In 1896, stimulated in part by Professor Röntgen’s laboratory-generated rays, Antoine Henri Becquerel (1852–1908) discovered that uranium salts spontaneously emitted rays of an unknown nature. Marie Curie (1867–1934) and her husband Pierre (1859–1906), fascinated by this discovery, began to study Becquerel’s invisible rays. Three years later, the Curies, working with one ton of Austrian pitchblende (uranium ore) at their laboratory at the Municipal School of Physics and Chemistry in the outskirts of Paris, identified two radioactive elements. The first element was named polonium after Marie’s native country, and the second element was named radium. The Curies’ tedious work with pitchblende is a familiar story, as is that of their triumphant announcement to the French Academy of Science on 26 December 1898. Some lines of this communication are as follows:

The various reasons we have just enumerated lead us to believe that the new radioactive substance contains a new element to which we propose to give the name of radium. The new radioactive substance certainly contains a very strong proportion of barium; in spite of that its radioactivity is considerable. The radioactivity of radium, therefore, must be enormous.

In 1901 Becquerel carried a small amount of the radium salts in his vest pocket and subsequently found that an ulcer was produced on the skin of his abdomen, directly under the pocket. Pierre Curie was intrigued by this and, as Marie Curie wrote in her thesis, “he applied a weak radium amount upon his arm for ten hours. A redness appeared immediately, and later a wound was caused which took four months to heal. The epidermis was locally destroyed, and formed again slowly and with difficulty, leaving a very marked scar.” The Curies loaned a small radium tube to Henri Danlos, a physician at the Saint-Louis Hospital in Paris who irradiated a patient with lupus. In 1903 the Curies and Becquerel jointly were awarded the Nobel Prize in physics for the discovery of radioactivity. The nuclear age had begun.

Alexander Graham Bell, in August 1903, wrote a letter to a Dr. Sowers, who subsequently forwarded it to the editor of American Medicine. In his letter Bell suggested the application of “a tiny
fragment of radium sealed up in a fine glass tube and inserted into the very heart of the cancer, thus acting directly upon the diseased material. The discovery of the X rays by Wilhelm Röntgen in 1895 and of radium by Marie and Pierre Curie in 1898 led immediately to cancer therapeutic trials. It appears that the first treatments were carried out with skin and breast cancer, but cancer of the cervix was also among the first cancers in which the new radiation was tried. Remarkable early results in skin cancer and lesions in the oral mucosa led to an explosion of interest in applications of natural radiation to a range of diseases.

Soon physicians in many countries in Europe established radium institutes. In 1906 Louis Wickham, a dermatologist, and Paul Degrais, a surgical pathologist, founded the Biological Laboratory of Radium in Paris. Henri Dominici was appointed as the clinical director with Jacques Danne in charge of physics. In 1907 Dominici demonstrated the different biological effects of the various qualities of rays emanated by radium salts and found that the superficial burn caused by a radioactive substance was due to both beta and soft alpha rays. Moreover, he found that these rays could be filtered by encasing the radium salt in a lead container, permitting the passage of only the “ultrapenetrating” rays with no detrimental effect on healthy tissue. Wickham and Degrais published an English version of their experiences with radium in 1910 (Fig. 7.1). While crossing a street in Paris on a rainy afternoon in April 1906, Pierre

RADIUM THERAPY

BY

DR. LOUIS WICKHAM

Dr. Degrais

Médico de Saint-Lazare, Ancien Chef de Clinique Dermatologique de la Faculté de Paris, Lévée de l’Académie de Médecine

Chirurgien à l’Hôpital Saint-Louis, Lévée de l’Académie de Médecine

TRANSLATED BY

S. ERNEST DORE, M.A., M.D.CANTAB., M.R.C.P.

WITH AN INTRODUCTION BY

SIR MALCOLM MORRIS, K.C.V.O.

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ILLUSTRATED WITH 20 COLOURED PLATES AND 72 FIGURES IN THE TEXT

Fig. 7.1 The English version of the Wickham and Degrais text on radiumtherapy issued in 1910. (Courtesy of the Center for the American History of Radiology, Denver, CO)
Curie was struck and killed by a heavy wagon drawn by two horses. Marie continued her research, determining the atomic weight of radium in 1907 and subsequently succeeding in isolating the element in a pure state (an operation which was never to be repeated). In 1911 she again received the Nobel Prize, this time in chemistry for the discovery of radium, and was the first person to receive the award twice. Marie Curie died in a sanatorium at Sancellemoz on 4 July 1934 of aplastic pernicious anemia, injured by a lifetime's work with radiation.

In 1912 the renowned Pasteur Institute and the University of Paris founded the Radium Institute devoted to the science of radioactivity. It was divided into the Curie Pavilion, directed by Marie Curie, for research in physics and chemistry, and the Pasteur Pavilion, directed by Claudius Regaud, for research in medicine and biology. These two institutions, materially independent, were to work in cooperation for the development of the science of radium. In 1910 the Radiumhemmet (literally, "Radium Home") was established in Stockholm with Gösta Forsell (1876–1950) as its first director. Forsell was to become the godfather of a new specialty using radium in the treatment of disease and would name it brachytherapy in 1931.

Brachytherapy, the treatment of cancer by radioactive sources placed at a short distance from a tumor, was thus born within a short period after the discovery of radium. However, the interest in radium as a cure for cancer created such a demand that its price soared from an already daunting $10,000 per gram in 1904 to $150,000 in 1918. The cost of science was beginning to increase.

**EARLY HISTORY OF RADIUM IN THE UNITED STATES**

As Marie Curie wrote in the 1920s, the radium industry in the United States, accompanied by photographic reproductions of letters which Pierre Curie had received in 1902 from Buffalo, New York. In those letters, engineers wanted to learn the process of radium purifications.

Pierre Curie, after consulting with Marie, had replied most fully (and without reservations as to patents or proprietary claims) to the questions asked by the American engineers.

One of the first published claims to the use of radium was that of Margaret A. Cleaves (1848–1917) of New York. She borrowed two sealed glass tubes of radium, imported from Paris, from Professor Charles Baskerville of the department of chemistry of the University of North Carolina. She treated a patient with advanced carcinoma of the cervix, through the vagina. She also treated a patient with recurrent sarcoma of the cheek and another with a recurrent carcinoma of the scalp. Shortly afterward Robert Abbe, also of New York, used radium imported from Germany to make a vaginal application for carcinoma of the cervix (Fig. 7.2).

In 1903 Francis Williams of Boston, whose book *The Roentgen Rays in Medicine and Surgery* had been received with enthusiasm two years earlier, went to France (Fig. 7.3). Antoine Béclère (1856–1939), who had just translated
Williams's book into French, interrupted his summer vacation to return to Paris and meet the admired American. Williams obtained firsthand information on radium and current therapeutic trials from Béclère and purchased a few milligrams (mg). Upon his return to Boston, he attempted to compare the effects of roentgen rays and radium in the treatment of tumors. He concluded that radium had definite advantages for intracavitary applications. In collaboration with his brother Charles, Williams investigated the possibilities of the use of radium in the treatment of inflammatory diseases of the eye. He also developed an intraoral instrument for the treatment of hypertrophic tonsils by radium.

Another pioneer of radium, Albert Soiland, who had organized the first department of radiology at the University of Southern California Medical College in 1904, traveled to Europe and purchased a plaque of 5 mg of radium suitable for the treatment of cancer of the skin. He remained a dedicated brachytherapist (Fig. 7.4).

The daughter of James Douglas, a Canadian mining engineer and president of the Phelps-Dodge Corporation, was diagnosed with breast cancer in 1907. She was operated on five times in New York but each time developed a local recurrence. Douglas took her to London for treatment with radium, which he obtained privately from Paris at an exorbitant cost. Despite these efforts, his daughter died in the spring of 1910. Soon afterward, Douglas, who was eager to put his money and energy to work in the cancer battle, met with James Ewing, professor of pathology at Cornell University. From a letter written by Ewing in December 1910, it is clear that he discussed the importance of cancer research and was persuaded to donate for this purpose a great deal of money to Memorial Hospital in New York. In addition, because radium was unobtainable in any quantity within the United States, he formed a partnership with Howard Kelly, a professor of gynecology at Johns Hopkins University, and Charles Parsons, director of the United States Bureau of Mines, to found the National Radium Institute to mine carnottite deposits on leased lands in Colorado (Fig. 7.5). From 1913 to 1917 the partnership produced and divided among themselves 8.5 grams of radium. Kelly’s share of radium went to his private clinic serving the Johns Hopkins Hospital, Parsons’s went ultimately to Harvard University and other institutions around the country, and Douglas’s was sent to Memorial Hospital in New York.

Douglas himself experimented with radium in his small laboratory at the rear of his office in the Phelps-Dodge Corporation headquarters. He developed a radium concoction which he drank regularly, applied to his wife's...
Fig. 7.5. Transporting hundreds of thousands of pounds of raw ore from the mines to Denver for refining into radium was a mammoth undertaking, even for the powerful partnership that made up the National Radium Institute. Here, ox carts haul raw ore from the mines to waiting railroad cars, 1914. (Courtesy of the Center for the American History of Radiology, Reston, Va.)

Fig. 7.6 Professor William Duane (1872–1935) and a diagram of his radon extraction plant, designed in 1915. (Courtesy of the Center for the American History of Radiology, Reston, Va.)

feet, and on occasion offered to visitors. Douglas died on 25 June 1918 at the age of eighty-one of pernicious anemia, perhaps related to his radium intake.19

Memorial Hospital

William Duane, professor of physics at Harvard, had perfected a radium emanation extraction and purification plant which made possible the production of glass radon seeds for interstitial implantation.20 Duane agreed to install a model of his plant at Memorial Hospital (Fig. 7.6).21

In 1914 a radium department was established at Memorial Hospital, and Henry Janeway (Fig. 7.7), a surgeon with unusual ingenuity, was charged with developing new techniques of radium therapy. The next year Janeway brought in a young engineering student, Giovanni Failla (Fig. 7.8), as an assistant physicist to take care of the radon plant and study methods of improving radon applications in cancer treatment. Failla learned to operate the plant, but he also learned everything known about radioactivity and its medical uses. Within a short time he became an authority to whom everyone else turned for information. The radium supply increased slowly from 36 mg in 1914 to 4 grams in 1917.22 It became possible to compress radon into capillary glass tubes. The vault for the storage of the radium had been skillfully connected with a pumping apparatus, so that the daily withdrawal of the radon gas for therapeutic use was relatively safe and rarely interrupted.

The year 1917 was noteworthy in the development of radium therapy at Memorial Hospital.23 At first the glass containers of radon had been placed in contact with accessible tumors in the same manner as surface applications of radium. Benjamin Barringer, the urologist at Memorial, now introduced them through the cystoscope and laid them directly on the surface of tumors in the bladder. Janeway provided other surgeons with radon sources for the treat-
ment of malignant tumors of various parts of the body. In the same year Janeway, Barringer, and Failla co-authored a book describing the early results of brachytherapy at Memorial Hospital (Fig. 7.9). The first fifty pages of the book were devoted to a didactic discussion of the physics of radioactivity by Failla. Janeway discussed the principles and methods of the application of radium to cancer and gave details of his experience with cancers of the skin and oral cavity. Barringer gave the results of the irradiation of patients with cancer of the bladder and cancer of the prostate.24

At the same time as these events at Memorial, John Jolly (1867–1933) and Walter C. Stevenson (1877–1931) in Dublin were successful in placing the capillary containers into the lumen of ordinary steel needles.25 This not only provided desirable filtration but, in addition, permitted the interstitial implantation of the radioactive sources into the tumors. Barringer adopted the innovation to facilitate the implantation of radium into carcinomas of the prostate using local anesthesia through the perineum.

In 1918 for the first time small capillary glass tubes containing radium emanation were introduced directly into the tissues through fine trocar needles and left in place—initiating the practice of permanent interstitial radiation. During the same period applicators with dental molding compound were constructed for holding radium in place on the skin and within the oral cavity. Other types of applicators were also constructed to allow the use of similar techniques on the eye and the vocal cords. In the outpatient radium department at Memorial, an average of fifty to sixty patients were seen daily.26

In addition to operating the emulsion plant and the calibration of its products, Failla took an active part in the various approaches and trials with radioactive sources. He developed a machine shop in the basement of the hospital and took delight in the design and construction of all kinds of accessories. Among many other gadgets, he built a bell-shaped lead container to hold radon so that it could be brought into contact with the cervix. The device was used by Harold Bailey (1878–1929) and William Healy (1876–1954), the institution's gynecologists.

World War I interrupted this work, and the young Italian-born engineer was needed for duty abroad. When he returned after the armistice, he was ready in earnest to develop a research laboratory. In 1919, at the insistence of Janeway, the hospital created a department of physics of which Failla was appointed director. In the same year, Edith Quimby (1891–1982) joined as an assistant to Failla. She later wrote that "I was fortunate enough to apply and be accepted for the position and thus started an association which was terminated only when we
both reached retirement age in 1961.  

The Treatment of Uterine Cancer by Radium

The oldest claim to the use of radium in cervical cancer in the United States, to our knowledge, is that of Margaret Cleaves, who apparently used a combination of X rays and radium. In a 1903 publication she stated:

The pelvic case has been under care for three months and has improved to date under the combined influence of the x-ray (internal applications entirely) and ultraviolet light. There is, however, a discharge of blood from the rectum upon defecation and now and then at other times. Because of this and believing that the radium rays would penetrate more deeply than the x-rays, the radium was used. A radium bromide tube was placed in the vagina and allowed to lie on the posterior surface for five minutes, and for an additional five minutes in the anterior wall. A second

five minute application was made a few days later. Five days subsequent to the use of radium, no bleeding, no odor; no discharge, no ulceration and vaginal and cervical mucous membrane are normal in appearance. There has been no bleeding from the rectum since the radium was used.  

Howard Kelly was another pioneer in the use of radium for treatment of gynecological cancers (Fig. 7.10). He devised the cystoscope, the Kelly pad, and rectal and vaginal specula among many related items. He began using radium in 1908, and in the beginning treated only inoperable cases and recurrences after surgery. In 1913 he extended the treatment to operable cases, giving prophylactic treatment before hysterectomy.

Despite the expense of acquiring radium and the difficulties of working with it on a daily basis, a number of clinicians by the 1910s were regularly not-
ing its beneficial effects on their patients. Clark began his radium therapy in 1913 and reported good results in 1917. In 1915 Bailey and Healy began systematic radiotherapy of carcinoma of the cervix at Memorial Hospital. Henry Janeway’s work there, beginning in 1914, with radium in uterine cancer was most notable. He was the first in the United States to advocate radium as the treatment of choice in cervical carcinoma. He developed the technique of burying radium emanation in the cervix, and, in fact, all his work with radium emanation needles was primarily original. His work on conservative surgery plus radium was recognized early, and his paper, “Treatment of Uterine Carcinoma,” remains a classic in the field.

The Founding of the American Radium Society

On 22 June 1916, during the annual meeting of the American Medical Association (AMA), a group of physicians involved in radium therapy met in Detroit and agreed to found a society in which workers in different disciplines would meet and exchange experiences relative to the therapeutic uses of radium. A few months later, on 26 October 1916 in Philadelphia, Henry Schmitz (1871–1939) of Chicago presented the bylaws for a new association, the American Radium Society (ARS), which were approved by the twenty present prospective members. The aims of the society were declared to be the promotion of the scientific study of radium, its physical properties, and its therapeutic applications (Fig. 7.11). William Akins (1859–1924) of Toronto was elected as the first president. It was decided that the society would meet annually for one day before the AMA meeting, with annual dues set at five dollars. In the course of time, eight of the twenty charter members would become ARS presidents. In 1921 the American Journal of Roentgenology became the official organ of the ARS, adding

Radium Therapy to its title in 1923.

The first honorary members were selected in 1921: Marie Curie of Paris, Howard Kelly of Baltimore, and Francis Williams of Boston. The following year, four additional honorary members were chosen: James Ewing of New York, William Duane of Boston, William Coolidge of Schenectady, and Claudius Regaud of Paris. A Janeway lectureship was established in 1933 by the initiative of ARS’s seventeenth president, Burton Lee (1874–1933). The first Janeway lecturer was James Ewing, who spoke on early experiences in radium therapy.

Both radium and X rays were increasingly applied indiscriminately by inadequately trained persons, opportunists, and quack charlatans in these years. As early as 1922 an ARS committee was appointed to seek agreement with other radiological societies to establish an accreditation institution for radiology. It was not until 1933, however, that the American Board of Radiology was founded to protect the public from irresponsible practices and to preserve the dignity of qualified professionals.

1920–1940: Golden Era of Radium

By the early 1920s radium work was done in several institutions in the United States. Marie Curie, in a May 1920 interview with Mrs. Meloney, editor of a New York magazine, stated with some envy that “America has about fifty grams of
radium, four of these are in Baltimore, six in Denver, seven in New York. Mrs. Meloney, after her return to New York, organized in 1921 the Marie Curie Radium Fund—with Robert Abbe among the active committee members—in order to collect enough money to buy a gram of radium as a gift to the discoverer. In 1923, in an official ceremony at the White House, a gram of radium was symbolically presented to Marie Curie by President Warren Harding (Fig. 7.12). The actual gift gram of radium was deemed too dangerous and valuable for a public ceremony.63

During this period, in addition to work by Failla and Quimby at Memorial Hospital, others, including Stensstrom at the New York State Institute for the Study of Malignant Disease (later Roswell Park), Weatherwax at Philadelphia General Hospital, and Glasser and Fricke at the Cleveland Clinic, began the development of radiation physics departments that steadily contributed to the science of radiation therapy. The Mayo Clinic was at the time one of the few institutions in the world where the practice of radiology was divided into three sections: diagnostic roentgenology, therapeutic roentgenology, and radium therapy. Henry Bowing (1884–1953) served as chief of radium therapy. It is of interest that Ralston Paterson’s first exposure to radium therapy came in 1926 when for a month he rotated through Bowing’s department as a fellow at the Mayo Clinic.65

Failla and Quimby during this period studied the production of erythema of the skin in laboratory animals and patients and concluded that the erythema could be taken as a biologic indicator with some degree of accuracy. Failla designed and built an apparatus that facilitated uniform segmentation and calibration of the glass radon seeds in a few minutes. This plant was semiautomatic in operation and greatly lessened the exposure of operators to radiation (Fig. 7.13).

In 1920 Janeway published his experience with the interstitial use of radon seeds in the American Journal of Roentgenology and Radium Therapy, outlining the indications and advantages of this technique.67 He recommended the use of radon in combination with external irradiation in lip and intracranial tumors, rectal lesions;
cancers of the cervix, prostate, bladder, and breast; in primary and metastatic tumors involving lymph nodes; and in sarcomas of the extremities.

In 1922 Quimby published tables of intensity distributions at various distances from point, linear, circular, square, and rectangular sources.²⁸ Within a few years, several other physicists published similar dosage tables, notably Paterson and Parker, who gave the doses in terms of roentgens.²⁹

The principal objection to the use of glass radon seeds, however, was the lack of filtration and inhomogeneous irradiation of the affected tissues. It is of interest that Janeway, who had suffered for twenty-one years from an adenomatosis of the mandible and had treated himself with glass radon seeds, had extensive necrosis of the soft tissues. Failla verified in laboratory animals the necrotic effect on the tissues adjacent to the source.³⁰ Quimby made comparative tests of various metals and found that gold tubes were adequately segmented and calibrated.³¹

Several large radon plants were built in the United States, according to a scheme devised by Failla.³² As a result of the ready availability, radon "gold" seeds became quite popular and were widely adopted and used for permanent implantation.³³

Some pioneering work performed during the late 1920s and 1930s at the General Radium Service of Memorial Hospital is worthy of special mention (Fig. 7.14). Hayes Martin developed "nerve-injection" for the relief of pain and, together with Edward Ellis of the pathology department, made a "notable contribution to the technical problem of obtaining biopsies through needle puncture by aspiration." Many new surgical procedures were devised to meet the "peculiar circumstances incident to radium application, which might well be designated as cancer surgery...laryngotomy for the purpose of accurate implantation of radium rather than for removal of a portion of the larynx...intensive radiation of rectal growths followed by a more limited type of surgical removal...."³⁴

The Dark Age of Brachytherapy

Radium, hermetically sealed in tubes, needles, or capsules, allowed the development of well-established techniques that produced satisfactory clinical results. However, since the radium salt was in the form of fine powder, rupture of the sealed container resulted in dispersal of the active material, with disastrous results owing to the long half life of radium and its high radioactivity.
Moreover, the gamma rays emitted by radium sources were of sufficiently high energy to present a serious problem in personnel exposure.

Despite good clinical results, professional concern regarding the harmful effects of radium exposure, technical difficulties related to source construction and availability, and laborious dose calculations limited the use of brachytherapy to major centers. In the 1940s and 1950s, spectacular technical developments in the field of external beam therapy and improvements in surgical techniques resulted in a declining interest in brachytherapy and a marked decline in its use. Many radiation workers felt that these disadvantages of radium warranted the investigation of other radionuclides for clinical use.

This became possible with the development of nuclear reactors. Enrico Fermi (1901–1954) and Leo Szilard (1898–1964) were among the individuals who produced the first self-sustained nuclear chain reaction leading to the release of nuclear energy, at the University of Chicago on 2 December 1942. The design and development of nuclear reactors, although initially devoted to the atomic bomb and nuclear destruction, had other consequences more important for mankind—the production of artificial radionuclides for a myriad of medical applications.

**Advances Through Atomic Medicine**

Increased production of artificial radionuclides resulted in a variety of commercially available sources for brachytherapy, each with certain advantages and disadvantages. Phosphorus-32 (\(^{32}\)P) was the first artificial radionuclide to be produced in the cyclotron for clinical use in 1936. With the advent of nuclear reactors, however, production of artificial radionuclides was accelerated: gold-198 (\(^{198}\)Au) was produced in 1947, followed by cobalt-60 (\(^{60}\)Co) in 1948; iridium-192 (\(^{192}\)Ir) in 1954; yttrium-90 (\(^{90}\)Y) in 1956; and cerium-137 (\(^{137}\)Ce) in 1957, which in the 1970s replaced radium-226 (\(^{226}\)Ra) as the radionuclide of choice for intracavitary therapy.

\(^{192}\)Ir, in the form of wires and/or seeds, was introduced in 1955 by Henschke as a substitute for radium needles and/or radon seeds. In the early 1960s, however, the United States Atomic Energy Commission (AEC) imposed several restrictions on its use for permanent implantation, and, as a result, the technique was abandoned following 361 implants performed at Memorial Hospital. \(^{192}\)Ir seeds are commercially available today in groups of twelve, spaced a centimeter apart in a nylon ribbon, and have completely replaced radium needles. The use of \(^{192}\)Ir wires, because of concerns about possible radioactive contamination, was also restricted in the United States; yet it became the standard practice for temporary implantation in Europe.

Low-energy iodine-125 (\(^{125}\)I) sources were introduced in 1965 at Memorial Hospital as a substitute for \(^{198}\)Au and \(^{228}\)Ra in permanent implantation. Their soft radiation had the advantage of being well localized and not exposing distant portions of the bone marrow. Localization and dosimetry procedures were developed specifically for these sources and contributed to their increasingly wide utilization for cancer therapy. The first clinical study with \(^{125}\)I was conducted at Memorial Hospital from 1966 through 1967, investigating low energy radionuclides for permanent interstitial implantation and measuring the reduced emission of radiation from their use. A more detailed study followed from 1968 to 1971. A final report was published by the Food and Drug Administration in 1975. The AEC removed the \(^{125}\)I seeds from the investigational procedure list on June 1975.

The availability of new radionuclides made it possible to introduce improved techniques for interstitial, intracavitary, and surface applications and created a renewed interest in brachytherapy.

**Afterloading of Radioactive Sources**

Afterloading, a household word today among radiation oncologists, was first described in 1903 by H. Stroebel, who afterloaded a radium source with

Hilaris
the help of a guide tube implanted into a tumor.\(^{39}\) Abbe is credited with a similar procedure in a 1910 reference.\(^{50}\)

The principle was reintroduced and the method refined and developed further by Ulrich Henschke (1914–1980), first at Ohio State University and, after 1955, at Memorial Hospital in New York. Henschke simultaneously studied medicine and physics at the University of Berlin and graduated in both fields with the highest possible marks in each of the twenty-eight required examinations. From 1937 to 1940 he was assistant to Professor W. Friedrich, the most famous of Roentgen’s pupils. Henschke’s contributions to science were many. His investigations at Friedrich’s Institute for Radiation Research at the University of Berlin led to the first accurate measurement of the roentgen unit using a large pressure chamber.\(^{31}\) At the radiation clinic of the Charity Hospital of the University of Berlin, he pioneered intraoperative radiation therapy of lung and stomach cancers, working together with surgeon E. Sauerbruch, and published on contact X-ray therapy and rotational therapy. Soon afterward he worked at Davos in Switzerland, analyzing the spectrum of the sun rays to determine the cause of skin burning and publishing the biological effects of ultraviolet and infrared radiation. In the early 1950s, after his arrival in the United States and in cooperation with H. Mauch, Henschke developed an artificial leg with a hydraulic system that is still widely used, enabling handicapped people to live more normal lives. “The field of radiation owes a large debt to Henschke for his grand vision. He was a brilliant inventor and innovator, and towards the end of his life a pioneer in bringing effective cancer management to many parts of the third world.”\(^{52}\) Henschke’s major contributions to radiotherapy were the development of afterloading in brachytherapy, the introduction of \(^{192}\)Ir sources for temporary interstitial implants, and the design of a simple double-headed cobalt teletherapy machine, appropriately named Jams and well adapted to third world conditions.

Afterloading of the radioactive sources has been responsible for the present renaissance in brachytherapy, providing greater flexibility of radiation source distribution, greater accuracy and control of the procedure, and enhanced personnel protection from radioactivity. The principle of afterloading consists of two steps: the insertion of unloaded tubes or applicators, and the afterloading with radioactive sources.\(^{33}\) Afterloading techniques are now used throughout the world. Three types of afterloading in brachytherapy should be distinguished:

(1) Operative afterloading, in which radioactive sources are inserted in the operating room after unloaded needles have been placed inside the tumor. This reduces, but does not eliminate, radiation exposure in other hospital areas.

(2) Postoperative afterloading, in which radioisotopes are inserted on the hospital ward hours or days after the implantation of empty needles or tubes. This eliminates all radiation exposure in the operating room, the recovery room, the diagnostic radiology department, and in hallways and elevators of the hospital. However, postoperative afterloading is still burdened with radiation exposure to the nursing staff and anyone who enters the patient’s hospital room.

(3) Remote afterloading, in which radioactive sources are inserted in a special sealed room from an outside control, and no one but the patient is exposed to radiation. Remote afterloading is, therefore, clearly the best technique for interstitial and intracavitary brachytherapy in terms of radiation protection.

Remote afterloading

Remote afterloading was developed in the 1960s along two different lines: high-activity and low-activity remote afterloaders. High-activity remote afterloading was favored by the group at Memorial Hospital from as early as 1961. Small cobalt sources of high activity, moving back and forth, were used to simulate sources of different and longer active length. It was concluded in a paper on
this subject that "...on the basis of our limited experience with such short treatment times in the last three years, we feel that they may be used with impunity if the total dose is divided into more fractions."

A subsequent paper stated that "...moving source remote afterloaders can be used with all gamma emitting radioisotopes, but \(^{137}\)Cs appears most suitable except in the case of short treatment times, for which \(^{60}\)Co and \(^{192}\)Ir are preferable because of their higher specific activity, which in turn permits smaller sources and applicators." The remote afterloader developed at Memorial Hospital in 1964 was commercially marketed by Atomic Energy of Canada under the name Brachytron and was installed in several medical centers, including those at the University of California in San Diego, the University of Southern California in Los Angeles, and the Cancer Center in Beijing. The first model at Memorial Sloan-Kettering Cancer Center in New York was used in the irradiation of tumors of the vagina, nasopharynx, and mouth. It was also used to treat cancers of the cervix and endometrium. The "hot room" consisted of a treatment room surrounded by a thick wall, with a control room on the other side of the wall. Communications between the treatment room and the control room were by closed circuit TV and a speaker system. A lead safe in the wall held the radiation sources—tiny, stainless steel rods containing radioactive cobalt. The rods were welded to the ends of long cables threaded into flexible plastic tubes, which extended out of the safe into the treatment room. In an actual procedure, to irradiate the vagina for example, a hollow plastic applicator was inserted into the vagina and three plastic tubes were connected to it. The medical personnel left the room. From the control room the three sources of radioactive cobalt were advanced electrically out of the safe, through the plastic tubes, and into the applicator. A sensor inserted in the rectum continuously monitored the treatment to avoid overirradiation and damage to healthy tissue. Early results were reported in 1974. This remote afterloader remained in use at Memorial Sloan-Kettering from its installation in 1964 until 1979, when it was replaced by a commercial unit (Gamma Med II).

1980 TO THE PRESENT

In the United States the role of brachytherapy in the last fifteen years has expanded dramatically. This success story is driven by extensive technological development, an increasing number of physicians who practice brachytherapy, and by the interest generated in other specialties due to its undisputed effectiveness. This increased role is reflected in the large brachytherapy literature (more than three thousand brachytherapy citations for the past ten years alone); the formation of the American Endocurietherapy Society (AES), which lists more than four hundred members; and the journal Endocurietherapy/ Hyperthermia Oncology (E.H.O.) which has been published under AES auspices since 1988.

The introduction of computer technology and the resulting ability to produce radiation dose distributions projections individualized for each patient has tremendously increased the accuracy of brachytherapy. Commercially-produced high dose-rate (HDR) units, optimization of brachytherapy, three-dimensional brachytherapy planning, and ultrasound-based real-time planning are now becoming available and are being investigated intensively. New radionuclides with lower energy, improved physical dose distribution, and radiobiological effectiveness were introduced in the 1980s: palladium-103 and \(^{137}\)Cs as alternatives to \(^{125}\)I, ytterbium-169 as an alternative to \(^{123}\)I, and americium-241 intended to replace \(^{137}\)Cs. Dose rates varying from low dose-rate (LDR) to HDR and/or pulsed (PDR) brachytherapy—which allows a pulsed variable low dose rate—are currently being explored.

The development of integrated brachytherapy units which will combine all steps required for the performance of a procedure are also being actively pursued. Such efforts attempt not only to integrate all the various pieces of equipment but also to inte-
grate the information flow and medical procedures, provide a sterile environment, and coordinate the activities of the surgical facility, fluoroscopy, radiography, treatment planning, and HDR afterloading treatment.\(^{29}\)

Tumor models developed in the laboratory offer a reliable quantitative approach for the evaluation of various combinations of brachytherapy, chemotherapy, and/or immunotherapy in an attempt to eradicate tumor cells at local and distant sites while decreasing morbidity. The realization of these goals will definitely have an impact on the future utilization of brachytherapy alone or in combination with other cancer modalities as we enter the next century.

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33. del Regato, "American Radium Society.
34. Curie, E., Madame Curie.
35. Ibid.