

Marie Curie: In the Laboratory and on the Battlefield

This year is the centennial of the Nobel Prize in Physics shared by Henri Becquerel and the Curies for their pioneering work on radioactivity. But Marie Curie's contribution to the medical use of x rays is not widely known.

Lawrence Badash

For nearly a century, physicians have routinely taken x-ray pictures of broken bones or wounds that contain foreign solid materials. So powerful is this diagnostic tool that not to employ it would seem almost medieval. Thus it comes as something of a surprise to recognize that, although there were numerous small-scale medical applications almost immediately after Wilhelm Conrad Röntgen's discovery of x rays at the end of 1895, it took the carnage of World War I, two decades later, to make such radiography widespread.

The surprising instrument of that change, in at least one country, was not a physician. It was, in fact, a physicist whose prior experience with x rays was minimal, a rare female in a profession generally hostile to her sex, and a person widely despised in her adopted country as a foreign predator who had attempted to destroy a colleague's marriage. Marie Curie's life consisted of overcoming one hurdle after another, and her wartime work with x rays was no different. It illustrates not only her great technical competence and perseverance, but also her high level of organizational and managerial skill.

The discovery of x rays

At the time of his historic discovery, Röntgen was a relatively unknown professor of physics at the University of Würzburg in Germany. Working feverishly, secretive even with his own assistants, Röntgen thoroughly explored this strange new radiation, which had a remarkable ability to penetrate opaque substances. Ordinary light could, of course, pass through transparent solids such as glass. But a mysterious emanation that could go through heavy paper, wood, and even sheet metal was something quite extraordinary.¹

Röntgen had initially noticed the phenomenon while testing a cathode-ray tube. The new rays, emitted from the tube but quite distinct from ordinary cathode rays, caused a screen of luminescent crystals to glow in his darkened laboratory. When he placed solid materials in the beam,

their outlines showed on the screen. Seeking to record these silhouettes, Röntgen then substituted photographic plates for the luminescent crystals. The most remarkable photographic images were of his wife's hand: Her flesh appeared dimly outlined, the bones stood out in sharper contrast, and her rings, denser than bone, were clearest of all.

By New Year's Day 1896, a few weeks after his momentous discovery, Röntgen's scientific paper, accompanied by striking photos, was in the mail to leading physicists around the globe. Because the apparatus needed to produce x rays—a Crookes vacuum tube with metal cathode, batteries, a high-voltage transformer and current interrupter, and photographic plates—were common implements in most physical laboratories, the discovery was quickly and widely reproduced.

Newspapers were so delighted with its easily appreciated novelty that this discovery, replete with imagined applications both fanciful and farsighted, became the most famous scientific event of the century, surpassed only by the demonstration of nuclear fission over Hiroshima 50 years later. X-ray instruments were widely marketed. A person could place his hand in an x-ray beam before a luminescent screen and view his own bones through a hooded visor. Thomas Edison, among others, offered this precarious experience as a diversion at amusement parks.

But all was not serene. Some women were reported to be buying lead-lined underwear to foil the x-ray vision of peering physicists. And no one really knew what x rays were. Röntgen himself was quite uncertain, which is probably why he named his radiation X.

The public, largely ignorant of what went on in a laboratory, embraced the image of the scientist that Röntgen represented. When asked by a reporter what he thought when he made the discovery, the professor replied, "I didn't think, I investigated." That is, nature is a book to be read by meticulous investigation, with scientists serving as unbiased automatons merely to record data. Judgment, he seemed to be saying, is not especially important.

Physicians immediately recognized the value of x rays in determining the extent of bone fractures and locating foreign objects. Early in 1896, for example, Gilman Frost, a doctor in Hanover, New Hampshire, aided by his Dartmouth physicist brother, Edwin, used x-ray imaging to set a boy's broken arm. Not long after, Columbia University's Michael Pupin took an x-ray picture, which would become famous, of a New York socialite's hand riddled with shotgun pellets. Before x-ray imaging became a possibility, a surgeon confronted with such a hunting accident would have had to probe painfully and blindly in the bloody pulp

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to feel the metal, bit by bit, and remove it. Now, a picture could show the number of particles and their locations, leading to better surgical technique and faster recovery.

Radioactivity

In early 1896, Paris, no less than other places, was abuzz with talk of the new x radiation. At the weekly meetings of the prestigious Académie des Sciences, Henri Poincaré suggested that all luminescent bodies might be emitting x rays, because the x radiation emanated from the glowing spot on the glass tube that was struck by the cathode ray. That was before better focused x-ray beams were made to emanate from metal targets inserted into cathode-ray tubes.

Becquerel, a physics professor at the Museum of Natural History in Paris and an expert on luminescence, decided to test Poincaré's conjecture. Although most physicists had access to the apparatus necessary to produce x rays, few had anything like Becquerel's access to the museum's collections of rocks that glowed in the dark. He was something of a throwback to the middle of the 19th century, when the study of luminescence in minerals was popular. His physicist father, and indeed his grandfather, had pioneered the subject.

Becquerel's working hypothesis was that some of his minerals might emit the penetrating x rays while they glowed. He therefore wrapped photographic plates in light-tight black paper to exclude visible light, placed luminescent rocks on top of the wrapping, and left those preparations on a window sill so that sunlight could stimulate the rocks. After some hours, he developed the plates and, for a uranium rock, found an exposed area.

That result seemed to confirm Poincaré, and the news was reported to the Académie. Soon Becquerel made images with coins and metal cutouts placed between the uranium rock and the wrapping paper. He noted that the uranium images were fuzzier and required much longer exposures than did x-ray photos from cathode-ray tubes—which themselves took as much as an hour. So these uranium "x rays" hardly seemed promising for medical imaging.

In the following days, Becquerel prepared more rock and photoplate arrangements. But the Paris winter skies remained cloudy for almost an entire week. Awaiting the sun, he stored the preparations in a dark desk drawer. The next meeting of the Académie was approaching, and Becquerel wished to remain in the spotlight. So he developed the plates from the desk drawer, presumably so that he could report that uranium rock does not emit the penetrating radiation unless it's been stimulated by sunlight.

To his surprise, however, the plate under the uranium rock was strongly exposed. Reluctant to abandon his hy-

Marie Skłodowska Curie (1867–1934) in February 1914.



pothesis, Becquerel concluded that his uranium compound exhibited a new phenomenon: long-lived phosphorescence. Subsequent experiments with the rocks continuing to expose photoplates after being kept in a dark box for longer and longer periods, merely confirmed for him that this was a new kind of phosphorescence. Further investigation showed him that uranium compounds that never glow, and even uranium metal itself, generated the radiation. Thus, thought Becquerel, he had extended his discovery of long-lived phosphorescence to metals. In hindsight this is an interesting example of reluctance to consider radical new explanations.

The element uranium, discovered by Martin Klaproth in 1789 and named after the planet discovered just eight years before (the first planet not known in antiquity) did not seem especially interesting. Its principal use was to give glass or pottery a greenish-yellow tint. Because of uranium's great density, attempts were made to incorporate it into military armor.

For unexplained reasons, Gerhard Schmidt at the University of Erlangen began to look into Becquerel's uranium rays in late 1897, after others had lost interest. He then sought to detect similar radiation from other elements, again without explaining his motivation. Among the elements Schmidt tested, only thorium exhibited a similar ability to penetrate opaque materials and ionize air. Neither Schmidt nor Becquerel explicitly labeled these rays as an atomic phenomenon, although their work suggests that they both understood that. In his February 1898 paper, Schmidt did note the high atomic weights of both thorium and uranium.² (See my article in *PHYSICS TODAY*, February 1996, page 21.)

The Curies

Just two months after Schmidt, a physicist in Paris independently announced the discovery of activity from thorium. A systematic worker, she tested a substantial part of the periodic table for such activity. Marie Skłodowska Curie, born in Warsaw in 1867, had the equivalent of master's degrees in both physics and mathematics from the Sorbonne. She also had a husband, Pierre, who was a physicist of international repute, and a newborn daughter, Irène, who would win the 1935 Nobel Prize in Chemistry with her own husband, Frédéric Joliot, for the discovery of artificial radioactivity. Marie had already published one paper on the magnetic properties of steel. That investigation was paid research, but it may also have been a test by her to see if the subject was suitable for a doctoral thesis.

If that was so, the subject proved unsuitable, and she did not choose her thesis topic until the end of 1897.³

Memoirs by Marie Curie and her younger daughter Eve incorrectly suggest that the doctoral topic she did choose was virgin territory.⁴ It is inconceivable that Curie had failed to read papers on uranium rays in the major scientific journals soon after they were published, and delusional to claim, decades later, that uranium's strange emanation was terra incognita. Curie does deserve credit, not for a leap into an unknown realm, but rather for selecting a topic that already seemed to have been exhausted by some of the best physicists in Europe. What she expected to extract from the subject is unclear. It may simply be that she was hoping for some publishable crumbs that would earn her a doctorate while avoiding the competition of a hot field in which she might be scooped and have to start again.⁵

Becquerel's method of detecting uranium rays by their effect on a photographic plate was essentially qualitative. Seeking to make it quantitative, Marie exploited the rays' ability to ionize air. To detect the small resulting current, she used an electrometer of an excellent design created by Pierre and his physicist brother, Jacques, some years earlier. Marie later claimed that she wished to test every element because she was convinced that she was dealing with an atomic property. But the original papers lack such an explicit statement. They merely note that numerous metals, salts, oxides, and minerals were examined. These materials were provided by scientific friends. Fortunately, thorium was among the elements she tested.

Marie's April 1898 paper was more than just a report of thorium's activity. When she tested pitchblende, a uranium ore consisting mostly of the oxide, it caused her electrometer to read higher than it did for metallic uranium. That suggested that another active material was entrained in the ore. So promising was the possibility of discovering a new element that Pierre dropped his own research and joined in his wife's efforts.

The hint of a new element in pitchblende materialized in July 1898, when the couple reported gathering a substance that was 400 times more active than metallic ura-

nium. The amount was too small for standard methods of chemical identification (dissolution and precipitation in various reagents) or for spectroscopic identification, which, along with determination of atomic weight, were the techniques required at that time for acceptance of a new element. On the chance that they did indeed have something new, the Curies proposed to name it "polonium," after Marie's native land.

The April 1898 paper contained something else of note: In it, Marie Curie coined the term "radioactive" to describe the phenomenon. In retrospect, we see that polonium was the first of many elements discovered solely because they were radioactive. Indeed, once the laws of radioactive decay were formulated in 1913, the technique was recognized as sufficient to establish a radioelement's chemical identity.

Polonium remained with the bismuth in pitchblende during numerous precipitations, and was only partially separated from it by sublimation. While performing these tedious purification tasks, the Curies noticed that the barium

fraction was especially radioactive. Gustave Bémont, the chief chemistry-lab assistant at the Paris Municipal School, where Pierre worked, now joined the effort, because the Curies were not skilled analytical chemists. Repeated fractional crystallization yielded a substance of increasing purity and enormous radioactivity, releasing enough energy to glow faintly in the dark. On the day after Christmas in 1898, the trio's paper was read to the Académie, and the name "radium" entered the language.

In the first years of the new century, Ernest Rutherford, the Curies, and a handful of other scientists came to understand that the radiation emitted by radioactive materials consisted of alpha and beta particles and the electromagnetic gamma rays. This small band discovered actinium, "gaseous emanation" (radon), and an assortment of other new radioelements. They learned, among much else, that the alphas and betas were electrically charged and that some radioelements retained their strength over long periods while others gained or lost activity over measurable time.

At the Municipal School, Marie moved her laboratory from a tiny storeroom to an abandoned shed. She needed



Marie and Pierre (1859–1906) Curie, caricatured in a lithograph titled "Radium," in *Vanity Fair*, 22 December 1904. (Gift of H. Richard Crane.)

The Curies with their daughter Irène (1897–1956) in 1904.

more space to spread out the growing number of dishes in which she was concentrating radium by fractional crystallization. The initial steps in the concentration involved back-breaking work: chemically treating large quantities of pitchblende residue (ore from which the uranium had already been extracted) in cauldrons.

Marie, although she was a physicist, became responsible for most of the chemical work, while Pierre focused on the physical examination of the rays. Those were heroic years. In addition to the intense pressure of research and the teaching positions both held, the Curies, in their beloved, dilapidated shed, had to endure freezing cold in winter and stifling heat in summer.

They were also years of other important accomplishments. In 1902, Marie determined the atomic weight of radium as 225, just one unit less than the value accepted today. That was more of a feat than it might seem. Atomic weight measurements were the province of specialists within the chemical fraternity, experts who had mastered esoteric procedures like refining reagents to exacting purity and removing trapped gases from the interior surfaces of their equipment. For an amateur like Marie even to undertake the work was rather daring, and her success was impressive.

Radium's atomic weight, along with its line spectrum, measured by the Curies' friend Eugène Demarçay, fulfilled the criteria for including a new element in Dmitri Mendeleev's periodic table. By that time, however, Marie's research career was largely over. Her scientific work after 1902 consisted mostly of refining established techniques and producing samples of radioactive materials, mostly for medical use.

Pierre also made headlines. With a young colleague, Albert Laborde, he placed one arm of a thermocouple in a tube of pure barium chloride, and the other arm in a tube of unseparated barium and radium chloride. The radioactive mixture, they noted, maintained a temperature 1.5°C higher than the pure barium salt. Public attention was riveted when newspapers turned this 1903 laboratory discovery into "real-world" applications such as the ability of one pound of radium to drive a motor car around the globe. Radium became the exemplar of all radioelements as a cornucopia of energy. It even threatened to undermine a pillar of 19th-century science: the law of energy conservation. But then, the explanation of radioactivity as an atomic disintegration, by Rutherford and Frederick Soddy, came to the rescue.

Radium's fame grew as the public became aware of its enormous cost (about \$100 000 a gram) and its ability to destroy cancer cells. Hospitals sought to obtain a gram for

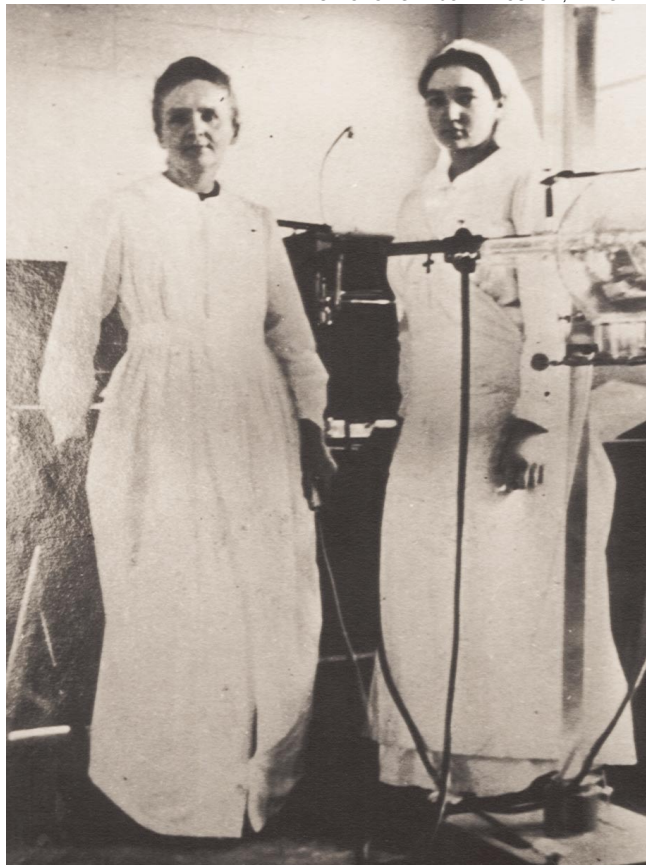


beam therapy or to collect radon, its gaseous daughter product, in tiny tubes that could be surgically implanted in cancerous tissue. The same crystals that Röntgen had illuminated with x rays could also be made to glow by radioactivity. Tiny amounts of radium and those crystals, mixed in paint, could make the paint glow in the dark. This luminous paint was applied to watch dials, light switches, and even to the costumes of nightclub dancers. The patrons could also drink luminous cocktails.

The variety of radioactive medical nostrums seemed endless: pastes, plasters, muds, inhalers, drinking water, and so forth. That few people were injured by this exposure to radioactivity suggests the weakness of the products. The danger was not widely revealed until the 1920s, when some radium watch-dial painters in New Jersey died after "pointing" their brushes on their tongues and ingesting toxic amounts of radioactive paint. But the danger was already known in smaller circles around 1900, when Becquerel received a burn on his waist after carrying a tube of radium in his vest pocket, and Pierre Curie deliberately gave himself a similar burn. Some physicians were alerted by such evidence to radium's clinical potential in dermatology.

While the Curies were not the paupers that some of the mythology suggests, they seem to have poured into their work and gifts of radium whatever was left of their salaries and the substantial prizes they received, most notably their half of the 1903 physics Nobel Prize. 1903 was only the third year in which the Nobel Prizes were given, but the handsome cash awards made the awards famous from the start. The first physics prize, in 1901, was awarded to Röntgen.

In 1900, Pierre had been offered a professorship in Geneva, but unwilling to interrupt their work by such a move, he declined the chair. Ultimately, he accepted a minor chair at the University of Paris, where his main responsibility was teaching physics to medical students. The attraction of the post was better laboratory facilities. At



Marie and Irène Curie (right) with diagnostic x-ray equipment in a French military hospital during World War I.

the time, Marie could not even dream of a professorship, but she was permitted to be her husband's laboratory chief. In 1905, Pierre was elected to the Académie. He had been rejected three years earlier, when he was 43 years old. For such a relatively young applicant, rejection by the Académie was common.

All too soon after Pierre had acquired the new position and facilities, tragedy struck. In 1906, emerging from a professional meeting, Pierre was struck and killed by a horse-drawn wagon. Marie grieved deeply, but with characteristic stubbornness she determined to carry on the work. Public sympathy pushed the Sorbonne to promote her to her dead husband's professorship.

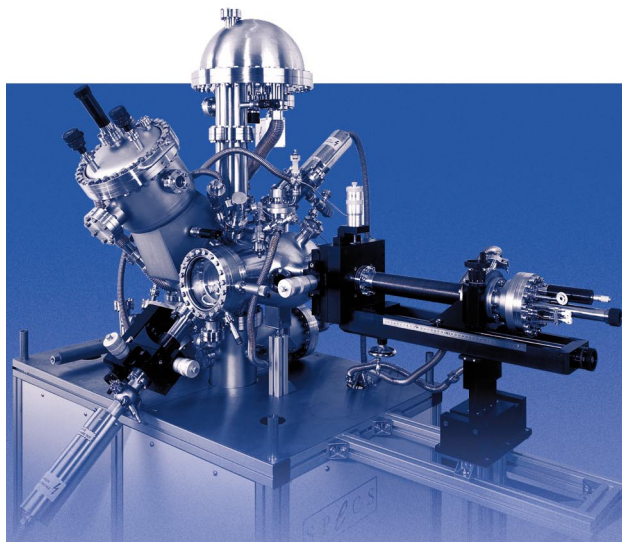
Toward the end of the century's first decade, the still-young widow and her husband's outstanding student, Paul Langevin, became lovers. Unfortunately, Langevin was married—unhappily, but nonetheless married. Portions of the press depicted Marie Curie as a homewrecker and, given her Polish origins, not a true Frenchwoman. At about that time, she was rejected for admission to the Académie, probably because she was a woman. She declined ever to apply again. Even the solo award of the 1911 Nobel Prize in Chemistry did little to mitigate the hostility shown her. (Linus Pauling and John Bardeen are the only others ever to win two Nobel prizes.) But finally, her selfless efforts on behalf of wounded soldiers during the war, or perhaps just the passage of time, put an end to the unfriendly attention.

The Great War (1914–1918)

Physicians had immediately seen the value of x rays in diagnostic (and even therapeutic) medicine. Military

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surgeons were enthusiastic about the “Röntgen-ray apparatus,” and sets were used in military hospitals during Italy’s Abyssinian War (1896), the Greco-Turkish War (1897), the British campaigns at Tyrah and the Khyber Pass (1897) and in the Sudan (1898), aboard a US ship in the Spanish-American War (1898), in the Boer War (1899), the Russo-Japanese War (1905), the Balkan War (1912–13), and in probably every other conflict of that era in which at least one combatant was technologically advanced.⁶

What seems clear, however, is that the medical use of x rays was limited by the supply of instruments and trained personnel. Even in major cities, few units were to be found. Why such a useful technique did not immediately enjoy more widespread application is uncertain. Possibly it was the heavy and unwieldy glass photographic plates, the unsteady x-ray tubes, and other such technological difficulties. Perhaps it was also because physicians and physicists traveled in different circles, and the professional specialty of medical physicist took time to evolve. Curie learned from an eminent French radiologist that x-ray machines were scarce in the army’s medical corps, and those that were available were “rarely in good condition or in good hands.”⁷

Medicine was only then changing from a craft largely taught by apprenticeship to a profession of university-trained specialists willing to adopt the latest instruments. Organizations to promote innovations were lacking. Whatever the explanation for the very limited use of x rays in medicine, Marie’s assertion, in her 1921 book *La Radiologie et la Guerre* (Radiology and the War), that there were very few radiologists in prewar Paris is surprising, even if it’s true.⁸ It took the vastly larger number of wounded in World War I to stimulate demand for more radiological units.⁹

Caring for the wounded was deemed an appropriate task for women. But virtually nothing in Marie’s past experiences prepared her for the role she would assume in the Great War. Her strong social conscience, however, fortified by evidence that radium was a precious medical tool, impelled her to use science and technology in the service of humanity. Radium was of no conceivable use on the battlefield, but x rays had for years shown their value for the type of wounds one sees in war.

Acquiring the requisite expertise with diagnostic x rays was a small step for Marie. But, it required a gigantic leap for her to raise the funds, fight the bureaucracy, get the equipment and vehicles, bring the technology to the battlefield—and do all this as a woman in a male society.



Marie Curie near the battlefield in World War I, with three of the many x-ray technicians she trained for war work at the Radium Institute.

All the major combatants employed x rays, scurrying in the first years of the war to train personnel and equip field hospitals. Curie discussed only France in her book, but we may assume that the problems she encountered were widespread. She called the French radiological services at the start of the war “notoriously inadequate.” Initially, she secured appointment as technical director of radiological services of a private organization. She then leveraged that position into that of radiology auxiliary to the Military Health Service. In that role, she was in charge of training x-ray personnel and became a frequent visitor to hospitals and ambulance stations. Marie not only hauled equipment to these locations, but also set it up and participated in x-ray examination of the wounded—a task in which she was joined by her teenage daughter Irène. Marie even learned to drive, an uncommon skill for a woman in those days, so that she could dispense with the services of a chauffeur.

Military leaders already recognized the value of x-ray units in rear-area hospitals. But they were slow to see their usefulness at aid stations close to the front line. Nor did they think, at first, that more than a few mobile x-ray units would be necessary. But they soon learned that the fast, accurate determination of a wound’s extent made possible by x rays yielded wiser triage choices. And faster and more precise surgery led to speedier recovery.

Private individuals donated many automobiles, which were fitted out to serve as mobile units, powered either by a generator or the car’s motor. Professors and engineers helped install and adjust equipment, while the team accompanying the *voiture radiologique* (also affectionately called a *petit Curie*) consisted of a physician, a technician, and a driver, each of whom could eventually perform some of the others’ tasks.

A typical x-ray unit weighed about 100 kg, not including the power source. The generators could not be standardized, because France used both alternating and direct current, at voltages ranging from 100 to 200 V. Indeed, buildings selected for field hospitals often lacked any electricity at all, which made the mobile units all the more indispensable. A transformer boosted the tube voltage to about 50 000 V, and x-ray imaging was done by both fluoroscopy and photography. For fluoroscopy, which was preferred because of its speed, a physician observed the patient’s wound “in real time” on a fluorescent screen. X-ray photography provided a permanent record, but it required a darkroom—usually in the car!

Indicative of the improvement in x-ray tubes since the

turn of the century is Marie's comment that exposures of only seconds were now adequate for sharp images. Toward the end of the war, the US Army began using Coolidge tubes, which had higher-melting-point tungsten anodes in place of the old platinum anodes and were thus able to produce narrower x-ray beams.¹⁰

Proficient teams could be ready for patients within an hour of arrival on the scene—sometimes even within half an hour. Some individual vehicles provided x-ray diagnosis to as many as 10 000 soldiers during the course of the war. Bone injuries were the most common damage. The x-ray teams were aware, to some extent, of the danger to themselves from radiation exposure, particularly from fluoroscopy. They wore lead aprons and gloves to avoid dermatitis.

The French military trained several hundred technicians. When that number proved insufficient, Marie and Irène produced about 150 more. These were women who were given an intensive six- to eight-week course at the Radium Institute in Paris. It is unclear how novel the presence of these female technicians near the battlefield was.

The statistics that Marie reported in her book on the war work are impressive. By the end of 1918, France had more than 500 fixed and semifixed radiological units, and about 300 mobile units. There were by now some 400 French radiological physicians, with their technicians numbering 800 men and 150 women. In the last two years of the war, almost a million soldiers were examined with x rays.

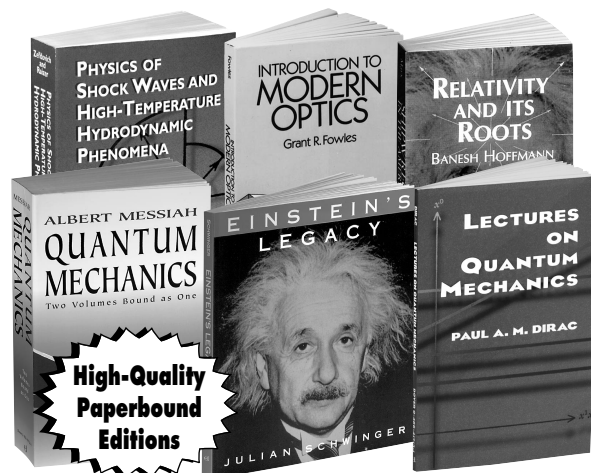
A medical technique that was but modestly employed in 1914 had become ubiquitous four years later. By war's end, no surgeon would think of removing a projectile without precise knowledge of its location. This remarkably fast change in attitude and practice was notably assisted by the efforts of Marie Curie. But it took a war unprecedented for its horrific slaughter of young men to inspire this great lifesaving work.

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