1895, 80 elements already had been identified (see figure below). Still, this classification was purely empirical.

Until this point in late 1895, chemistry was still much less developed than physics despite the existence of a chemical industry (acids, bases, salts, glasses, metallurgy, colorants, pharmacy, and perfumery), rapidly expanding chemical knowledge, and chemical theories for certain fields. However, unifying and generally accepted chemical concepts were still missing.

## The Search for New Natural Elements through Atomic Properties

It was against this backdrop that in 1897 Marie Skłodowska Curie started her thesis on the origin and properties of “uranic rays” discovered by Becquerel. Curie promptly showed, by careful and systematic quantitative measurement, that the radiation intensity (linked to radioactivity) of many chemical compounds was proportional to the quantity of uranium in the compound. She was surprised that certain natural, uranium-containing minerals such as pitchblende, chalcocite, and autunite were much more radioactive than the metallic uranium freshly prepared by Henri Moissan. If chalcocite was synthesized in the laboratory from pure uranium compounds, no such enhanced radioactivity was encountered. This led Marie Curie to search in these natural minerals for a small quantity of another yet-unknown element, the source of these stronger intensity rays (see excerpt next page). She invented a new “radiochemical” method combining ordinary chemical analyses with the measurement of radioactivity.

One substance she identified, polonium, had properties similar to bismuth. In 1898, Pierre and Marie Curie couldn’t isolate a sufficiently large quantity of polonium to measure its atomic weight or to obtain the spectral signature. Today, we know that only about 6 nanograms were isolated, beyond any method of measurability available at the time; however, measuring its “radioactivity” was feasible. Pierre and Marie Curie didn’t immediately try to

	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b	6a	6b	7a	7b	8	0	
1	H															He	
2	Li		Be		B		C		N		O		F			Ne	
3	Na		Mg		Al		Si		P		S		Cl			Ar	
4	K		Ca			Sc		Ti		V		Cr		Mn	Fe	Co	Ni
		Cu		Zn	Ga		Ge		As		Se		Br				Kr
5	Rb		Sr			Y		Zr		Nb		Mo		Tc	Ru	Rh	Pd
		Ag		Cd	In		Sn		Sb		Te		I				Xe
6	Cs		Ba			La		Hf		Ta		W		Re	Os	Ir	Pt
		Au		Hg	Tl		Pb		Bi		Po		At				Rn
7	Fr		Ra			Ac		Th		Pa		U					

Periodic system at about 1895. All lanthanides were known except Pm (radioactive) and Lu discovered in 1907 (only La could be presented). In yellow are the missing non-radioactive elements. Discovered were Ge in 1896, Ne, Kr and Xe in 1898, Hf and Re in 1923 and 1925. In red are the missing radioelements with mass lower than uranium.

### Separating Uranium from Ores

In non-perturbed uranium ores,  $^{238}\text{U}$  and  $^{235}\text{U}$  are in secular equilibrium with their 23 main daughters (alpha or beta emitters) with the total activity being 178 kBq/g of uranium. Only five of them give easily detectable gamma rays. When U is separated from ores by chemical processes, the remaining activity is 25 kBq/g of the original activity content. Due to the ingrowth of the two short-lived daughters of  $^{238}\text{U}$ , it needs around one year for the activity to reach the limiting value of 51 kBq/g. The emission of gamma rays increases progressively. In Marie Curie's co-precipitation experiments, the amounts of Po and Ra were around 70 ng/kg and 300  $\mu\text{g}/\text{kg}$  of uranium, respectively. In Otto Hahn's co-precipitation experiments of Ra, the amount of  $^{228}\text{Ra}$  was around 400 ng/kg of thorium.

place polonium in the Mendeleev system. Since its behavior was similar to that of bismuth, they may have felt compelled, according to this system, to look for an eka-bismuth, but this element would have been heavier than uranium. It was not until 1906 that the chemical similarity of polonium and tellurium was identified, giving polonium its place close to bismuth in the periodic system. In 1910, a weighable quantity of about 100 micrograms of polonium was concentrated in few milligrams of bismuth.

The other substance Marie Curie identified was radium, which had chemical properties similar to barium. Spectral analyses by Eugène Demarçay of isolated "pure radium" salts confirmed the hypothesis that radium was a new chemical element. Gravimetrically, Marie Curie initially obtained an atomic weight of 225; in 1907 she obtained a weight of 225.9, close to the correct value of 226.

The position of radium in the periodic system was easily determined by the Curies. Indeed, radium is the higher homologue of barium in the family of alkaline-earth metals and it could easily be entered into Mendeleev's chart in the corresponding column.

Since 1899, many chemists have tried to isolate new radioactive elements from uranium- or thorium-containing compounds using the separation techniques of Marie Curie. They were frequently surprised by the "emanations" and "active deposits." In 1910, 44 "radioactive elements" were identified. For example, one could clearly distinguish three "radioactivities" associated with three supposedly new elements (called at the time mesothorium I, actinium X, and thorium

X) which all had the chemical properties of radium. The question was how to classify them in the periodic system? Only 12 spaces were left empty in the table. Frederick Soddy found the solution in calling these "elements" *isotopes*, which had all the same chemical properties and the same place in the periodic system, but differing in their radioactive half life. Nevertheless, it took until 1935 until the complexity of radioactive decay chains was really understood.

### The Way to a Unifying Concept for Chemistry

Ernest Rutherford, as well as Hans Geiger and Ernest Marsden, used radium as a powerful source of alpha particles to probe the inner structure of the atom by directing the beam of particles onto a thin foil of gold. This scattering experiment led to the surprising result that most of the atomic mass was concentrated in a very small nucleus about 10000 times smaller than the atom. It showed that atomic weight and nuclear charge are related. This key observation allowed Rutherford, in 1911, to develop a new atomic model of a positive nuclei with a charge roughly proportional to atomic mass. This nuclei, he theorized, was surrounded by electrons moving around it in a yet unspecified way. This model, in turn, was rapidly improved upon with the concept of atomic number (de Boer 1911; Mosley 1913) and by Niels Bohr's introduction, in 1913, of "energetic quanta," which placed the electrons in a definite orbit around the nucleus. The path was now opened to understanding periodicity and chemical bonding, such as in the work of Walther Ludwig Julius Kossel in 1916. A new unifying concept for chemistry had formed, but it would hardly have been possible if Marie Curie had not isolated radium. Hence, polonium and radium are not only the cornerstones of the science of radioactivity as Marie Curie suggested in her Nobel lecture in 1911, but they are cornerstones for modern chemistry as a whole.

### Moving beyond Naturally Occurring Radioelements

The use of alpha particles as projectiles not only helped scientists probe the atom's inner structure, but it led directly to a number of new discoveries. For example, in 1934 Irène Joliot-Curie and Frédéric Joliot used very intense radioactive alpha emitters such as polonium, much stronger than radium, to discover the first artificial radionuclide: radioactive phospho-

## Chemistry after Polonium and Radium

rus. In irradiating a foil of aluminium of mass of 27 by a source of 80 millicuries of Po, they observed the emission of neutrons and of positive electrons; the later were emitted in a delayed fashion because of the irradiation exposure event. Only phosphorus 30 could have been formed, which must have been radioactive by positron emission. It was the separation and identification of phosphorus 30 as phosphine, which provided the first chemical proof that a transmutation by a nuclear reaction had occurred producing a new type of radioactivity.

This discovery by Joliot-Curie of artificial radioactive matter motivated many chemists to look for new radioisotopes. They irradiated light elements with alpha particles and the more heavy elements with neutrons. It took only three years to discover about 200 new radionuclides. New chemical elements were also artificially produced. For example, technetium was produced in 1937 by Casimir Perrier and Emilio Segrè, who bombarded molybdenum with deuterons and isolated an irradiation product with chemical properties similar to rhenium.

The procurement of radioisotopes for a large suite of chemical elements with periods ranging from a fraction of a second to several years has enabled their use in areas as diverse as chemistry, geosciences, material science, biology, medicine, industry, and agriculture. Radiochemistry has become a new tool for studying chemical reaction mechanisms in all these fields.

It was soon recognized that the neutron transmuted one atom of mass  $A$  into a new atom of mass  $A + 1$ , which, by beta emission, decayed to an atom with atomic number  $Z+1$ , thereby becoming the element next to the irradiated one in the periodic table. So, it was the logical next step to irradiate uranium with neutrons to search for new elements even heavier than uranium. The pursuit of these “transuranic elements” quickly led to a riddle. The best radiochemists were unsure how to analyze the chemical behavior of the “new radioactivities” they encountered in light of their supposed homologous elements such as rhenium, osmium, or platinum, or of heavy elements such as radium, which might have originated from decay of the supposed transuranic elements. Ida Noddack, Irène Curie, and Pavel Savich (1938) found products with the properties of lanthanum, but they did not believe in the presence of a radioactive lanthanum.

A crucial experiment was conducted by Otto Hahn, Lise Meitner and Fritz Strassman in 1938–1939 in which they tested the hypothesis that radium was the radioactive irradiation product coming from the decay of a

supposed transuranic element. Proceeding by co-precipitation with barium, it was impossible to increase the activity of the precipitate, i.e. to enrich it in radium. Was this because the “hypothetical radium” was an imponderable quantity? (see excerpt). The answer was no (supplementary experiences showed that an imponderable quantity of radium 228 could easily be enriched in a precipitate with barium; the laws of co-precipitation were independent of concentration). One had to conclude that the activity measured in the precipitate was indeed radioactive barium and this could only be explained by the hypothesis that the uranium nucleus could break upon neutron irradiation. The fission of uranium had been discovered. Meitner’s rapid calculation showed a gain of about 200 MeV from this nuclear reaction, sufficient energy to change the fate of humanity. From there it all became clear. The neutrons irradiating uranium produced barium and lanthanum. The identification of hundreds of radionuclides, isotopes of 30 chemical elements formed in the fission process of uranium 235, was a Herculean accomplishment for radiochemists.

### Going beyond Uranium

Even though early attempts failed to produce “transuranic elements” by the neutron irradiation of uranium due to the predominance of fission, the initially intended nuclear reaction did occur, although with a probability about 15 times less, too small to be identified in the background of fission. However, careful neutron irradiation of a thin foil of uranium allowed the breakthrough. All fission products should have escaped the foil due to their extremely high recoil energy. However, a newly produced radioactive substance did not escape the thin foil. This was indeed the long-sought-for proof of a series of new elements heavier than uranium. This new chemical element, discovered by Edwin McMillan and Philip Abelson in 1939–1940, was named neptunium. It behaved like uranium and was not homologous to rhenium, which was expected. It was the first evidence of a new family of elements. The decay product is plutonium of mass 239, also a fissile material and much more simple to separate from uranium than uranium 235. It was initially difficult to find its place in the periodic table. The modern version of this table contains the actinides and the lanthanides. The periodic table now has 118 elements (see figure next page). The search for new chemical elements still continues.

## Chemistry after Polonium and Radium

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
	s										d						p		
1	H 1																		He 2
2	Li 3	Be 4											B 5	C 6	N 7	O 8	F 9	Ne 10	
3	Na 11	Mg 12											Al 13	Si 14	P 15	S 16	Cl 17	Ar 18	
4	K 19	Ca 20	Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30	Ga 31	Ge 32	As 33	Se 34	Br 35	Kr 36	
5	Rb 37	Sr 38	Y 39	Zr 40	Nb 41	Mo 42	Tc 43	Ru 44	Rh 45	Pd 46	Ag 47	Cd 48	In 49	Sn 50	Sb 51	Te 52	I 53	Xe 54	
6	Cs 55	Ba 56	La* 57	Hf 72	Ta 73	W 74	Re 75	Os 76	Ir 77	Pt 78	Au 79	Hg 80	Tl 81	Pb 82	Bi 83	Po 84	At 85	Rn 86	
7	Fr 87	Ra 88	Ac** 89	Rf 104	Db 105	Sg 106	Bh 107	Hs 108	Mt 109	Ds 110	Rg 111	Cn 112	113	114	115	116	117	118	
*		Ce 58	Pr 59	Nd 60	Pm 61	Sm 62	Eu 63	Gd 64	Tb 65	Dy 66	Ho 67	Er 68	Tm 69	Yb 70	Lu 71				
**	Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95	Cm 96	Bk 97	Cf 98	Es 99	Fm 100	Md 101	No 102	Lr 103					

Periodic table showing radioelements and artificial elements (fission products). Blue symbols (like Po) are naturally occurring radioelements. Red symbols are man made radioelements. Light blue boxes indicate fission products (artificial elements with special isotopic composition) and green boxes indicate actinides found in spent nuclear fuel (over 50 g/metric ton), the most radioactive material that exists today.


### Radiochemistry Becomes Part of Chemistry

Since Marie Curie's discoveries, a new branch of chemistry dealing with the chemical properties of radioactive matter has progressively emerged. Such matter is in perpetual renewal due to the radioactive decay of radionuclides and the emission of ionizing radiation. Radiochemistry is based on its own methodology. It allows scientists to look at many processes beyond the scope of chemistry and it has become a key discipline for understanding actinide behavior—so important in nuclear industry and environmental science. In this regard, we know how to extract plutonium, a fissile material, from spent nuclear fuel. However, we have yet to find an ultimate solution for isolating the radioactive waste associated with this endeavor.

### Conclusions

The era of radioactivity and radiochemistry, which started between 1896 and 1898, led to discoveries that have profoundly influenced chemistry. Until 1915, only a few teams of researchers—in Paris, Cambridge, Berlin, Vienna, and Montreal—had worked with radioactive material. The isolation of radium and polonium allowed these teams to probe the structure of the atom, and from this a unified concept of chemistry emerged. From that point forward, chemists have used the properties of radionuclides to understand

chemical reactions and transport mechanisms in all areas of the science. The chemical knowledge gained from radiochemistry was decisive in many fundamental discoveries: radioactivity as an atomic property, artificial radionuclides, the completion of the periodic table, nuclear fission, and transuranic elements. Today, radioactive matter is used by radiochemists for fundamental research in many fields, especially medicine and energy.

The discovery of polonium and radium and the course of chemistry and society would have been different were it not for the extraordinary patience, determination, and curiosity of Marie Curie as she searched for the origin of the strong radiation from uranium compounds. Her unwavering belief in the hypothesis of radioactivity as an atomic property and her spirit of adventure and readiness to pursue unorthodox thinking, changed the course of history. 

Robert Guillaumont is an honorary professor of chemistry (University of Paris-Sud, Orsay) and a member of the French Academy of Sciences. His research field in radiochemistry focused mainly on tracer scale chemistry and on thermodynamics of actinide chemistry. He is a member of several committees on radioactive waste management.

Bernd Grambow is a professor of radiochemistry and head of Subatech Laboratory, a mixed research unit of the Ecole des Mines, the university, and the IN2P3/CNRS in Nantes. He obtained his Ph.D. in chemistry at the Free University of Berlin. Principal research interests are in the thermodynamics and kinetics of chemical reactions involving radionuclides and in the radiochemistry of nuclear waste disposal.

# How Röntgen and Becquerel Rays are Linked with the Discoveries of Polonium and Radium

by *Andrzej Kajetan Wróblewski*

**A**s with a number of scientific discoveries, Henri Becquerel's discovery of uranium's radioactivity occurred by accident. While investigating Wilhelm Conrad Röntgen's recent work on X-rays, Becquerel decided to test Poincaré's hypothesis that the emission of X-rays could be related to phosphorescence, essentially the delayed emission of light by a substance after its exposure to light. As he later said in his Nobel lecture (Becquerel 1903): "At the beginning of 1896, on the very day that news reached Paris of Röntgen's experiments and of the extraordinary properties of the rays emitted by the phosphorescent walls of the Crookes tubes, I thought of carrying out research to see whether all phosphorescent material emitted similar rays. The results of the experiment did not justify this idea, but in this research I encountered an unexpected phenomenon."

During the course of his research, Becquerel wrapped exposed uranium mineral in photographic plates and black material to prepare for an experiment requiring bright sunlight. However, since the weather in Paris had been overcast for days, he kept the little exposed mineral and the plates in a drawer awaiting for a sunny day. Once the weather improved, Becquerel decided to develop the plate and found, to his surprise, that it was blackened. At



*Wilhelm Conrad Röntgen  
(1845–1923).*

the meeting of the Academy of Science on 2 March 1896, he announced that the uranium mineral emitted unknown penetrating radiation by itself (Becquerel 1896a).

After this breakthrough, Becquerel began studying the newly discovered radiation in more detail. He presented his results at three meetings of the Academy of Science in March 1896. On 9 March, he announced that the rays emitted by the double sulphate of uranium and potassium were capable of discharging an electroscope after passing through a 2-millimetre-thick aluminium plate. He also found that the invisible rays could be reflected and refracted (Becquerel 1896b). On 23 March, he presented more detailed results on the ionizing power of the new rays. Using a gold leaf electroscope, Becquerel compared the rate of discharge (radiation) of a potassium uranyl sulphate crystal with a Crookes' tube and found that the effect from the tube was over 100 times greater than that of the crystal (Becquerel 1896c). On 30 March, Becquerel announced (Becquerel 1896d) that the rays emitted by uranium salts were doubly refracted by tourmaline, whereas in a parallel experiment with a Crookes' tube no such effect was detected for the cathode rays.

At the five meetings of the Academy of Sciences in March 1896 there were more than 30 reports on X-rays. Amidst this flood of reports, the communications by Becquerel on uranium radiation didn't cause much excitement and the initial interest in the new rays faded rapidly. There was a proliferation of false or doubtful observations of radiation similar to uranic rays in a variety of substances, and yet these results were unreliable due to the relatively poor quality of the photographic plate. To other leading scientists at the time, the uranium rays appeared to have "normal" properties, similar to those of ordinary light, and were therefore regarded as less intriguing than the mysterious X-rays.

Thus, when John Joseph Thomson delivered the Rede Lecture on “The Röntgen Rays” at Cambridge University on 10 June 1896, he had this to say (Thomson 1896):

“Since the discovery of the Röntgen rays, Becquerel has discovered a new kind of light, which in its properties resembles the Röntgen rays more closely than any kind of light hitherto known. . . . Becquerel has shown that the radiation from the uranium salts can be polarized, so that it is undoubtedly light: it can also be refracted. It forms a link between the Röntgen rays and ordinary light, it resembles the Röntgen rays in its photographic action, in power of penetrating substances opaque to ordinary light, and in the characteristic electrical effect, while it resembles ordinary light in its capacity for polarisation, in its liability to refraction.”

Other physicists were of a similar opinion. For example, Oscar M. Stewart of Cornell University had this to say about the rays in a review published in April 1898 (Stewart 1898):

“Becquerel rays occupy a unique position, inasmuch as far more is definitely known about them than any of the other ‘new’ ‘rays.’ With X-rays nothing has been proven one way or the other about their character, save that if they are ultra-violet rays their wave-length must be extremely small, so small that the refractive index for nearly all bodies is practically unity. With the rays of Becquerel there can be no reasonable doubt that they are short transverse ether waves.”

Meanwhile, in August 1896, Pieter Zeeman of Leyden University discovered splitting of spectral lines in the magnetic field. Many physicists concentrated their attention on this long awaited connection between magnetism and light. It was around this time that Becquerel also left the “non-interesting” field of radioactivity, and from 1897 to 1899, he delivered at meetings of the Academy of Sciences, a number of papers on the Zeeman effect and the Faraday effect.



*For some time before Nov-Dec 1895, scientists had been reporting bizarre apparitions when they electrified the thin gas in vacuum tubes. On the Sunday before Christmas 1895, Wilhelm Conrad Röntgen invited his wife Bertha into the laboratory and took a shadow-graph of the bones of her hand with her wedding ring clearly visible. This is one of the most famous images in photographic history and propelled Röntgen in no time into international celebrity. The medical implications were immediately realized and the first images of fractured bones were being made by January 1896 even though none yet knew what the mystery rays were. The radiograph reproduced here is of the hand of Albert von Kolliker, made at the conclusion of Roentgen's lecture and demonstration at the Wurzburg Physical-Medical Society on 23 January 1896. (Credit: AIP Emilio Segre Visual Archives, Lande Collection)*

It is difficult to say how history would have been shaped if it were not for Maria Skłodowska-Curie who decided at the end of 1897 to study the “non-interesting” subject of uranium radiation. If she had continued her applied research on the magnetism of tempered steel, her name would probably not be widely known today.

## Röntgen and Becquerel Rays

Her first study of radioactivity (Sklódowska-Curie, 1898)—the term she first proposed—was a real break with the past. First, she applied a precise and sensitive electrometer; method much more reliable than the photographic method that gave qualitative, non repeatable, and often erroneous results because of

the quality of the manufactured plates. Second, she decided to perform a systematic study of all available minerals, rocks, and other substances. This quickly resulted in a breakthrough since it was found that the intensity of radiation from various uranium minerals was not proportional to the amount of uranium they contained. This led Curie to hypothesize on the existence of a new unknown radioactive element. Her systematic studies led her to discover the radioactivity of thorium, which was also discovered independently by German physicist Gerhard Schmidt (Schmidt, 1898), who used a photographic method similar to that of Becquerel and

found that thorium rays could be refracted and reflected (diffused) but not polarized.

Here is an excerpt from Curie's paper (M. Curie 1898):

"I have examined a great number of metals, salts, oxides, and minerals. . . . All the compounds of uranium studied are very active and they are, in general, the more active the more uranium they contain. The compounds of thorium are very active. The oxide of thorium even exceeds metallic uranium in activity. It should be noted that two most active elements, uranium and thorium, are those which have the greatest atomic weight. . . . Two ores of uranium, pitchblende (uranium oxide), and chalcocite (phosphate of copper and uranium) are much more active than uranium itself. This fact is very remarkable and leads to the belief that these minerals may contain an element much more active than uranium. . . . To interpret the spontane-

ous radiation of uranium and thorium one might imagine that all space is constantly traversed by rays analogous to Röntgen rays but much more penetrating and able to be absorbed only by certain elements of high atomic weight, such as uranium and thorium."

Thus, it was Curie's first paper, published in April 1898, which again concentrated the interest of researchers on Becquerel rays. "It appeared that the results of my work were so interesting that Pierre Curie put aside his current research and joined me in the effort to extract and study new radioactive substances," she wrote later in the introduction to her doctoral dissertation (M. Curie, 1903).

In July 1898, Maria and Pierre Curie announced the discovery of a new radioactive element (P. Curie and M. Curie 1898):

"Certain minerals containing uranium and thorium (pitchblende, chalcocite, uranite) are very active from the point of view of emission of Becquerel rays. In earlier work, one of us has shown that their activity is even greater than that of uranium and thorium, and has made the statement that this effect must be due to some other very active substance contained in a very small quantity in these minerals. . . . We believe, therefore, that the substance, which we have recovered from pitchblende contains a metal not yet described, related to bismuth in its analytical properties. If the existence of this new metal is confirmed, we propose to call it polonium, after the native country of one of us."

However, because of the previous erroneous results by Becquerel, many physicists received the news about the new radioactive element with scepticism.

The January 1899 issue of *Philosophical Magazine* carried a paper by Ernest Rutherford (Rutherford 1899) that had been sent from Cambridge to the editors on 1 September 1898. Thus, it seems certain that Rutherford began studying radioactivity much before that date, probably at the same time as Curie. In the beginning of his paper, Rutherford stated that the following:



**Henri Becquerel**  
(1852–1908).



## Röntgen and Becquerel Rays

“The results of Becquerel showed that Röntgen and uranium radiations were very similar in their power of penetrating solid bodies and producing conduction in a gas exposed to them; but there was an essential difference between the two types of radiation. He found that uranium radiation could be refracted and polarised, while no definite results showing polarisation or refraction have been obtained for Röntgen radiation.”



*Marie Curie in her laboratory.*

In his paper, Rutherford reported the important finding that uranium radiation contained two components differing in their penetrating power: strongly absorbed alpha radiation and penetrating beta radiation. It convinced Rutherford that uranium radiation is more complicated than it appeared from the study by Becquerel. Therefore, he questioned whether it was indeed necessary to postulate the existence of new substances:

“It is possible that the apparently very powerful radiation obtained from pitchblende by Curie may be partly due to the very fine state of division of the substance rather than to the presence of a new and powerful radiating substance.”


Meanwhile, Marie and Pierre Curie and Gustave Bémont continued their efforts to extract yet another substance from the pitchblende. The discovery of radium was announced on 26 December 1898 (Curie P., Curie M., Bémont G., 1898):

“The different reasons which we have enumerated lead us to believe that the new radio-active substance contains a new element to which we propose to give the name of radium . . . The new radio-active substance certainly contains a very great proportion of barium; in spite of that, the radioactivity is considerable. The radio-activity of radium must therefore be enormous . . .”

The discoveries of polonium and radium dispersed earlier doubts concerning the existence of new elements. In addition it convinced many physicists that radioactivity was an exciting field of study. Becquerel also returned to his research on uranium, and on 27 March 1899, he presented a paper to the Academy of Sciences. He stated that the intensity of the uranium radiation, as measured by its photographic action, appeared to be unchanged since May 1896; he also announced that the rays did not appear to be capable of refraction and polarization. All attempts to repeat two earlier experiments

had failed. Thus, Becquerel withdrew the results that had contributed to the lack of interest in the field.

The following years were full of new discoveries. André Debierne (Debierne 1900) discovered actinium (results presented to the Academy of Sciences on 16 October 1899). Ernest Rutherford made an important impact on the study of radioactivity with the discovery of thorium emanation (1900) and the first theory of radioactive transmutations developed jointly with Frederick Soddy. In 1903, Becquerel and the Curies received the Nobel Prize in Physics.

It is difficult not to agree with the American historian Lawrence Badash who had this to say about the first years of radioactivity (Badash 1965): “In early 1898, radioactivity was something of a “dead horse”—it was there, but no one knew what to do with it. It took not only the discovery of thorium’s activity, first by Gerhard C. Schmidt and then by Marie Curie, but the subsequent discoveries of polonium and radium by the Curies to produce a sustained renewal of interest. For then it became apparent that this was an atomic phenomenon of great significance.” 

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# Physics and Radioactivity after the Discovery of Polonium and Radium

by Pierre Radvanyi

Physics and chemistry were quite interwoven in the early history of radioactivity. In fact, the man considered to be the father of nuclear chemistry, Ernest Rutherford, was a physicist by training and title. In 1908, he was awarded the Nobel Prize in Chemistry.

The young Rutherford arrived in England from New Zealand in 1895 with a scholarship and began working with Joseph J. Thomson at Cambridge on the ionization of gases. After the discovery of polonium, but before the discovery of radium by the Curies, Rutherford studied the Becquerel rays, the radiation emitted by uranium. He found that this radiation was complex and consisted of "at least two distinct types . . . one which will be termed for convenience the  $\alpha$  radiation, and the other . . . which will be termed the  $\beta$  radiation." In



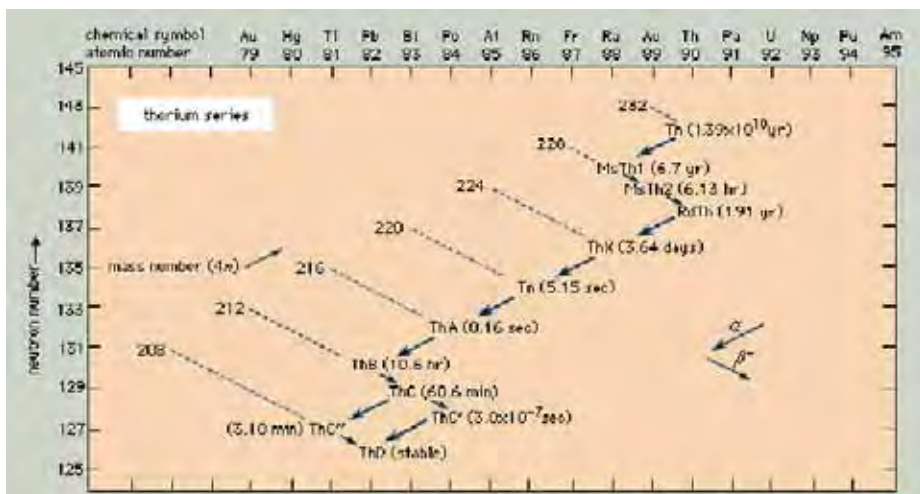
Ernest Rutherford (1871-1937).

1900, at the École Normale in Paris, Paul Villard discovered a third type of radiation that is very penetrating and analogous to X-rays, which will be later termed  $\gamma$  radiation.

At the end of 1898, Rutherford became a professor of physics at McGill University in Montreal, Canada, where he began studying the radioactivity of thorium compounds. He observed, in 1899, a strange phenomenon: the continuous production by thorium of what seemed to be a radioactive vapor or gas which he called "emanation." This emanation left on all bodies with which it came in contact an "excited radioactivity," later called the "active deposit." (Rutherford 1900). In 1900, in Germany, Ernst Dorn observed a similar emanation from radium.

Perplexed by the nature of emanation, Rutherford asks Frédéric Soddy, a young chemist just arrived from Oxford, to work with him on the problem. To them it appears to be an inert gas. At the beginning of 1902, on the basis of new experiments, they reach the conclusion that there exists an

intermediate substance, which they call thorium X (called today radium 224), formed continuously in thorium, and giving rise to the emanation (today radon 220). They generalize that radioactivity is thus the spontaneous transmutation of an element into another by the emission of radiation. At first, Pierre Curie does not believe in the "material existence" of emanation. However, when Rutherford and Soddy succeed in liquefying emanation passing through liquid air, Pierre Curie gives in and accepts the interpretation of Rutherford and Soddy. At the beginning of 1903, Pierre Curie and Albert Laborde observe that radium continu-



Many of the symbols used in the three natural, or classical, series (i.e., the uranium, thorium, and actinium series) were assigned before the nature of the isotopes was understood and now are obsolete. For example, in the thorium series, thoron (Th) is now called radon-220, and thorium D (ThD) is now called lead-208 (1996, Encyclopedia Britannica, Inc.).

ously gives out heat: in one hour radium is able to melt more than its own weight of ice.

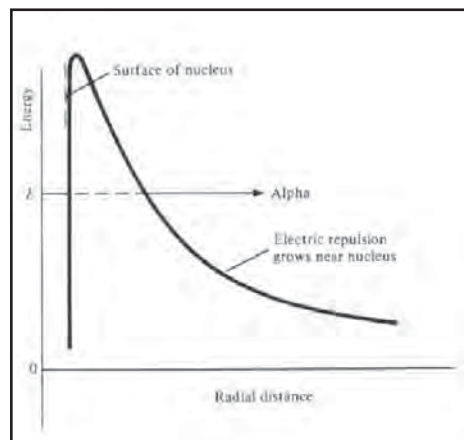
In their leading paper of 1903 (Rutherford 1903), Rutherford and Soddy explain radioactive change, put forth the exponential law of radioactive decay, and define the radioactive constant. The two young scientists also provide the first tentative sketch of radioactive series; such a series should begin with a very long-lived radio element and end with a stable element. Measuring the kinetic energy of an alpha-particle and estimating the number of alpha-particles emitted, they compare the energy of radioactive change in one gram of radium to the energy liberated in a chemical reaction such as the union of hydrogen and oxygen to form one gram of water. They conclude that “the energy of radioactive change must therefore be at least twenty-thousand times, and may be a million times, as great as the energy of any molecular change.” In addition, they state that “The maintenance of solar energy, for example, no longer presents any fundamental difficulty.”

Their findings soon allow scientists to determine the age of rock and mineral samples. Between 1905–1907, the American physicist Bertram B. Boltwood, following Rutherford’s suggestions, makes the first significant measurements of the age of minerals by comparing their lead (ultimate product of the radioactive series) and uranium content: he finds ages on the order of billions of years. Boltwood also discovers ionium (thorium 230), the long-lived parent element of radium.

From this point on, many laboratories worldwide—Paris, Montreal, Manchester, Vienna, Berlin—endeavor to complete the radioactive series (e.g., U 235, the long-lived parent of the actinium series, is not identified until 1929 with the help of mass spectroscopy).

## Alpha-Particles and the Discovery of the Nucleus

At that time of Rutherford’s early work on radiation, it was strongly suspected that alpha-particles were swift helium atoms. After becoming a professor of physics in Manchester in 1907, Rutherford spent much time obtaining decisive experimental proof that these particles carry two unit electric charges. To do so, he wished to count the alphas one by one. The scintillation method, developed by W. Crookes, J. Elster, and H. Geitel, allowed just that. However, Rutherford



*Potential barrier around a uranium nucleus presented to an alpha particle. The central well is due to the average nuclear attraction of all the nucleons and the hill is due to the electric repulsion of the protons. Alpha particles with energy  $E$  trapped inside the nuclear well may still escape to become alpha rays, by quantum mechanically tunnelling through the barrier.*

wanted to count them by an “electric” method and constructs, together with his young German co-worker Hans Geiger, the first particle counter in 1908. In order to ascertain the properties of the alpha-particles, he asks Geiger and an English-New Zealand student, E. Marsden, to study their scattering through thin metallic foils. In 1909, the two physicists observe that some alpha-particles are scattered backwards by thin platinum or gold foils (Geiger 1909).

It takes Rutherford one and a half years to understand this result. In 1911, he concludes that the atom contains a very small “nucleus” where almost all its mass is concentrated; the nucleus should carry the positive charges he theorizes, whereas it is surrounded by negatively charged electrons (Rutherford 1911). The consequences of this discovery for physics are substantial. A Dutch amateur physicist, Antonius van den Broek, suggests that the Mendeleev serial number corresponds to the charge of the nucleus; so for each of these numbers there exists a distinct element. This is verified experimentally with the help of X-ray spectroscopy by Henry Moseley in 1913. On the basis of the Rutherford atom, using Planck’s quantification rules, the young Danish theoretician Niels Bohr calculates a new model of the atom (Bohr 1913). Radioactivity, he asserts, is a property of the nucleus.

The number of new radioelements, in the limited higher part of the Mendeleev table, become larger

## After the Discovery of Polonium and Radium

and larger, and some appear to be chemically identical (e.g., radium D and lead). To explain this phenomenon, Soddy proposes in 1911 the existence of “isotopes,” radioelements of the same chemical species that have different atomic weights. Such isotopes should then also exist for nonradioactive elements he proposes. The so-called “displacement laws” for  $\alpha$ - and  $\beta$ -decay are formulated in 1913, independently by K. Fajans, G. v. Hevesy, A.S. Russell, and Soddy.

Meanwhile, at the Radium Institute in Vienna, Victor Hess wishes to understand the background always present in radioactivity measurements. In the course of balloon ascents during 1911–1912, he discovers the existence of radiation from outer space, later called “cosmic radiation.” The first observation of a “nuclear reaction” is made by Rutherford, still in Manchester, in 1919, on nitrogen nuclei bombarded by alpha-particles; this reaction gives rise to the emission of protons. This is the beginning of nuclear physics. This same year, Rutherford becomes director of the Cavendish Laboratory at Cambridge.

### Further Progress in the Study of Radioactivity

Rutherford and others have shown that the  $\alpha$ -rays emitted by radioactive substances are monoenergetic. But what about the  $\beta$ -rays? Between 1910 and 1912 in Berlin, Adolf von Baeyer, Otto Hahn, and Lise Meitner used a simple magnetic spectrometer followed by photographic plates to find that the beta-spectra consist of discrete lines, which they think are the primary  $\beta$ -rays. However, in 1914, James Chadwick uses a magnet followed by counters to observe a continuous  $\beta$ -spectrum under the discrete lines. Chadwick informs Rutherford, who reaches the conclusion that these spectra are actually the primary  $\beta$ -decay rays.

Following World War I, Charles D. Ellis, who was a prisoner of war with Chadwick, joined Rutherford's laboratory in Cambridge; he shows that the discrete electron lines are internal conversion electrons of  $\gamma$ -rays, and that these  $\gamma$ -rays correspond to different energy states of the nucleus. Ellis is the first to draw a nuclear level scheme (Rutherford 1930).

There remains a puzzle: Why do  $\beta$ -rays form continuous spectra? A heated discussion takes place between Meitner, Chadwick, and Ellis. Finally, Ellis and W.A. Wooster show in 1927, in a careful calorimetry experiment, that the mean energy liberated in the  $\beta$ -decay of radium E is only about one third of the maximum energy of its  $\beta$ -spectrum. Physicists are abashed: where is the rest of the available energy going? Niels Bohr is ready to give-up on the idea of energy conservation in individual nuclear events. However, in 1930 in Zurich, Wolfgang Pauli comes up with an unexpected explanation: in  $\beta$ -decay two particles are emitted and not just one. The electron is emitted together with a yet unknown particle, which is electrically neutral and a negligibly small mass. This new particle will be called a “neutrino.” However, the first



*Enrico Fermi (1901-1954).*

direct experimental observation of neutrinos will not be made until 1953–1956.

Pauli's proposal finds general acceptance. On the basis of this hypothesis, at the end of 1933 in Rome, Enrico Fermi formulates his theory of  $\beta$ -decay: electrons and neutrinos (antineutrino) are not present inside the nucleus; they are emitted at the instant of their creation (Fermi 1934). A new type of interaction is postulated that will later be called “weak interaction.”

In 1928, a Russian-born young theoretician, George Gamow, travelled from Copenhagen to Cambridge to give a talk on his new results. With the newly developed quantum mechanics, he is able to explain and to calculate  $\alpha$ -decay on the basis of a “tunnel effect” through the potential barrier surrounding the nucleus (Gamow 1928). This potential barrier arises from the opposed effects of the electromagnetic interaction and the forces providing the cohesion of the nucleus (later called “strong interaction”). Listening to this talk, J.D. Cockcroft, one of Rutherford's associates, gets the idea that Gamow's argument could be reversed: low-energy protons should be able to penetrate a light nucleus and split it. Rutherford agrees; Cockcroft and E.T.S. Walton construct a low-energy proton accelerator and, in 1932, succeed in observing the first artificial disintegrations of lithium 7 nuclei.

In 1932, following an experiment of Frédéric and Irène Joliot-Curie in Paris, James Chadwick at the

## After the Discovery of Polonium and Radium

Cavendish Laboratory discovers the existence in the nucleus of “neutrons,” neutral particles having about the same mass as the proton. The following year in Germany, Werner Heisenberg assumes that nuclei are formed by protons and neutrons put on the same footing; they will later be called “nucleons.”

### Artificial Radioactivity

In 1932, in California, Carl David Anderson discovers, with the help of a cloud chamber, the positive electron (or positron) among the cosmic rays; it is the “antiparticle” of the ordinary negative electron.

At the Institut du Radium in Paris, directed by Marie Curie, in January 1934, Frédéric and Irène Joliot-Curie discover “artificial radioactivity” (I. Curie and Joliot 1934). They had observed positrons and neutrons, emitted by an aluminium foil bombarded by a strong source of alpha-particles. They now realize that the number of these positrons diminishes according to the exponential law characteristic of radioactive decay, when the  $\alpha$ -source is removed. They had produced radioactive phosphorous 30, an isotope



*In January 1934, Frédéric and Irène Joliot-Curie discovered “artificial radioactivity.”*

of the stable phosphorous 31, inside the aluminium foil, by the nuclear reaction:  $\text{Al } 27 + \alpha \rightarrow \text{P } 30 + \text{n}$ . Radioactive P 30 decays into stable Si 30 by positron emission; this is the first case of  $\beta^+$  radioactivity. In  $\beta^+$  radioactivity a proton of the nucleus changes into a neutron, whereas in  $\beta^-$  radioactivity a neutron changes into a proton. Frédéric and Irène Joliot-Curie confirm their conclusions by the chemical separation of the radioactive phosphorous from the aluminium foil. They find two other cases of artificial radioactivity among light elements. This is a remarkable generalization of the natural radioactivity discovered by Becquerel and the Curies in 1896–1898. In a few months, Fermi and his


team in Rome, making use of neutrons as projectiles in order to penetrate heavier nuclei, were then able to produce almost 50 new artificial radioelements.

Several important applications followed from this discovery. In 1935 in Copenhagen, George von Hevesy used radioactive isotopes of elements with great interest to biologists to develop his indicator method. In 1949 in Chicago, Willard F. Libby, having observed the continuous production of carbon 14 (the half-life of which is 5570 years) on atmospheric nitrogen by cosmic rays, invented his dating method (used for age determinations in archeology, geology, and geophysics).

Then, other types of radioactivity are discovered.

Quantum mechanics predicts that an inner electron of an atom (mainly a K electron) has a finite probability to be found inside the nucleus; so radioactivity by electron capture can take place, in possible competition with  $\beta^+$  decay, if permitted by energy balance. In 1937 in Berkeley, Luis W. Alvarez finds the first case of electron capture. In December 1938 in Berlin, Otto Hahn and Fritz Strassmann discover fission of uranium nuclei bombarded by

neutrons. In 1940, the Russian physicists Goegyry N. Flerov and K.A. Petrjak observe the spontaneous fission of uranium, which takes place by a tunnel effect analogous to what happens in  $\alpha$  decay. In 1981 in Darmstadt, Germany, radioactivity by the emission of protons is observed.

In the 1920s, nuclear physics was considered to be part of the field of radioactivity; less than 20 years later, radioactivity was considered to be part of nuclear physics. 

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# Medicine after the Discovery of Radium

by Julian Liniecki

In the final decade of the 19th century, several important findings in the domain of physics had a major influence upon the field of medicine. The first was the discovery by Wilhelm Conrad Röntgen of X-rays and their basic characteristics (Eisenberg, 1992; Hellman, 1996). The second was made by Marie Skłodowska-Curie and her husband Pierre Curie, who proved that radiation emitted by uranium ore originates in the ore itself and comes from a new element they named radium. The Curies developed a technique for isolating radium, but they refrained from patenting the process in the belief that the potential benefits to society from the new element—especially in medicine—were too great to keep to themselves.

As predicted, it wasn't long before radium and X-rays found widespread application in medicine.

However, in the early years the low electric potential between poles of the cathode bulb and low current intensity made it difficult to use X-rays for diagnostic imaging. Over the next 20 years, these disadvantages had been gradually, but effectively eliminated so that during World War I, X-ray machines were put to widespread use in medical units and hospitals, both permanently installed and mounted on ambulance cars to diagnose wounded soldiers. In fact, Marie Curie pushed for the use of these mobile radiography units, which came to be known as *petites Curies*. In 1914, Marie

and her 17-year-old daughter Irène took their first trip to the battlefield in one of these ambulances.

Around this time, the first attempts were made to use X-rays for the treatment of superficial skin ailments (Eisenberg 1992). In the early 20th century the treatment of pathological foci localized in deeper spaces of human body was still ineffective because of

the low energy of X-ray quanta and their poor penetrating power. It was not until the 1920s and 1930s that X-ray machines were developed that utilized higher voltage (called orthovoltage) in the range of 120–140 kV. From this point forward, the new specialty of radiology rapidly emerged.

There was a great deal of early interest in using radium in medicine, although some proponents argued for widespread, almost indiscriminate application. Quite soon it became obvious that when introduced into the human body in the form of a solution it was quite harmful or even deadly. Thankfully, dangers of this practice were promptly recognized and these treatments discontinued.

The use of radium for cancer treatment was soon recognized as an effective therapy. The therapy involved the use of sealed metal containers containing radium salts that were placed inside the patient's body close to the tumor site. Cancer of the uterine cervix was treated with radium tubes more than other malignancy. This procedure was commonly used up through the 1960s and 1970s until other radionuclides were substituted.

A number of other types of malignant tumors have been treated with radium as well. Radium tubes were used to treat skin cancer and mammary carcinoma. This type of treatment, called brachytherapy, allowed for the irradiation of many patients per day by the same installation. It is still used today, with dose distribution between the tumor and healthy tissues close to optimal.

Radium was also used inside needles that were inserted into the mouth, lip, and other areas. Later, surgeons were able to plant tiny doses of radium close to the tumor bed, minimizing exposure to the radiation. Effectiveness of this procedure contributed to the emergence of oncological radiotherapy (Del Regato 1993).

Following the discovery of radium's medical potential, numerous Radium Institutes were established in several countries (e.g., Paris, Stockholm, and Warsaw). Marie Curie's role in this activity cannot be overestimated.

An important milestone in radiation treatment occurred when Rolf Sievert's definition of the dose of radiation (exposure) was accepted by the II International Congress of Radiology in Stockholm in 1928. Since then, steady improvements in dosimetry



*Early proponents of the medical use of radium argued for its widespread, almost indiscriminate application.*

have taken place. By substituting other gamma ray emitting radionuclides of very high activity, obtained later from fission products and/or nuclear reactions, doctors radically shortened the time of local irradiation.

For effective radiological treatment with gamma rays (e.g., from  $^{60}\text{Co}$  and other sources) and with ionizing beta particles and quanta from accelerators, an accurate dosimetry is essential. Optimal irradiation of a tumor means achieving the highest planned dose in the tumor volume (called target) while reducing the dose—as effectively as possible—in neighboring healthy tissues. The modern tools for satisfying such demands include precise three-dimensional imaging of tumors and healthy tissues using X-ray tomography and magnetic resonance imaging. Sophisticated computer programs are used to steer the irradiation procedure. In recent decades, three-dimensional irradiation has become more commonplace. It involves the dynamic adaptation of radiation-beam crosssections (beam shape and intensity modulation) to concentrate the dose at the target tumor while reducing the impact on healthy tissues that the beam travels through.

Another more recent advance has been the use of proton-beam therapy to treat a variety of tumor types. With proton-beam irradiation, the distribution of doses is very close to theoretically optimal and the treatment appears to be more effective than traditional radiation therapy. However, it requires a very high investment which has limited its availability to a few oncological centers.

The practical problem encountered early in the history of radiotherapy was how to irradiate patients and their tumors. It became quite clear that application of a single high dose (X, gamma rays) of radiation to the tumor led to serious damage of neighboring healthy tissues and life-endangering complications. After numerous studies (experimental, clinical, and epidemiological) it became clear that the fractionation of radiation doses was the solution.


The discovery of artificial radioactivity by Frédéric and Irène Joliot-Curie in 1934 as well as the controlled fission of uranium 235 atoms in nuclear reactors lead to the availability of a large number of radioactive nuclides for use in medicine. By binding selected nuclides with molecules that have affinity to various tissues and organs, researchers created a category of compounds called radiopharmaceuticals, which are now widely used for diagnostic and therapeutic purposes.

As scientists developed instrumentation to detect and follow radiopharmaceuticals in the human body,

a new branch of science emerged: nuclear medicine. One of the milestones in this field was the development of positron emission tomography (PET), a three-dimensional imaging technique which allows physicians to follow specific processes in the body. A so-called tracer, a positron-emitting radionuclide, is introduced into the body on a biologically active molecule, and the annihilation events are detected and followed in space and time.

The most commonly used tracer is a derivative of glucose ( $^{18}\text{F}$ -fluorodeoxyglucose), which is readily taken up by cancerous cells. This enables detection and localization of cancerous cells and tissues. In addition, PET scans are used to understand the metabolic activity of tissues and can therefore be used to study and diagnose a range of physiological and pathological processes.

In recent decades, targeted radionuclide therapy has shown promise as an effective form of treatment for certain cancers with far fewer side effects than traditional radiation therapy. Several procedures of this type have been developed and validated for several tumor types (e.g., malignant lymphoma). The concept depends on use of molecules labeled with radionuclide to deliver radiation to cancerous cells in disease sites. Radiation may come from nuclides emitting alpha- and beta- particles or Auger electrons. The affinity of molecules to cancer cells results from genetic characteristics (immunotherapy). Two drugs in particular,  $^{90}\text{Y}$ -ibritumomab tiuxetan—"Zevalin" and  $^{131}\text{I}$ -tositumomab (Bexxar) used for the successful treatment of indolent B-cell lymphoma, have confirmed that the concept of targeted radionuclide therapy has great potential (NRC 2007).

A century ago, few could have foreseen that the discoveries of Wilhelm Röntgen and Marie Skłodowska-Curie would lead to radiotherapy becoming one of the mainstays of treatment for cancer. According to available statistics, there were approximately 5 million patients treated with ionizing radiation annually between 1991 and 1996 (UN 2000). Regretfully, because the treatment is often expensive and highly complicated and there is limited availability of medical staff and appropriate technology, the therapy is unavailable to a large proportion of the world's population. 

**Dr. Med. Julian Linecki is professor emeritus of nuclear medicine at the Medical University of Lodz, Poland; he was a member of the International Commission on Radiological Protection from 1969 to 2008.**

# The Museum of Maria Skłodowska-Curie in Warsaw

by Małgorzata Sobieszczak-Marciniak

The Museum of Maria Skłodowska-Curie in Warsaw is located at 16 Freta St., in between the “Old Town” and “New Town,” and not far from the famous Barbican, constructed in 1548 as part of the original defensive wall around the city, and the enchanting New Town Marketplace. Freta St., which dates to around the 17th century, was originally an area of bustling, unregulated trade that was at the heart of the expansion of Warsaw. Until World War II, the street was full of craftsmen and merchants, such as shoemakers, tailors, pharmacies, and photography shops. Nowadays, it is one of the most beautiful places in the Old or New Towns, with many restaurants, cafés, and galleries.

## The Story of 16 Freta St.

In the 18th century, the architect Szymon Zug constructed a residence at 16 Freta Street for the Warsaw banker Łyszkiewicz. In 1839, it was converted to a boarding school for girls, one of the best in the city at the time, which was managed by Eleanora Kurhanowicz. In 1860, Bronisława Skłodowska, a former student and graduate of Kurhanowicz’s boarding school, became the matron and owner of the school and made it her home, along with her husband Władysław Skłodowski (see footnote, p. 8). Their five children were born there in eight years: Zofia, Józef, Bronisława, Helena, and Maria, the youngest. Born on 7 November 1867, Maria often went by the nickname



*Maria Skłodowska, the youngest in the middle, with her brother and sisters.*

“Anciupecio,” roughly “something nice and small.”

The building, which has been rebuilt several times, looks somewhat different now than it did originally, but these differences are only apparent upon a careful look at the 19th-century photograph of the place. At the end of the 1930s, a third floor was built, but due to a construction error the building collapsed, killing many dwellers. It was during the 1930s, still during Maria Skłodowska-Curie’s lifetime, that Warsaw citizens erected a commemorative plaque marking the birthplace of the two-time Noble Prize winner. Today, the Old Town’s old-fashioned horse-drawn carriages stop at the building to point out this famous landmark.

During World War II and the Warsaw Uprising, the building shared the fate of most of Old Town’s build-



*From left: Freta St. in the 19th century, the birthplace of Maria Skłodowska; 16 Freta St. in the 1930s; the building at 16 Freta St. was demolished during the Warsaw Uprising; the Maria Skłodowska-Curie Museum today.*



ings—it was destroyed and burned. A photograph taken just after the war shows Maria Skłodowska-Curie's sister, Helena Skłodowska-Szalay, and brother, Józef Skłodowski, standing before the entrance to the partially demolished building (bottom of page 38, third from left). Clearly visible is the original commemorative plaque from the 1930s. When the building was rebuilt in the 1950s, this same plaque was again placed on the building and is still there today.

In 1954, Maria and Pierre Curie's older daughter, Irène Joliot-Curie, opened a science museum in the building at 16 Freta St., with a small exhibition devoted to Maria.

As she was the youngest child, Maria lived at the home the shortest. A year after she was born, in 1868, the family moved to an apartment on Nowolipki St. to be near the Men's Governmental Gymnasium at which Maria's father Władysław Skłodowski taught (Jaworski 2006). A physics and mathematics teacher educated in Petersburg, Władysław was an open-minded man who kept up on the latest scientific discoveries. A Polish patriot, he had many problems with the tsarist officials supervising the schools in which he worked. Maria's mother, Bronisława Skłodowska, died of tuberculosis in 1878 when Maria was only 11.

## Launching the Museum

In October 1967, on the 100th anniversary of Maria Skłodowska-Curie's birth, the first and only museum dedicated to her was created at 16 Freta St. Eve Curie Labouisse, with her husband, Henri Labouisse, the scientist's grandchildren, Héléne Langevin and Pierre Joliot, Kazimierz Fajans, Janusz Groszkowski, the president of the Polish Academy of Sciences, as well as nine Noble Prize winners, participated in the museum's opening ceremony.

The museum was the work of Professor Józef Hurwic, the President of the Polish Chemistry Association, an expert on Curie's life and achievements. It is not surprising that the Polish Chemistry Association manages the museum, since Maria Skłodowska-Curie has been an honorary member since 1919.

The idea of creating a Marie Skłodowska-Curie museum was born in the hearts of Poles shortly after her death. Originally, the Radium Institute's building at 15 Wawelska St. was to house the museum. It was here that items to be placed in the museum were collected: reminders of the scientist, photographs personal things, correspondence, and more. The plans were strongly supported by the National Museum's



*The opening ceremony of the Maria Skłodowska-Curie Museum at 16 Freta St. in 1967: Prof. J. Huriwc, president of the Polish Chemical Society (left) and Eve Curie Labouisse.*

director, Professor Stanisław Lorentz. Warsaw citizens and private benefactors contributed. Sadly, most of the collected items were destroyed in the war and occupation. Fortunately, the content of some of the letters and documents were preserved in a great book written by Maria's daughter Eve Curie Labouisse. Fortunately, there was, and still is, much regard and sentiment for Maria Skłodowska-Curie, so after WWII the museum managed to obtain many original items, letters, and documents. Even now, the museum sometimes obtains or purchases items to exhibit.

The Maria Skłodowska-Curie museum currently occupies the entire first floor of the building, as well as several offices on the second floor. Next to the offices of the Polish Chemistry Association there is a lecture



*Irène Joliot-Curie tours an exhibition in memory of Maria Skłodowska-Curie at the Science Centre at 16 Freta St. in Warsaw, 1954.*

## The Museum of Maria Skłodowska-Curie in Warsaw



*An exhibit celebrating the 100th anniversary of the discovery of radium and polonium in 1998. To the right is the granddaughter of Pierre and Marie Curie: Helene Langevin-Joliot.*

and projection room, in which lectures and films are organized. In the exhibition part of the museum, there are three rooms with a total area of over 100 sq. metres. Since it is a biographical museum, the exhibition is permanent, changed only in fragments or in whole from time to time. In general, it does not organize temporary exhibits, although one of the rooms,

Maria Skłodowska left Warsaw in November 1891 and went to Paris to make the biggest dream of her 24 year-old life come true—to study at Sorbonne. It was only possible thanks to her stubbornness and the help of her family. It seemed that she might not leave for long, just a few years, that after graduation she would come back and share her power, wisdom, and heart with her motherland. Yet, fate can be tricky sometimes. Fortunately, she never lost contact with Poland and Warsaw. She came back many times and often emphasized how much she loved her country, her city, and the river that flows through Warsaw. In 1913, upon being awarded honorary citizenship of Warsaw, she said these famous words: “If Professor Napoleon Milicer and his assistant, Dr. Kossakowski, did not teach me analysis in Warsaw, I would have never separated radium.” It was also here that she fulfilled another dream—to build the Radium Institute in Warsaw, a twin institute to the one she created in Paris. “My greatest dream is to build the Radium Institute in Warsaw.”

the “Skłodowskis Lounge,” houses displays that may not be thematically related to the scientist herself.

The last room of the museum contains a reproduction of Maria and Pierre Curie’s first, and most primitive, laboratory. This was the laboratory in which they were the happiest Maria wrote in her autobiography. It was the lab in which they made their first discoveries, and first saw the “gleaming radium.” The small-scale model of the laboratory at Lhomond Street in Paris includes replicas of the devices that the scientists used, a computer station on which the visitors can see presentations about the Curies, devices that Maria used in her work, and the whole scientific process that led to the discoveries of polonium and radium.

### Museum Activities

Maria Skłodowska-Curie was a person of great depth, with compelling insights not only about science, but about life, raising children, friendship, and human relations. She was friends with many interesting people, and held views that were well ahead of her time. For these reasons, the themes of the meetings and exhibitions in the “Lounge” part of the museum are extensive. The aim of the organizers of the current exhibit was clear: to interest visitors about who Curie was as a person and her achievements as a scientist, not to spoon-feed them information. The exhibit should encourage visitors to enquire further on their own, to read books on Curie and the consequences of her work, search the archives or libraries, and encourage them to think about her uniqueness as a person and the times and social conditions in which she lived and worked. After visiting the museum, visitors often write down in the guest book that they were surprised that



*The author (right) and children at the museum during the 2009 Science Festival.*

## The Museum of Maria Skłodowska-Curie

this great scientist, sometimes so boringly described in textbooks, had such a rich personality.

Apart from strictly exhibit-oriented functions (i.e., collecting and cataloging collections, organizing exhibitions), the museum also fulfills educational and public relations functions explicitly emphasized in the statutes of the museum and the Polish Chemistry Association. In this regard, the museum participates in numerous activities and events organized by the City of Warsaw and scientific institutes, including the Night at Museums, the Science Festival, Scientific Picnic, Children's University, and more. During the events, the museum hosts lectures, meetings, and competitions, as well as chemical shows and experiments involving the scope of radioactivity. During this year's Night at Museums, the Maria Skłodowska-Curie museum hosted over 5000 visitors, ages two and up.

Staff of the museum have assisted many students with their M.S. and B.S. theses on Maria Skłodowska-Curie and her scientific studies, her personality, and the example she was, and still is, for women.

Over 16000 people visit the museum annually, of which students and foreign tourists, mainly from



*The honorary diploma issued to Maria Skłodowska-Curie in 1924 by the Polish Chemical Society.*

Asia, constitute a significant proportion. During the school year it offers biographical and chemistry museum lessons for students. As part of such lessons, students watch biographical or chemistry films and visit the museum with a guide. Due to the large number of foreign tourists, we offer films in English and French and the exhibition was also prepared in English and French. Biographical leaflets on Curie are available in 10 languages: Polish, English, French, Spanish, Italian, Russian, Korean, Japanese, Chinese, and German.

The museum is, as visitors proclaim, an exceptional place—a tribute to the unique connection between Poland and France and to the spirit of scientific discovery for the good of humanity.

As Maria Skłodowska-Curie said during her visit to the USA in 1929: “the radium that the U.S. offers to me must become the ownership of science for all time . . .” (E. Curie 1937) 🇺🇸

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### A Special Visit from Eve Curie

In 1998, the museum opened a new exhibition marking the 100th anniversary of Maria Curie's discoveries of polonium and radium. At the opening, it again hosted Professors H. Langevin and P. Joliot, several Nobel Prize winners, including Józef Rotblat, the winner of the Nobel Peace Prize. A year later, when Eve Curie Labouisse came to Warsaw for an unofficial visit, she wanted to see the museum. The author of this article was happy and honored to show such a great guest around the museum. I can still remember the joy, incredible youthful sense of humour, curiosity, and warmth of that remarkable woman. I can also remember her invitation to eat lunch together “When you come to New York, by any chance,” which has, unfortunately, never taken place.

# Programs and Institutions Bearing Maria Skłodowska-Curie's Name

by Barbara Petelenz and  
Andrzej Kułakowski

One of the most visible ways in which the legacy of Maria Skłodowska-Curie (Maria Curie-Skłodowska, Marie Curie, or Madam/Madame Curie) has been preserved is through its use—in its various iterations—as part of the name of numerous institutions and programs around the world. To find all of them, even with modern tools, seems practically impossible, so, we apologize if—despite our best efforts—this list is incomplete.

In Poland alone, the name Maria Skłodowska-Curie has been given to several hospitals originating from the Radium Institute, as well as to a state university<sup>1</sup> (see endnotes, p. 46), a government research institute,<sup>2</sup> a private college,<sup>3</sup> a nuclear reactor,<sup>4</sup> several



*Construction of the Reactor Maria at the Institute of Nuclear Energy in Swierk, Poland.*

dozen primary and secondary schools, and to a few scientific societies. Many other Polish hospitals, research institutes, schools, or university faculties (colleges or schools) are located at Maria Skłodowska-Curie street or square; a similar pattern is evident in other countries around the world. Institutions or activities bearing the name of Marie Curie are usually related to her profession, but sometimes also to her Polish descent, her links with France, her gender, or to a combination of these factors. The international character of these institutions or activities is expressed either by the manner they are organized or by their scientific and social impact, or both.

## Institut Curie, Paris, France

The first institute in the world to receive the name of Curie, was the Radium Institute (l'Institut du Radium)

in Paris. It was established in 1909 as a central *national* laboratory, dedicated to fundamental studies on radioactivity and on its applications in physics, chemistry, biology, and medicine. It consisted of two divisions: the Curie Laboratory, headed by Marie Curie, which focused on physics and chemistry, and the Pasteur Laboratory, headed by Claudius Regaud, which was devoted to studies on the biological and medical effects of radiation. The laboratories were finished in 1914, just before the outbreak of World War I.

A hundred years later, the Curie Institute, along with its two hospitals located in Paris, is a top-notch scientific institution, oriented mainly toward cancer research, diagnosis, and treatment. It has retained its international character, both in the constitution of its Scientific Board and in the continuing pursuit of its educational mission, which emphasizes providing opportunities for foreign students. The Curie Institute offers “Ph.D. grants for foreign students who wish to do their thesis work in one of its laboratories” and participates in the “European Programme for doctoral studies in the sciences.”

The Curie Institute<sup>5</sup> extends its educational mission to the wider public through the Curie Museum,<sup>6</sup> located on the ground floor of the Curie Pavillion—one of the oldest buildings in the Institute. Its exhibitions commemorate the history of radioactivity and the contributions of the Curie family to the development of related disciplines.

## Centre of Oncology—Maria Skłodowska-Curie Memorial Institute, Warsaw, Poland<sup>7</sup>

Although she was a French scientist, Marie Curie remained forever a Polish patriot. Her great wish, expressed in 1923 during the celebration of the 25th anniversary of the discovery of radium, was to create a Radium Institute in Poland. That same year, a group of Polish physicians formed the Polish Committee for Cancer Control and established the First Polish Program Against Cancer. The three main objectives of the program were the following: cancer research, health education, and creation of a national network of oncological institutes, starting with the six largest cities in Poland. A fund-raising campaign, the “Maria



*The Maria Skłodowska-Curie Institute of Oncology in Warsaw, the leading and most specialized cancer research and treatment center in Poland, it was founded in 1932 as the Radium Institute (Photo: Hubert Śmietanka).*

Skłodowska-Curie National Donation to Build the Radium Institute," also was initiated in 1923. Gifts and donations were so generous that two years later Marie Curie placed the cornerstone of the new Institute and planted a memorial tree at the area donated by the University of Warsaw.

Curie and Regaud consulted on and supervised the construction of the Warsaw Institute. The clinical ward of the institute was officially opened in 1932. At the opening ceremony, Marie Curie, officially presented the 1 gram of radium, the purchase of which had been generously funded by Polish women's groups from Canada and the USA.

By 1937 the Radium Institute in Warsaw had its own laboratories of physics, metrology of radioactive bodies, and X-ray standardization. In 1939, following the outbreak of World War II, the first director of the institute, Franciszek Łukaszyk, had to take drastic steps to prevent the radium from being confiscated by the Nazis and to keep the clinics running. In 1944, during the Warsaw Uprising,<sup>8</sup> German troops killed the hospital's patients and burned down the building. The reconstruction of the Institute started immediately after the liberation in 1945; it resumed activity in 1947. In 1951, the name "Centre of Oncology— Maria Skłodowska-Curie Memorial Institute" was officially given to the Radium Institute in Warsaw and to its branches in Kraków<sup>9</sup> and Gliwice,<sup>10</sup> both in Southern Poland.



Today, Poland has 16 oncology centers and a number of oncology wards in general hospitals. Each of these centers is involved in international scientific cooperation. The Center of Oncology in Warsaw has a new big hospital whose first clinics were opened in 1984, and which began full operation in 1995. The building of the former Radium Institute, which still serves patients, also houses a permanent exhibition commemorating the life and deeds of this great woman: "Tribute to Maria Skłodowska-Curie."<sup>11</sup>

## Marie Curie Hospitals in the World

Other examples of cancer hospitals in the world named after Marie Curie, include the Maria Curie Cancer Hospital in Buenos Aires, Argentina<sup>12</sup>; the "Madame Curie" Provincial Oncological Hospital in Camagüey, Cuba<sup>13</sup>; and the chain of Cancer Centres in India: Curie Centre of Oncology, Bangalore; Gokula Curie Cancer Center, Bangalore; NMR Curie Centre of Oncology, Hubli; Curie Manavata Cancer Centre, Nashik, Maharashtra; SMH-Curie Cancer Centre, Delhi; Curie-Abdur Razzaque Ansari Cancer Institute, Ranchi, Jharkhand; Panda Curie Cancer Centre, Cuttack, Orissa; Curie Centre of Oncology, Vijayawada, AP.<sup>14</sup>

## Marie Curie Hospices

An important aspect of cancer treatment is the palliative care of terminally ill patients. Such is the mission of Marie Curie Cancer Care in the UK<sup>15</sup> (formerly the Marie Curie Memorial Foundation), which is "a charity dedicated to alleviating suffering from cancer" that started in 1952. The organization inherits its name from the former Marie Curie hospital for women cancer patients, founded in 1929 in Hampstead (and staffed by women). Now, it runs nine specialist hospices throughout the UK, provides nursing for cancer patients at home, and educates the public about cancer.

The Marie Curie Research Institute, a branch of the organization that began in the early 1980s, is composed of eight research groups located at several sites in the UK. More recent initiatives are the Marie Curie Palliative Care Research and Development Unit, created in 1999 at the Royal Free Hospital, London, and the Marie Curie Palliative Care Institute of Liverpool in 2004.<sup>16</sup>

## Named in Her Honor



### Pierre and Marie Curie University, Paris, France

The most famous university to bear the Curie moniker is the Pierre and Marie Curie University (Université Pierre et Marie Curie, UPMC)<sup>17</sup> in Paris. Its origins date to 1109, when it was a training center for clerics at the Saint Victor Abbey in the Latin Quarter of Paris. After numerous historical perturbations, the school adopted its modern form when the new Faculty of Sciences of the University of Paris was established in 1968. In 1971 it

was named the University Paris 6, but in 1974 it was renamed in honor of Pierre and Marie Curie.

Today, UPMC has 31 campuses and locations, 162 laboratories, 3000 doctoral students, and 6000 international students. UPMC is a partner in about 20 international bachelor and master's programs shared with other universities all over the world.

### Maria Skłodowska-Curie University, Lublin, Poland

The Maria Curie-Skłodowska University (UMCS) in Lublin, Poland, was established in October 1944 and officially opened on 14 January 1945. It is a *state* university, which initially consisted of five faculties: Medicine, Veterinary Medicine, Natural Sciences, Agriculture, and Pharmacy. It now has 10 faculties, 25 institutes, and 5 independent research groups, including the radiochemistry group, which is one of the strongest in Poland.



*Pierre and Marie Curie University in Paris (top) and a statue at the Maria Curie-Skłodowska University in Lublin, Poland.*

### Marie Curie Primary and High Schools

Our search has revealed a handful of schools named after Marie Curie outside of Poland. One is the Curie Metropolitan High School in Chicago, Illinois, USA,<sup>18</sup> which offers an International Baccalaureate. Another example is the Collège Pierre et Marie Curie<sup>19</sup> in St. Germain-en-Laye, France, originating from a school established in 1950 for the children of military personnel working for the Supreme Headquarters of the Allied Powers in Europe.

A school which is particularly proud of its students' achievements in English is the Marie Curie School in Dhaka, Bangladesh<sup>20</sup> established in 1995. Two francophone Marie Curie schools were established in the former French colonies. One of them is the Marie Curie High School in Ho Chi Minh City, Vietnam,<sup>21</sup> established in 1918 by the French colonial government as an "all-girls school" (nowadays, it is public, accepts both girls and boys, and remains one of a few schools in Vietnam that offers French as a foreign language). The other is the ISBI (Independent, Special, Boarding, International) school, École Marie Curie in Cité El Marhagène, Tunis-Mutuelleville, Tunisia,<sup>22</sup> for young boys.

At least two schools named after Maria Skłodowska-Curie<sup>23,24</sup> have been organized and are run by the Polish communities in the USA. Their aim is to conserve Polish cultural heritage among children of Polish immigrants.

When it comes to the Polish schools named after Maria Skłodowska-Curie, the files of the Maria Skłodowska-Curie Museum in Warsaw<sup>25</sup> show 12 primary, 28 junior, and 42 high schools, as well as 47 clusters of educational units, many of which include the chemistry-oriented high schools and vocational schools.<sup>26</sup>



*Marie Curie High School in Ho Chi Minh City, Vietnam.*

## Named in Her Honor

### European Union Marie Curie Actions

The two young half-orphaned Skłodowska sisters represent an unusual example of strive for education and of the family solidarity expressed by mutual financial and technical help. Both ladies have achieved professional success, but they had to pay for it with a long period of bitter poverty and of extremely hard work in a friendly but foreign country.

A century after Marya (Curie) and Bronya (Dłuska) Skłodowska struggled to complete their education, the European Union demonstrated its belief that graduate and post-graduate education is one of the best investments in society by enacting a system of financial assistance for young people to develop their talents.

The most spectacular of such assistance programs are the EU Marie Curie (MC) Actions, started within the 6th Framework Program (FP6)<sup>27</sup> in 2002 and continued (with a slightly modified organization) within the 7th Framework Program (FP7).<sup>28</sup> A search in the CORDIS database, using “Marie Curie/PEOPLE” as the keywords, resulted in 2604 projects running within the FP7 so far.



### Other International Programs and Grants Named after Marie Curie

Apart from the EU programs, there are also initiatives on a smaller scale (e.g., the Marie and Pierre Curie joint annual meetings of young Slovak and Czech chemists and biologists). The meetings are organized and sponsored by the Sigma-Aldrich company, which offers a Curie prize. In Japan, the program “Be the Next Marie Curie,” launched by Ochanomizu University in Tokyo,<sup>29</sup> sponsors successful female applicants to study at research institutes in Europe.

### Professional Societies and Awards Named after Marie Curie

In Poland, the name of Maria Skłodowska-Curie has been adopted by the Polish Chemical Society (PTChem),<sup>30</sup> established in 1920, and by the Polish Radiation Research Society (PTBR),<sup>31</sup> established in 1967. The PTChem awards its prestigious Maria Skłodowska-Curie Medal to outstanding chemists per-


manently working abroad, and PTBR grants the Maria Skłodowska-Curie Medal and Award to outstanding foreign scientists involved in radiation research.

On the other side of the ocean there are at least two organizations identified with Marie Curie. The Marie Skłodowska-Curie Professional Women’s Association,<sup>32</sup> affiliated with the Polish National Alliance of Brooklyn, New York, USA, awards scholarships for female high school seniors. The American Association for Women Radiologists<sup>33</sup> presents its annual Marie Skłodowska-Curie Award to an individual who has made an outstanding contribution to the field of radiology. Another Marie

Skłodowska-Curie Award was established in 2008 by the Institute of Electrical and Electronics Engineers,<sup>34</sup> and is granted annually for outstanding contributions to the field of nuclear and plasma sciences and engineering.

Last but not least, the former Eureka Bioscience Database—a comprehensive resource in Bioscience and Medicine—is now known as the Madame Curie Bioscience Database.<sup>35</sup>

### Conclusion

In her diverse capacities as a great scientist, dedicated humanitarian, a successful researcher, a teacher, a wise and tender mother, a loyal citizen of her adopted homeland and a faithful patriot of her mother country, Maria Skłodowska-Curie was perceptive to a variety of human needs and longings. In effect, as a personage of international standing and repute she is a perfect role model for various domains of human endeavour. It is only fitting that different organizations adopt her personality and name as their icon. 

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## Named in Her Honor

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### Endnotes

1. The Institute of Nuclear Chemistry and Technology in Warsaw, established in 1983, formerly operating since 1955 as the Chemistry Division of the former Institute of Nuclear Research. The publisher of the international journal *Nukleonika*.
2. [www.ichtj.waw.pl/drupal\\_eng](http://www.ichtj.waw.pl/drupal_eng)
3. <http://uczelnia.warszawska.pl>
4. Reactor Maria at the Institute of Nuclear Energy in Swierk, was operating from 1975 to 1985. After a refurbishment, it has been operating since 1992. [www.cyf.gov.pl/historia\\_ang.html](http://www.cyf.gov.pl/historia_ang.html)
5. [www.curie.fr/](http://www.curie.fr/)
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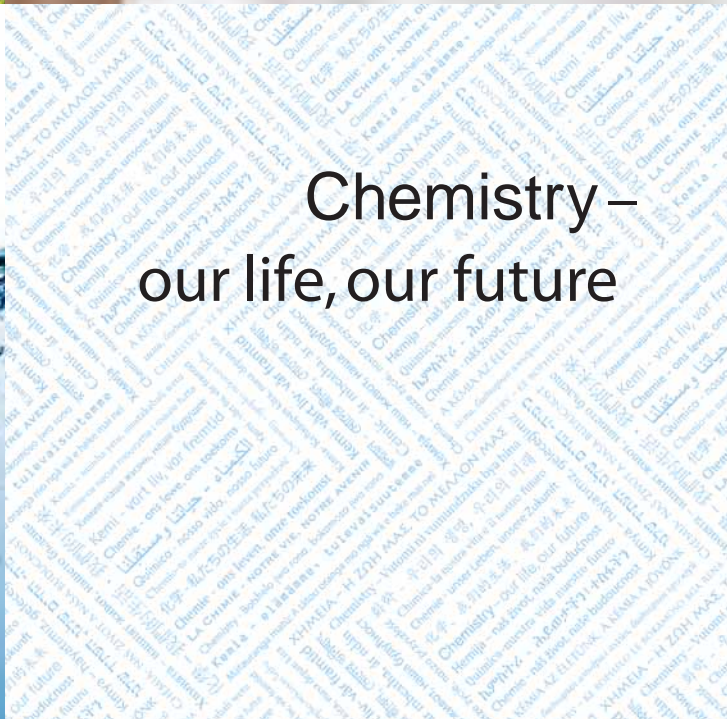
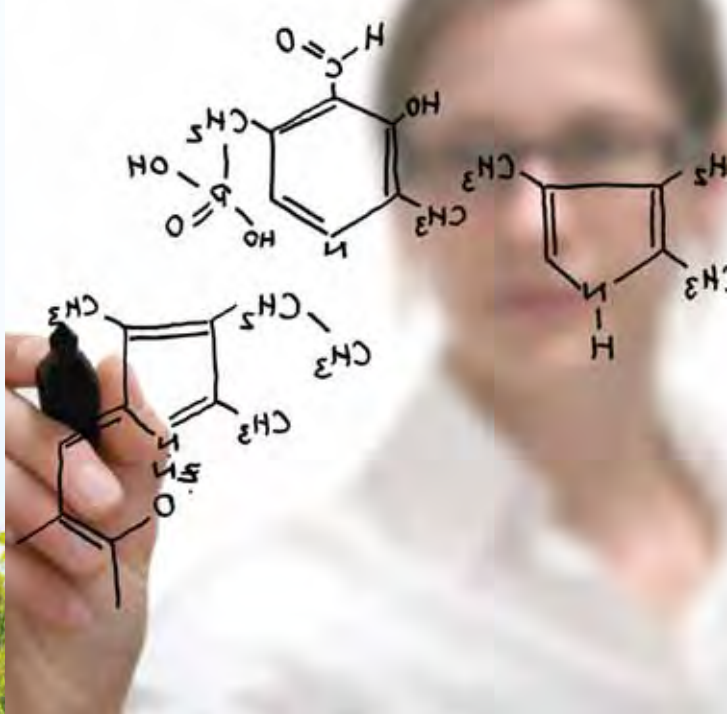
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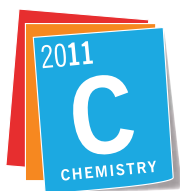
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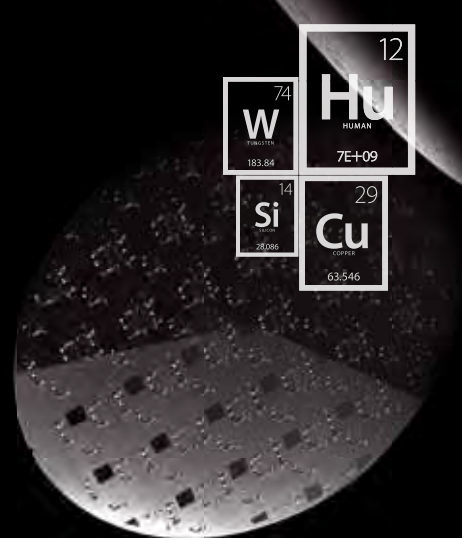



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