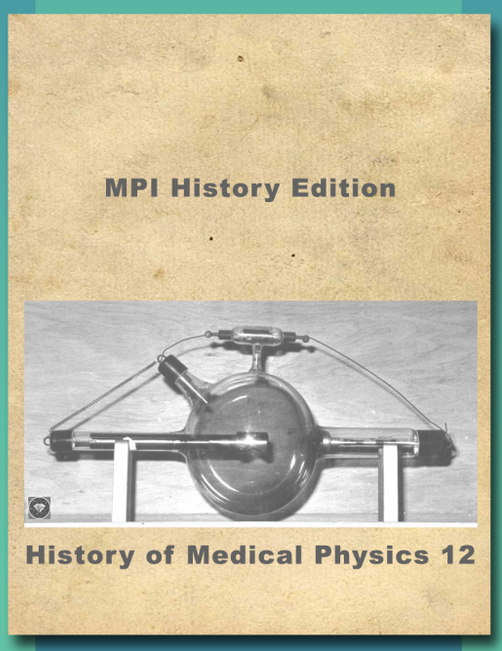
# MEDICAL PHYSICS *International*






**The Journal of the International Organization for Medical Physics**

**History Edition 12, June 2026**

MPI

# MEDICAL PHYSICS INTERNATIONAL

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**THE JOURNAL OF**

**THE INTERNATIONAL ORGANIZATION FOR MEDICAL PHYSICS**

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**MEDICAL PHYSICS INTERNATIONAL**
The Journal of the International Organization for Medical Physics

**Aims and Coverage:**
Medical Physics International (MPI) is the official IOMP journal. It provides a platform for medical physicists to share their experience, ideas and new information generated from their work of scientific, educational and professional nature. The e-journal is available free of charge to IOMP members. MPI- History Edition is dedicated to History of Medical Physics.



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# EDITORIAL

Slavik Tabakov, Perry Sprawls and Geoffrey Ibbott - Co-Editors-in-Chief of MPI History Editions

This issue of the *Medical Physics International History Edition* (MPI-HE), previously known as *MPI Special Issues* published materials about the history of medical physics. Starting in 2018 MPI-HE attracts thousands of readers per month at http://www.mpijournal.org/history.aspx . The articles published in this Journal MPI-HE 12, 2026 have a major focus on Radiotherapy physics (with contributions arranged mainly by G Ibbott). Additionally it includes papers relate to activities related to medical physics education. As in several previous MPI-History issues, a number of articles here are made in collaboration with the AAPM History Committee.

**The History topics extensively covered in MPI-HE so far include:**

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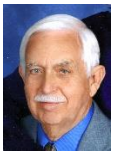
MPI-HE 11 - http://www.mpijournal.org/pdf/2025-HE-11/MPI-2025-HE-11.pdf with papers on history of Neutron therapy; Nobel prize winners related to medical physics; Medical Doyens; Edinburg medical physics contributions.

The content of the MPI-HE (previously known as Special History Issues) of the Medical Physics International (MPI) Journal supports the objective of the History project: to research, organize, preserve, and publish on the evolution and developments of medical physics and clinical applications that are the foundations of our profession. Our young medical physicists and students will benefit from getting to know our pioneers. This can be achieved by sharing these articles and including presentations and discussions within your education and training programs. We are grateful to all authors who submitted papers and to the Technical Editor M Stoeva. We welcome contributions of colleagues from all societies, organizations and companies who would like to join the History project with articles on specific topics.


Prof. Slavik Tabakov


Prof. Perry Sprawls


Prof. Geoffrey Ibbott

# SMALL SOURCES, BIG IMPACT: WHAT BRACHYTHERAPY SOURCES ARE REALLY MADE OF

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*Abstract*— **Following the discovery of radium in 1898, the scientific community set out to procure as much of the radioactive material as possible in Europe, the US, and the rest of the world. Radium, in the early 20th century, was considered the most valuable substance on earth. The mining, processing, standardization, and encapsulation of the world's first brachytherapy source is a journey through geology, chemistry, and physics.**

*Keywords*— **brachytherapy, brachytherapy sources, brachytherapy source construction, radium, radon**

## I. Introduction

Most radiation physicists are well acquainted with the discovery of radium-226 by Marie and Pierre Curie in 1898 and the subsequent award to Marie Curie of the Nobel Prize in chemistry for her work isolating radium. What is less often shared is the complex process of mining and procuring radium and radium byproducts for medical use. Radium and its daughter product, radon-222, were the preferred radioactive materials used during the early 1900s because they were isolatable from rocks and ore containing uranium, had comparatively long half-lives, and had detectable radiation emissions. In Europe, most uranium deposits were found in pitchblende, also known as uraninite. It has a dark, heavy appearance and resembles black tar or pitch. In the US, it was primarily found in mineral carnotite, which is famous for its canary-yellow coloring. This paper will describe how radium and radon were extracted in Europe and the US and how they were used for medical purposes in the early 20th century.

## II. The hunt for radium in europe

In the decade following its discovery, radium's potential as a medical and imaging device caused great excitement. Marie Curie and her colleagues desperately needed more radium to advance scientific study and medical experimentation. Uranium minerals had been mined since the mid-1500s in the Ore mountains along the modern Czech-German border, long before the formal 'discovery' of uranium in 1789. [1] Pitchblende was initially applied in the glass-making industry for the creation of yellowish-green glass, known as 'uranium glass' or 'Vaseline glass'. After the discovery of radium, large uranium mining areas, such as those in Bohemia (Austria), switched their operations to focus on radium ore extraction. [2]

### *A. The process of extracting radium from pitchblende*

Compared to carnotite found in North America, pitchblende contains more uranium (in the form $UO_2$) and is not contaminated with vanadium. Rather, it contains lead and rare earth elements. The radium is not part of the surrounding rock but is embedded in the ore structure itself due to natural radioactive uranium decay. Pitchblende also contains large amounts of barium. The radium must be chemically released before it can be separated. First, the pitchblende is crushed and treated with boiling sulfuric acid. Acid dissolution removes the uranium as $UO_2SO_4$, leaving radium behind in the solid residue or sludge, which can then be converted to carbonates - and ultimately salts. The chemical process of extracting radium from pitchblende is similar to the extraction from carnotite (described in more detail in Section III). However, unlike radium separation which happens immediately with carnotite, radium extraction is the last stage when processing pitchblende - after the removal of the uranium, lead, and other metals. As described in her PhD thesis, it took Marie Curie 3 years to isolate just 0.1 gram of pure radium chloride from several tons of pitchblende. [3]

### *B. Isolation of metallic radium*

After the mining and production of radium salt became routine, it was important to isolate radium to confirm its properties and place it properly on the periodic table. Isolated radium was also required to characterize the emission spectra. Marie Curie used electrolysis to isolate metallic radium from a radium chloride solution in 1910. When passing current through a radium chloride solution, the radium ions migrated to the cathode, and a radium-mercury amalgam was created. As mercury has a much lower melting point (357°C) than radium (700°C), the mercury could be distilled in a heated, hydrogen environment or a vacuum, leaving behind pure radium metal. Radium was kept in salt form for storage and stability purposes as metallic radium is too chemically reactive to handle safely in air or water.

### *C. Radium production in Europe and WWI*

In 1911, Austrian mines of St. Joachimsthal (now Jáchymov in the Czech Republic) produced 2.65 grams of radium chloride and processed the ore in their own radium factories. [4] The New York Times stated the world's supply of radium in 1913 amounted to "not more than 6 or 7 grams" as reported by a French scientist. At that time, Marie Curie was identified as the chief holder with approximately 2.6 to 3 grams of radium. [5] Unlike the US, where radium production was commercialized by private corporations, Europe reserved its supplies through state monopoly to benefit research and medicine. Austria nationalized their mines and stopped the export of uranium ore in 1904. Radium production dropped after this time to less than one gram annually. This was unfortunate as 1 gram of radium could be obtained from 5-6 tons of pitchblende as opposed to 500-600 tons of carnotite. [2] Production decreases were due to export limitations and the start of World War I. In parallel to the escalation of hostilities in Europe, the demand for radium shifted from medicinal to practical. When mixed with zinc sulfide, radium would glow and was thus widely incorporated for military purposes. By 1918, military use accounted for 95% of the radium produced in the US. [6]

Unknown at the time and not revealed until after the completion of the war, the Shinkolobwe mine in the Belgian Congo (now known as the Democratic Republic of Congo) contained exceptionally rich ore containing up to 65% uranium oxide. European deposits averaged between 0.5 and 5% uranium, and North American ores were approximately 1%. Use of the Shinkolobwe mine caused the price of radium to drop by over 50% by the early 1920s. This ore deposit was critical in supplying uranium for the Manhattan Project several decades later.

## III. The hunt for radium in the US

After Marie Curie's discovery, US mining operations also pivoted to take advantage of the new market. Carnotite that was already being mined in Colorado for heavy metal extraction was sent to France for analysis and was identified as containing radioactive uranium in addition to the heavy metal vanadium. [7] For a few years following this discovery, carnotite was mined in the US and then shipped to Europe for radium extraction, which was a very inefficient process given the quantity of ore required to produce a small amount of product. Radium mining and extraction in the US started around 1910 and was considered large-scale by 1911 with the founding of the Standard Chemical Company (SCC) by Joseph Flannery. [2] The production of radium was essentially a spin-off of Flannery's carnotite ore business named the American Vanadium Company, which he owned with his brother James. The American Vanadium Company was mining carnotite ore for use in the steel and glass industries, but the development of carnotite as a source of radium resulted in a new business venture. Flannery was motivated beyond financial reasons; the previous year his sister was diagnosed with uterine cancer. Following a trip to Europe, he learned that cancers could be treated with radium, but the supply for the medical industry was critically low. Furthermore, Europe had enacted an embargo on pitchblende exports, so Flannery realized that any radium for medical purposes in the US would have to come from US deposits. The SCC established mines in the Colorado region and transported ore by train to a processing plant in Pennsylvania.

### *A. The process of extracting radium from carnotite*

As mentioned previously, the extraction from carnotite was similar to extraction from pitchblende, mostly due to Europeans inventing the pitchblende process but not patenting it. Carnotite is a naturally occurring potassium uranium vanadate mineral with a chemical formula of $K_2(UO_2)_2(VO_4)_2\ 3H_2O$ and contains around 50% uranium. A bright yellow radioactive material often found in sandstone, carnotite was primarily located in the high plateau region of the US including deposits in western Colorado, eastern Utah, and Wyoming. [8] The target radium, along with trace amounts of barium, exists in the host rock. Carnotite deposits at the time were thought to contain approximately 3.5 – 15 mg of radium per ton. [9] To isolate radium, one method was to dissolve the other materials and precipitate the radium in a sludge or slime. Several different methods to extract radium existed at the time and the precise chemicals used varied from plant to plant. [10] In one example, the carnotite ore was first crushed and then leached (*i.e.*, dissolved and separated by a solvent) with sulfuric or nitric acid. [11] The result was a solution of dissolved uranium, vanadium, and radium called a "pregnant liquor" or "pregnant leach solution":

$$K_2(UO_2)_2(VO_4)_2 * 3H_2O + 4H_2SO_4 \rightarrow 2UO_2^{2+} + 2VO_2^{+} + 2K^{+} + 4SO_4^{2-} + 7H_2O + RaSO_{4(S)} + BaSO_{4(S)} \quad (1)$$

The target $RaSO_4$ and $BaSO_4$ were left behind as an insoluble residue, called "slime," immediately following the acid leaching. If there were not enough naturally occurring barium, barium chloride could be added to the liquid to precipitate radium and barium sulfate. [12]

For completeness and interest, the process of uranium oxide separation will be briefly described, as it was important to extract and use these other metals from Equation (1) for financial reasons because radium extraction was inefficient and complicated. Remaining impurities were removed from the solution through separation chemistry by filtration and the addition of lime or limestone (*i.e.*, calcium carbonate) that solidifies metal byproducts which can then be removed. The remaining solution containing liquid uranium and vanadium compounds is doused with ammonia or other materials to precipitate the uranium as ammonium diuranate. Carefully controlling the pH of the solution allows separation of uranium and vanadium. The precipitate is centrifuged before

being calcined (*i.e.*, thermally treated to remove oxygen) to a stable uranium oxide commonly known as "yellowcake."

$$(NH_4)_2U_2O_7 \rightarrow U_3O_8 + NH_3 + H_2O \qquad (2)$$

A graphic of this complicated process is shown in Figure 1. The mildly radioactive yellowcake could then be packaged and shipped to a refinery. Modern use of yellowcake includes producing nuclear reactor fuel. Further processing of the original solution would eventually precipitate the vanadium for commercial use in steel and iron production.

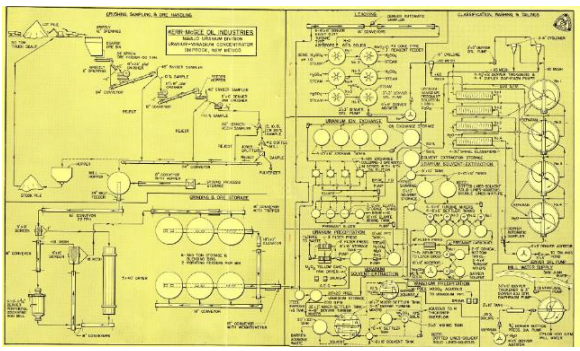

Figure 1: Flowsheet of the "Raw Leach" extraction method [13]

Continuing from the radium rich slime - it was difficult to separate the barium sulfate (99% by weight) from the radium sulfate (1%) as they are both Group 2 alkaline earth metals and react similarly. [14] The next step was turning the precipitates into soluble forms through the addition of sodium carbonate or soda ash. Once the residues were boiled with soda ash, the insoluble radium sulfate converted into soluble radium carbonate. Carbonates were desirable because they are generally more reactive to acid-base reactions than sulfates.

$$RaSO_4 + Na_2CO_3 \rightarrow RaCO_3 + Na_2SO_4 \qquad (3)$$

It was then dissolved with hydrochloric acid:

$$RaCO_3 + 2HCl \rightarrow RaCl_2 + CO_2 + H_2O \qquad (4)$$

Using a fractional crystallization technique, the solution would slowly crystalize. The radium carbonate was slightly less soluble than the barium carbonate, allowing separation of the two compounds over thousands of iterations. The radium would finally be isolated as $RaCl_2$, also known as radium salt.

*B. Radium production in the US*

By 1913, the shortage of radium for use as a medical product in the US and Europe was indisputable. Political discourse arose over the privatization of mining operations and the US Secretary of the Interior, Franklin Lane, got involved. James Douglas, a mining engineer and industrialist, and Dr. Howard Kelly joined together to incorporate the National Radium Institute (NRI), which was a private institute that partnered closely with the US Bureau of Mines (with Lane as the cabinet official overseeing it). Kelly, a physician at Johns Hopkins University, wanted to use radium products for the treatment of gynecological diseases. Douglas had his own, personal interests in procuring radium – his daughter was treated for cancer in England during 1911. Douglas made many financial donations to Memorial Hospital (later known as Memorial Sloan Kettering) with the stipulation that the center should focus on treating cancer with radiation. In conjunction with the Bureau of Mines, the NRI leased land in Colorado and built their main production plant in Denver. None of the radium produced through this plant would be available for shipping and selling abroad. Lane continued his attempts to develop a radium supply from both public and private lands, which affected the success of the SCC. Lane publicized their extraction methods through Bureau of Mines publications (conveniently used in this document) rather than keeping them a secret.

The NRI/Bureau of Mines method utilized a similar procedure to that described above in their extraction operations. In terms of efficiency, a report from the US Department of the Interior described a total US production of 28.8 tons of uranium oxide containing approximately 9.77 grams of radium chloride in 1912. [4] The 1910 market price of radium was $120,000 per gram. [8]


Figure 2: Carnotite ready for shipment to the SCC [2]

By late 1915, Lane announced that 5 grams of radium had been extracted in Denver. Half went to Kelly's clinic in Baltimore and the Memorial Hospital in New York. After sustaining political pressure from Flannery and the SCC, the NRI plant closed in 1917 after producing a total of 8.5 grams of radium and processing 1500 tons of uranium ore. Also in 1917, the United States Radium Corporation was founded in New Jersey to process carnotite ore and later became infamous for the radiation sickness of dial workers. [15] By 1920, 90% of the world's radium supply came from the US, which was remarkable given that far superior radium yield from pitchblende. [2] In 1921, Marie Curie visited the US and received a gift of one gram of radium (mined by the

Flannerys), presented to her by President Harding. By 1921 SCC had produced half of the world's radium. [16] Following the breakup of their monopoly and the publicization of the high-grade deposits in Europe, the SCC ceased radium production in 1922 and focused instead on uranium reclamation.

## IV. DEVELOPMENT OF CALIBRATION STANDARDS

It soon became clear that there was a compelling need to establish a radiation standard; for example, one report noted that no other material on the open market offered a better chance for fraud due to the inability of the average chemist to tell whether the radium salt was pure or not. [4] In 1912, the price of radium salt was $70 per mg, corresponding to $2,000,000 per ounce (approximately $70 million dollars in 2026 US dollars). The fraud went beyond financial repercussions as physicians noted treatment outcomes being influenced by misrepresented quantities of radium as well. [17] Initial methods of standardization involved comparing darkening of photographic plates. Another method was to measure the radioactivity via electroscope and ensure that the radium was 2,000,000 times as radioactive as a similar weight of uranium oxide. The Curie method involved measuring the ionization of air. [18] Using a Quartz-Piezo electrometer, Curie could measure currents induced as small as $10^{-12}$ amps detecting radium in ore in the one part per million range.

In 1910, the International Radium Standards Committee was formed in Brussels to establish more robust standards for radium. Key members included Marie Curie, Ernest Rutherford, Otto Hahn, and American radiochemist Bertram Boltwood. The first order of business was to establish a unit for radioactivity. All agreed on the use of the "Curie" in memory of Pierre Curie that was equivalent to the quantity of $^{222}$Rn in equilibrium with one gram of its parent $^{226}$Ra. [19] Of note, the elemental name of radon was not accepted until 1923, and it was known mostly as an "emanation" or "radium exhalation" during this time period.

The second goal was to establish an international standard for radium that could be used across the globe. This was highly important for medical uses and intercomparison of treatment methodologies. The physical "standard" as prepared in Paris by Marie Curie was 21.99 mg of radium chloride sealed in a glass tube and stored at the International Bureau of Weights and Measures (BIPM) in France. [20] In 1912, the original standard was compared to three similarly constructed devices manufactured in Vienna by evaluating the gamma-ray emission rates and thus created several secondary standards. In 1913, the US National Bureau of Standards (NIST) received a secondary standard certified to contain 20.28 mg RaCl, equivalent to 15.40 mg of Ra as shown in Fig 3.

COMMISSION INTERNATIONALE DES ÉTALONS DE RADIUM.

CERTIFICAT.

Figure 3: Certification of Curie standard received by NIST [19]

Following the calibration standardization of sources came early attempts at treatment standardization, at least within a particular institution. The Radium Institute of London attempted to standardize treatments with their radium applicators. A "full strength" applicator represented 0.5 cg of radium bromide covering 1 cm$^2$ of surface area, "half strength" was 0.25 cg of radium, and "quarter strength" was 0.125 cg. These were eventually modified to match the colloquial naming convention of full being =1 cg, half = 0.5 cg, and quarter =0.25 cg. [21] Other less rigorous methods involved prescribing a qualitative skin erythema dose or watching for moist desquamation and necrosis. The Roentgen, or R, was not defined until 1928.

## V. ENCAPSULATION AND APPLICATION

As soon as it was discovered, radium was used to treat various maladies. At the time, it was understood that radium possessed α, β, and γ emissions and each had different penetrating power. In 1901, Parisian Danlos and colleagues started applying radium sulfates (gifted by Pierre Curie) directly to skin lesions. However, to prevent radium salt loss, the material had to be stored in some sort of container. He used small glass tubes containing radium salt or radium sulfites covered in rubber sheathing. [22] Alexander Graham Bell suggested in 1903 to seal the radium in glass tubing and implant within a tumor. [23] Radium could also be mixed with a varnish and painted over a surface for topical application.

In Figure 4, radium was enclosed in a brass case with a 0.01 in. thickness of aluminum for all radiation emanations to pass through, and a 0.1 in. lead backing, to act as a "screen".

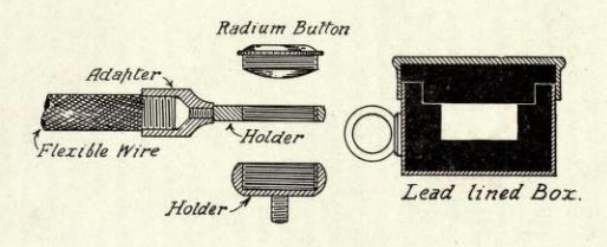


Figure 4: Example of an early radium applicator [24]

The outside of the radium button had a screw threading where it could be placed on a holding device and inserted into small holes of the body, such as the nostril or larynx. The holder was for use in external applications, carrying the radium at the end of a brass rod with a lead shield to protect the hand of the treating physician.

Other methods of "screening" or filtration were noted in skin applications where a variety of materials were used, including shoe leather and asbestos. Applying such materials to absorb the alpha and lower energy particles was associated with better cosmetic results. [25]

The radium salts such as those shown in Figure 5 were often put into platinum tubes with a wall thickness of 0.5 mm. Attempts were made for a 0.3 mm thickness, but it was challenging to embed a screw thread at such a small thickness. It was known that the use of this thickness of platinum would absorb 75% of the β emissions and 4% of the γ rays. The tube was then filled with the powder, and a screw plug was gold-soldered into position. Care had to be taken to "tin" the thread with gold before screwing in the plug or the emanation could escape. [26] The efficiency of the seal could be tested by leaving the source in a box for a few days and then testing to see if the box itself became contaminated. Radium tubes were most often used in external applications (surface/skin), intracavitary (nose, vagina), or implanted surgically. The use of radium tubes and needles were short lived for practical reasons, as will be described below.

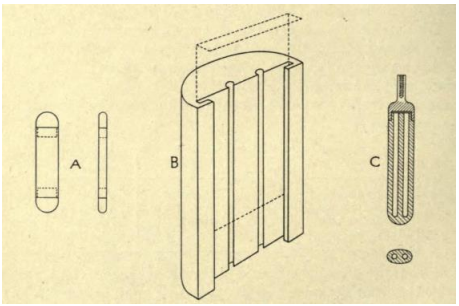


Figure 5: A) flat applicator for use with radium salt in the dashed lines. B) silver applicator bored out for use with two tubes of radium salts and ten platinum shutters that could be slid down. C) oval section filter, also for use with two tubes. [26]

## VI. FROM RADIUM TO RADON

Radon, in its unnamed state, was discovered almost in conjunction with radium as scientists knew that "something" was being emitted. Its discovery is attributed to both German scientist Friedrich Dorn and the team of Rutherford and Owens at McGill university. [27] It was further understood in London during 1903-1904 that radium was "giving off" helium (See Fig. 6). [24]

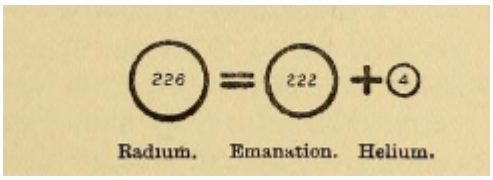


Figure 6: An emanation and an α particle [28]

Radon was finally isolated by Ramsay and Whytlaw-Gray in 1911. They also subsequently determined the density and atomic weight of the gas. Radon was given its official name in 1923.

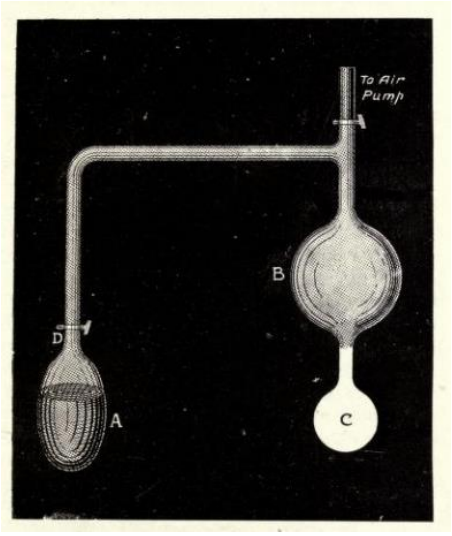


Figure 7: Method for radon gas isolation [24]

Curie's method to isolate radon gas via condenser is shown in Figure 7. The source (bulb A) contained radium bromide in solution that undergoes α decay, constantly producing radon gas. Air was removed from bulbs B and C, which were coated with zinc sulfide. While the stop cock (D) was closed, a vacuum was created. When the stop cock was opened, the particles struck the coating and acted as a scintillator. By immersing bulb C in liquid air (~200°C), the radon gas would condense (radon's boiling point is -61.7°C). The rest of the gases were then pumped away, leaving isolated pure radon. This method was nicknamed the radium "cow" because it could be milked every few days.

Radon was instantly used in a therapeutic manner, as being a gas, it could be sealed in capillary glass tubes that were

smaller than radium tubes (Fig 8). One Ci of radon occupies less than 1 $mm^3$ in volume at standard temperature and pressure, thus a radon needle could be much thinner than a radium one. [29] Additionally, once radium was procured, the amount of radon that could be acquired and used was virtually endless. The glass tubes were 3-4 mm in length, 0.3-0.4 mm in diameter, and the glass thickness was on the order of 0.1 mm. With a higher specific activity than radium, radon emanations were able to treat malignancies faster. It was found that these tubes could also be permanently implanted in tumors and left to decay. [30] Interestingly, these sources were assumed to be point sources and the inverse square law was applied to calculate radiation intensity.

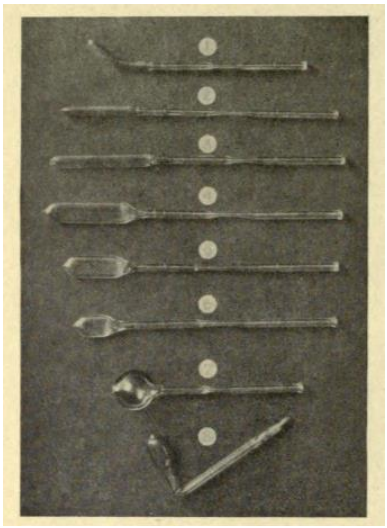

Figure 8: Small glass and platinum tubes used for radon treatment. [26]

The shift away from radium tubes and needles continued as they were prone to leaking; micro-leaks allowed radon gas to escape, which would leave radioactive dust everywhere (even in this early period, it was identified as a health hazard). It was also due in part to the need to off-gas the helium build-up inside tubes and needles. Radium tubes exploding due to internal pressures up to 20 atmospheres were not only a financial loss to the institution of the radium source, but also a radiation safety incident (though little was known about all of the related risks at the time). [31] Marie Curie was aware of the build-up of helium in 1912 when developing the radium standard, and she recommended source venting every 15 years. [20]

In 1915, the first radon plant in the US was built at Massachusetts General Hospital (MGH) in Boston under Dr. William Duane. He had studied with Marie Curie in Paris and became interested in radium byproducts, namely radium milk or radon gas. Memorial Hospital soon followed and began using radon-filled needles for the treatment of prostate cancer as early as 1915, though they didn't have their own radon plant at the time. In 1917, Duane helped establish the Memorial radon plant after a radium gift from James Douglas and the NRI. [32] The first director of medical physics at Memorial, Dr. Failla, trained with Marie Curie and developed his own radon collection system. He hired the soon-to-be famous Edith Quimby in 1919, who would be instrumental in establishing systems of dose calculations. [33]

## VII. INITIAL DOSING SYSTEMS AND FILTRATION

Initially, the methodology for a radium dosing system was extremely rudimentary:

$$\text{Dose (mg} - \text{hr)} = Q(mg) * T(hr) \tag{5}$$

Where Q was the amount of radium bromide in milligrams (not "radium element") and T was the exposure length in hours. [34] Of course, this did not consider the effects of filtration or of the encapsulation of the source. It also did not specify the type of application or malignancy to which the radium would be applied.

Failla's team modified the above equation for use with radon glass tubes, incorporating the absorption by tissue and decay of the radon in the tubes. Equation 5 was thus modified to:

$$\mathrm{Q}_x = kI_x * T * R_{av} \tag{6}$$

Where $Q_x$ was the quantity of radiation absorbed by an elemental volume of tissue at distance x from the center of the source; $I_x$ was the radiation intensity at distance x; T was the duration in hours; and $R_{av}$ was the average value of radon in mCi during time T in hr. The factor k was a constant associated with scattering properties of the source and medium. [30] With these radon seeds, the critical time-activity relationship was defined in mCi-hr.

While glass tubes were cheap and easy to work with, they resulted in overdoses and necrotic tissue. Failla discovered that replacing the glass with 0.3 mm gold tubing filtered out most of the beta rays (that were unneeded therapeutically) and thus gold seeds began to replace glass ones. They were also more durable than glass. Failla's team was instrumental in laying the foundation for modern brachytherapy dosimetry. In his landmark paper "Dosage in radium therapy" he proposed that radiation doses should be expressed in terms of energy absorption and not in mg-hr. [35] In this 1921 paper, he also proposed specifying conditions of the treatment, which look amazingly similar to the components of the modern day written directive. He wrote that the following must be carefully specified:

1. The strength of the radioactive source
2. Its distribution
3. The total filtration used
4. The duration of the irradiation
5. The relative positions and distances of the source of radiation, pathological tissue, and normal tissue.

Platinum was often used for needles as it was inert and performed well as a filter. However, its softness led to the need to add an iridium alloy for rigidity. Silver was more cost-effective than platinum and used at 0.5 mm thicknesses with rubber casings to absorb secondary x-rays. Quimby realized in 1922 that adding layers of filtration modified the delivered dose to the oblique radiation passing through it. She published the first clinical along and away tables for tubes, circles, squares, and rectangles. [36] In this same time frame, the Sievert integral was defined to describe the distribution of radiation accounting for filtration. [37]

## VIII. CONCLUSIONS

Early brachytherapy sources emerged from a demanding pipeline of mining, chemical separation, transportation, isolation, and encapsulation. Almost immediately, radium and radon were used in therapeutic methods. Treatments had a steep learning curve with no standardization of activity or dose. These driving factors led to initial dosimetry concepts that resulted in modern practices performed today.

## ACKNOWLEDGMENT

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# Early Innovations and Explorations in Radium Therapy

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*Abstract*— **The discovery of radiation and radioactivity at the dawn of the 20th century led to an explosion of scientific activity. X-rays discovered by Roentgen quickly became instrumental in medical diagnosis and treatment, and nearly in parallel, radioactive radium salts discovered by Pierre and Marie Curie became one of the most expensive and sought-after materials worldwide. Through historical publications, reprinted scientific addresses, and textbooks from the era, this work explores early clinical practice in the pre-nuclear age, including a selection of applicators and devices that illustrate the inventiveness and creativity of that era.**

*Keywords*— **Historical texts, Radium, Brachytherapy, Medical Devices**

## I. Introduction

As the therapeutic modality brachytherapy approaches a quasquicentennial of clinical use, it is appropriate to mark the achievements and discoveries of the pioneering practitioners whose adventures and discoveries paved the way to modern medical practice. This work comprises a selective review of published literature from the pre-nuclear era, *i.e.*, prior to 1945, to summarize notable examples of early and innovative medical practice utilizing brachytherapy. In order to limit the breadth of this topic, this review deliberately excludes use of radium baths, elixirs, or external beam treatments treated via radium-bombs.

## II. Medical practice

Biological effects attributed to radiation exposure were observed from the very pioneer who discovered radioactivity. H. Becquerel experienced a skin burn in April 1901 after carrying radium for six hours in his shirt pocket [1]. This exposure caused an erythema that transformed into moist desquamation and ultimately left a depigmented scar. P. Curie experienced a similar reaction following a 10-hour exposure from radium powder intentionally placed on his forearm. However, the first *published* description – in a 1900 German photography journal - was made by F. Walkoff, who described 'a skin inflammation that has now persisted for two weeks, exhibiting exactly the same symptoms that appear after long-term X-ray exposure' [2].

These early demonstrations of superficial biological changes likely led to early clinical use of radium by H. Danlos, a dermatologist working in Paris, who treated a patient with lupus on their face using radium chloride (see Figure 1). [**Error! Reference source not found.**]

Fig. 1: Photo of H Danlos treating lupus using radium [**Error! Reference source not found.**]

In the 1905 textbook *Radium and Radio-Active Substances, Their Application Especially to Medicine* (~ 160 pages), C. Baskerville – a Professor of Chemistry at The City College of New York – described many reports of skin ulceration caused by exposure to radium, including self-exposures by Walkoff, Becquerel, Curie, and others [3]. Baskerville also summarized radium-mediated experiments on guinea pigs, rabbits, larvae, meal worms, mice, milk, bacteria (B-coli, B-diphtheriae, bacillus typhus, etc.), and plants, among others examinations. It is notable that this very early text – appearing within years of the discovery of radium – encapsulated a myriad of reported therapeutic interventions, some of which are listed below using the spelling and phrasing present in the original text.

- Lupus, including hypertrophicus and vulgaris
- Epithelioma
- Telangiectesis
- Cancers / carcinoma & malignant disease
- Rodent ulcers (*i.e.*, type of basal cell carcinoma)
- Eczema
- Psoriasis
- Acne
- Moles
- Cyclitis and irido cyclitis (*i.e.*, forms of uveitis or ocular inflammation)
- Hair removal

In many of the indications above, Baskerville included comparison to equivalent studies utilizing X-rays and discussed observations of the different effects of X-ray, γ-ray, and β-ray radiations. As a summary of this impressive 'Catalog of Ships' (*i.e.*, detailed listing of studies and published references), Baskerville stated, "It is too soon to draw any conclusions from much that has been done. It is unwise to make any final statements. However, we know this much: that the radium rays possess the power of dilating the vessels; that they have an electric action; also, an influence upon the cells of quickly growing tissues and possible bactericidal properties. These three factors give bright promise of its therapeutic use, when we shall have learned more about this wonderful substance" [3].

The landmark clinical guide *Radiumthérapie*, originally written in French, was published by dermatologist L. Wickham and physician P. Degrais in 1909. [4] A second edition followed only three years later [5]. Translated versions were readily produced, including an English translation by S. Ernest Dore that featured a preface by Wickham and incorporated additions and updates to the original French version, namely the "development of radiumtherapy as applied to malignant tumors, and the unquestionable value of the method devised by us for the treatment of most forms of vascular nævi" [6]. The tome is divided into three parts: physics (~15 pages), use of instruments (~50 pages, see also Section 0), and clinical therapeutics (> 200 pages). The treatment concept of 'cross-fire' is introduced as "a bombardment of the tissues by rays emitted from different points at the same time, and therefore crossing each other" [6]. The definition is demonstrated by a clinical case of an infant successfully treated in 1907 for a "reddish-violet erectile tumour" by Wickham where the radium appliances were moved externally to prevent erythema to the skin while focusing the applicators at depth in tissue.

The sections describing therapeutic results were grouped into sections as follows, using the language and phrasing of the original text.

- Carcinomata and other malignant growths
- Cheloids and disfiguring scars
- Angiomata
- Pigmentary nævi
- Tuberculosis of skin and mucus membranes
- Analgesic action of radium
- Pruritus, neuro-dermatitis, eczemas;
- Various diseases (e.g., mostly case studies)
- Gynæcology

Each section was essentially a collection of case studies, and the authors concluded each section with a summary statement or concluding remarks.

Other texts from this era had similar breadth and scope to Wickham and Degrais's work. These included *Radium Therapeutics* (~110 pages), a 1913 publication by dermatologist N. S. Finzi [7] and *Radium and Radiotherapy; Radium, Thorium, and Other Radio-Active Elements in Medicine and Surgery* (~310 pages) by W. S. Newcomet, a professor of Roentgenology and Radiology [8]. Of interest, Newcomet incorporated a final chapter titled "Treatment of Untoward Effects of Radio-Active Elements" that described potential acute or chronic sequelae of exposure to radionuclides, often comparing effects to those obtained via Roentgen-rays. Newcomet stated, "If the person withdraws from his vocation and ceases to handle these radio-active elements the condition rapidly subsides, and in a few weeks or months he may return to duty..." [8].

In a 1913 speech at the Seventeenth International Congress of Medicine in London, R. Abbe, a New York surgeon, spoke about his experience using radium sources, including a 150 mg radium-barium chloride source obtained directly from Madame Curie in 1903 [9]. Referencing past successes using radium to remove common warts, Abbe successfully used radium to treat large vocal cord papilloma for multiple patients, including some that failed prior surgery. In this address, Abbe mentioned the practice of 'radiosurgery' where surgery was employed to de-bulk a tumor attached to the carotid artery, with radium subsequently applied to treat residual tumor and prevent recurrence; however, the use of the term 'radiosurgery' as a course of surgery with adjunct brachytherapy did not persist.

Abbe shared promising results for several patients with advanced cervical cancer and is often credited as a pioneer of radium-based gynecological therapy in the United States [10]; although, the electrotherapeutist M. Cleaves published her experience treating cervical cancer with sources loaned from C. Baskerville in 1903 [11]. In a similar vein, Abbe is frequently associated with pioneering the technique of afterloading, namely placing a hollow applicator into a tumor and later loading sources into the applicator to reduce dose to the physician during temporary treatments; however, that distinction more appropriately belongs to H. Strebel working in Munich. [12] These nuanced attributions should not detract from the pioneering and inspirational role played by Abbe as a champion for the medical use of radium in the United States [10].

The use of radium to treat brain tumors was reported in 1922 by H. K. Pancoast and included contributions from C. H. Frazier at University Hospital dating back to 1914 [13]. Radium treatments were conducted either by afterloading sources into the resection cavity or by cross-fire radiation externally applied through the scalp. The risks attendant to these procedures included the general risk of surgery, infection risks related to placing and removing radium sources, healing of the surgical flap following external radiation, and radiation doses to normal brain.

The Chicago-based dermatologist F. E. Simpson published the textbook *Radium Therapy* in 1922 (~320 pages) [14]. Approximately half of the text featured a physical, chemical, and biological discussion of radium and radium emanations, including a detailed description of a radium emanations generation plant and several depth-dose

measurements of radium dose using ion chambers. For treatment applicators, Simpson described radium tubes, radium needles, and "flat plates, or plaques, on which the radium salt is spread" that were generally constructed using linen (known as "toiles"), rubber, or metal. Radium emanations were primarily captured in capillary glass tubes 3 to 20 mm in length with outer diameter of 0.3 to 0.6 mm. For external use, Simpson recommended an "ingenious method" based on a secondary encapsulation of the glass tube within a silver tube (16 mm length, 3 mm diameter, and 0.5 mm wall thickness), as described by G. Failla.

The chapters on treatment were grouped by medical practice:

- Surgery,
- Gynecology,
- Dermatology,
- Ophthalmology (including rhinology and laryngology),
- Diseases of the ductless glands, and
- Internal medicine.

The final chapter was titled "professional injuries due to radium" and described potential local and constitutional effects for radiation workers. The final recommendation in the text was "it is imperative that radium workers should abstain from work for at least two days per week and should have frequent vacations of one or more months' duration."

A 1926 book by A. E. Hayward Pinch on practice and technique in radium therapy further provided insight into the growing appreciation of radiation safety two decades into the clinical use of radioactive material [15]. The text stated that frequent handling of sources "will sooner or later induce definite inflammatory and trophic changes in the fingers and hands of … workers." Recommendations stressed that "All apparatus should be handled with wooden or rubber covered metal forceps, at least a foot in length, and the hands should be protected with leather gloves." The publication featured a large number of photographic plates that illustrated the state of brachytherapy practice a century ago (e.g., see Figure 2).

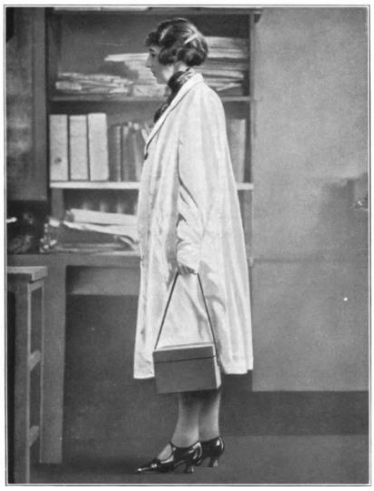

Fig. 2: An attendant carrying radium in a shielded container [15]

Hayward Pinch's text was focused on equipment and technique and included only a brief discussion of clinical methods. Sources were applied in three different ways: direct insertion of sources into superficial tumors; use of "trocar, canula, and plunger" as an afterloading technique; or, the introduction of seeds. A subsequent chapter was dedicated to special situations, specifically, the nose, mouth & tongue, pharynx and fauces, larynx, esophagus, stomach, rectum, uterus, bladder, prostate (via the urethra, perineum, bladder, or rectum), and (female) urethra. It provided a high-level summary of the general technical approach in these anatomic locations, but did not discuss prescriptive practices. Additionally, a chapter listed the most common complications and sequelae arising from treatment, with headings summarized as follows.

- Bacterial infection
- Telangiectasia
- Pigmentation
- Ulceration
- Annular fibrosis (commonly in the vagina & rectum)
- Burns (due to accident, negligence or ignorance)

Hayward Pinch distinguished between expected sequelae of desquamation and ulceration from inappropriate use of radium resulting in more serious soft-tissue damage.

G. E. Birkett authored a 1931 textbook based on the technique employed at the Manchester and District Radium Institute [16]. This text featured six color plates, reflecting printing advances in the early part of the 20th century. The second chapter was titled "Protection" and stated the risks to radiation workers. Birkett provided examples of three workers, where two developed aplastic anemia and the third experienced myeloid leukemia. Formal recommendations of the x-ray and radium protection committee are reproduced in this text. To further emphasize care in the use of radium, the fourth chapter was titled "Radium Burns." The discussion differentiated between burns caused by β rays and those caused by γ rays, with the former largely prevented by using appropriate source filtration and the latter resulting in more serious morbidity. Birkett further described 'immediate burns' that presented 2-3 months after beginning treatment and 'delayed radiation necrosis' that arose potentially years after treatment.

The remainder of Birkett's text was devoted to clinical practice. Birkett stated, "The indiscriminate use of radium on the off chance of something happening has never appealed to us, and there should be good grounds for its use in each and every case" [16]. This mindset parallels the 'evidence-based medicine' approach that formally dawned at the close of the 20th century. Birkett included the following carcinoma-related uses: rodent ulcer, bladder, buccal cavity, anal canal, cervix uteri, rectum, skin, and vagina / vulva. A handful of other examples are listed (e.g., Hodgkin's disease in the parotid, lympho-sarcoma, and mediastinal tumors, among

others); however, Birkett repeatedly warned "against the indiscriminate use of radium."

While radium use for carcinoma was well documented, some researchers pursued applications in benign disease. An example of this was illustrated by a 1934 publication by Phaneuf who treated 150 patients for small fibromyomas, menorrhagia (*i.e.*, heavy menstrual bleeding), and metrorrhagia (i.e., abnormal uterine bleeding unrelated to menstruation) in uteri [17]. Phaneuf achieved good results using a small amount of radium and minimal apparatus; however, this is one example of medical practice that did not become standard of care.

Prior to the dawn of the nuclear age, New York physician D. Quick provided an overview of the current medical use of radium at a 1940 address to the Conference on Applied Nuclear Physics (Cambridge, MA) that was later published in 1942 [18]. While acknowledging that radium was also used in inflammatory and hyperplastic conditions, the focus of the address was cancer therapy. Quick acknowledged that during the same period, significant advances in the technology and equipment used for Roentgen ray therapy had occurred. There was enthusiasm by many to focus on the rapidly advancing Roentgen ray technology, and Quick stated that "Some of the [roentgen therapists] had little opportunity to study radium concurrently, and many have not taken the time."

He reviewed the three primary treatment processes for radium use: external / surface, intracavitary, and interstitial. While Quick noted that a small skin growth responded better to a "larger amount of radium at 1 cm distance," much of the surface treatment discussion compared Roentgen rays to teleCurie therapy. For intracavitary treatments, Quick noted the "outstanding results" reported for cervix uteri treatment. For other sites, he commented that "in the entire gastrointestinal tract radium is of negligible value until the lower sigmoid and rectum are reached." He discussed the potential benefit of evaluating dose and fractionation, stating "My experience with intra-uterine irradiation has been much more favorable with smaller amounts over several days rather than larger amounts for twenty-four to thirty-six hours." Finally, Quick reviewed the interstitial uses of radium and radon, with a focus on irradiation accompanying surgical procedures. He said, "It may salvage an operative procedure which would otherwise have been a failure through inability to carry out a complete removal, or the operative procedure may have been solely for the purpose of permitting proper localization of the needles or implants." He listed a number of sites that could benefit from this adjunct method as follows:

- Epidermoid carcinoma of mouth & pharynx
- Cervical Metastases
- Axilla in breast cancer
- Primary breast cancer (some)
- Bladder
- Prostate
- Cervix uteri carcinomas (some)
- Inguinal metastases of external genitalia carcinoma
- 'Various other growths'

On this topic, Quick enthusiastically added, "it is my firm conviction that practically no surgical procedure on a growth of questionable operability should be undertaken, in all fairness to the patient, without a proper supply of radium, in some suitable form, available to aid in the possible salvage of a difficult situation" [18].

In summary, Quick reviewed the "close and complementary relationship between surgery, roentgen rays, and radium." He reviewed how filtration had reduced the rate of necrosis, but also admitted that the very good past results obtained from unfiltered sources warranted additional study. He also commented on the intravenous use of aqueous compounds, the growing interest in radiosensitizers, and the potential for new radioactive compounds. It was unlikely that he appreciated the coming nuclear age and the availability of new radionuclides.

## III. Instruments and applicators

The first decades incorporating radioactive material in medicine produced a wide variety of techniques and applications. In the very early years, radium was primarily available in the form of mineral salts that could be infused into applicators and molds. Even encapsulated sources were produced in different forms using various materials, which challenged standardization. However, clinicians designed and implemented a number of tools to achieve therapeutic goals. This section explores notable examples from the pre-nuclear era.

C. Baskerville in his 1905 textbook included a short discussion of equipment used in therapeutic treatments that highlighted the heterogeneity of devices at the dawn of medical use [3]. Patient-facing materials included rubber (for "higher activity"), quartz, mica, silver, glass, lead, and others, demonstrating the often physician-specific customization of applicators. Figure 3 shows a variety of surface applicators produced by Philadelphia manufacturer Williams, Brown & Earle.

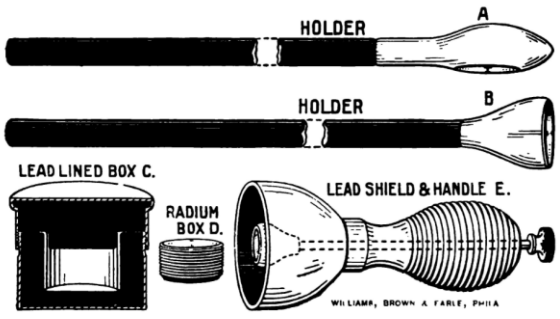


Fig. 3: Surface radium applicators for applying radium compounds [3]

*Radiumtherapie* includes a robust description of equipment available only five years later. Wickham and

Degrais spend little time on the use of radium in the form of tubes, which were generally radium salts sealed in glass with the option to be inserted into a second tube of gold, silver, or platinum of variable thickness to obtain a desired radiation intensity [4-6]. Instead, they described a family of devices created by using varnish to seal radium salts onto an applicator comprised of either metal or linen / toile. Metal applicators were created in numerous shapes and forms (cylindrical, spherical, round, etc.) to achieve treatment goals, and the radium salt applied using approximately 10 cg of radium salt per square centimeter. Once dried, a coating of resin would be applied to seal and fix the radium. Toile applicators provided no filtration, were fragile, and had to be handled with great care. In some cases, a toile could be sandwiched between thin sheets of lead to make an apparatus that could be applied in the mouth, vagina, or cervix uteri.

A notable example of a metal applicator from this era is Wickham's "radio-uterine apparatus" (Figure 4). The applicator incorporated cylindrical rods of variable sizes that were coated with radium varnish. The rods were affixed to a cup, also with varnish applied, to treat the external cervix when the rods were inserted into the uterus. Lead or silver screens could be placed over the apparatus to provide filtration.

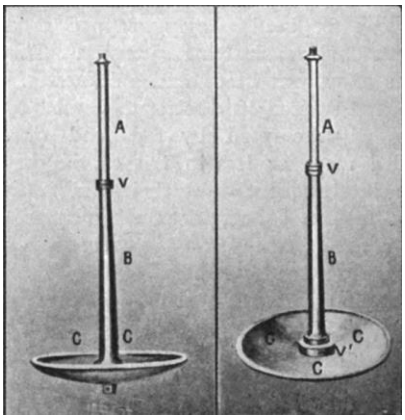


Fig. 4: Illustration of Wickham's uterine applicator [4]

As noted in Section II, much of the clinical use of radium during the first decade of the 1900s was pioneered by dermatologists treating superficial conditions. There was a need to identify appropriate material for creating superficial molds and plaques to facilitate optimal treatment. One relatively well-known solution was the invention of Columbia Paste or "pàte Colombia" that was named after the home country of radiation oncologist A. Esguerra-Gómez, who developed it [19]. Esguerra-Gómez was working at the Curie Institute in Paris and described Colombia Paste in a 1922 French language publication, as a mixture of beeswax, paraffin, and sawdust [20]. Esguerra et al. noted, "Surface Curiethérapy, though simple in appearance, is in reality very delicate to perform correctly. The number of sources to be used, their arrangement relative to one another, their strength, their filtration, and the distance from the skin at which the tubes must be placed are all problems that must be carefully considered." The material could be heated into a pliable state (48 °C) and molded to patient anatomy as required. A hot awl could be used to punch holes for attaching string or to create openings in the material. Similarly, a heated piece of iron was used to melt cavities in the material for source placement, and a backing mixture of paraffin and beeswax applied to secure the sources. Colombia paste had several advantages: it did not deform at body temperature, was lightweight, was smooth, could be washed with soap and water, could be sterilized by heating to 120 °C, and could be melted down and reused indefinitely [20]. Colombia Paste was eventually available commercially in different thicknesses; however, it was difficult and costly to import, and similar products were produced, including radon wax described by I. I. Kaplan, a physician at Bellevue Hospital in New York, and produced in the United States [21]. Kaplan's 1930 publication included a figure illustrating the variety of applicators that could be constructed (See Figure 5).

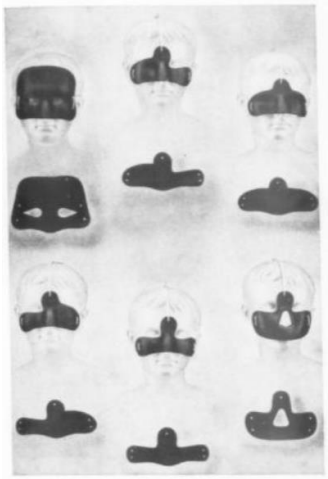

Fig. 5: Applicators made with radon wax, a variant of Colombia Paste [21]

In a 1922 article, B. Allen described a concave applicator designed to hold an applicator tube-style radium source over the eye for the "treatment of cataracts" [22]. The device, shown in Figure 6, was intended to be comfortably inserted under the eyelids to "obviate… the necessary tanning of the skin … when applying the radium externally." Dr. Allen was a pioneering radiologist working in Iowa City. Unfortunately, the article did not include the treatment paradigm for this clinical setting, *i.e.*, prescription dose and pattern, or the expected efficacy.

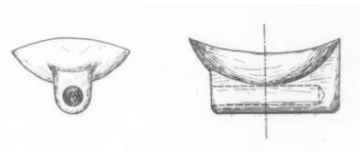

Fig. 6: Illustration of an applicator for the treatment of cataracts [22]

As noted repeatedly above, radium was extensively utilized to treat skin disorders during this era. Reporting on work performed at Memorial Hospital in New York City, D. Quick and F. M. Johnson, a clinical assistant, described an apparatus that captured radium emanations in a small (5 mm diameter), thin, glass bulb [23]. The bulb was sealed into a steel cone using paraffin and attached to a 45 cm pliable metal rod. During clinical use, the operator would be positioned behind a board lined with 6 mm of lead that included an observation window and holes for the passage of the applicator. (Figure 7) Quick and Johnson noted that unfiltered radiation from radon sources (with higher specific activity compared to radium) allowed for rapid treatment of superficial lesions. After three weeks of collecting radium emanations, "as many as 40 or 50 cases may be disposed of in an afternoon" [23].

Fig. 7: Treatment of skin lesions through a shielded board (to protect the operator) using radium emanations [23]

In a subsequent 1923 article, N. T. Beers, a New York City-based dermatologist, described a radium-based applicator intended to treat "small lesions about the face" that was inspired by the work of Quick and Johnson [24]. Beers employed radium instead of radium emanations; however, in lieu of a large applicator with a traditional window screen, he employed a 1 cm diameter radium element embedded in a glaze that had mechanical threading on the back. This element could be attached to a customized applicator, and Beers noted that a T-shaped support made of soft lead could be used to permit easy molding and placement (see for example Figure 8).

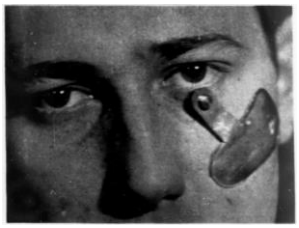

Fig. 8: The Beers lead finger-plate applicator near the eye [24]

As an improvement and modification of the bottle corks originally used as colpostats at the Curie Institute, I. I. Kaplan described an H-shaped apparatus comprised of two gum rubber cylinders (3 cm long, 1.5 cm in diameter) connected by a 10-cm long spring that was also covered in vulcanized rubber [25]. The spring was "just tense enough to spread the cylinders apart in the vagina, and keep an even pressure against the fornices and cervix." Kaplan noted several advantages over the use of cork colpostats, including that it could be sterilized, did not absorb body fluids, and did not require the use of string, among others. From a dosimetric perspective, Kaplan noted that the parallel orientation of the cylinders allowed for "crossfiring" when abutting the cervical lesion.

At the Thirteenth Annual Meeting of the American Radium Society, R.E. Loucks presented an applicator used for the treatment of urethral caruncle, which was published in 1929 [26]. Treatment was delivered via a 25-mg radium tube in a 0.5-mm silver capsule, placed within a 1-mm brass tube, and covered with a rubber cot (0.5 mm). The source is placed between two dummy sources positioned on either side of the meatus, and above a vaginal obturator used to hold the entire assembly in place (See Figure 9).

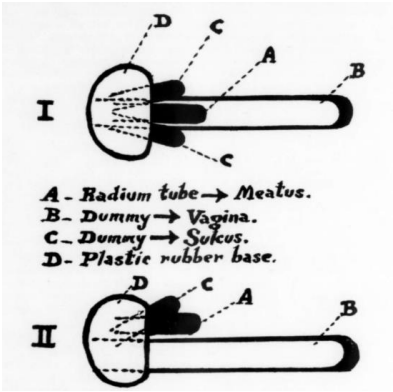


Fig.9: Illustration of the urethral caruncle applicator [26] using overhead (I) and lateral (II) views

Dr. Loucks described two patient cases that experienced at least two years without pain or discomfort following treatment-related reactions. Of note, publication of this presentation in the *American Journal of Roentgenology and Radium Therapy* included a summary of the discussion that took place at the meeting following the presentation, during which some physicians argued for the role of

electrocoagulation or surgery while others supported the use of radium. One commentor, Dr. O. L. Norsworthy of Houston, TX, reported use of the Clark cervical applicator in treating the meatus of the urethra. They similarly used a heavily filtered, 25-mg radium source for two hours.

A variation of the Clark applicator was described in a 1928 publication by H. Swanberg [27]. The Clark applicator was a single T-shaped applicator that replaced the traditional combination of a uterine applicator and colpostat favored by the so-called "French School" of radium use championed by C. Regaud at the Curie Institute of Paris. The Clark applicator used 1 mm of brass covered by 0.5 mm of aluminum, while Swanberg's variation utilized a gold alloy for additional filtration to protect the vaginal mucosa. The uterine channel could be adapted to patient-specific lengths as shown in Figure 10. Swanberg recommended that the applicator be used with colpostat described by Kaplan (above) to best follow the treatment paradigm recommended by Regaud.

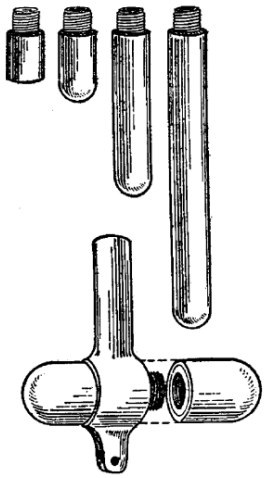

Fig. 10: Illustration of the Swanberg variation of the Clark Applicator [27]

A 1930 discussion of the role of radium in treating thyroid disease by S. Ginsburg included a general overview of the technique and a collection of twenty-five patient cases [28]. The authors first used a linear "radium block" of balsa wood with radium sources attached in a parallel array, which evolved into a semi-circular radium "collar" with small blocks of balsa wood bound with plaster and gauze to conform to the patient's neck (Figure 11).

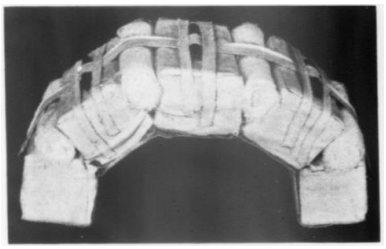

Fig. 11 Radium "collar" employed by Ginsburg to treat thyroid disease [28]

Of note, the treatment paradigm employed by S. Ginsburg was to employ a fractionated course of "one-sixth to one-quarter of the erythema dose … at intervals of five to seven days until a full erythema dose was reached." The patient would then pass an interval of four weeks before being checked for clinical status and metabolic rate. If indicated, the treatment could be repeated. Approximately 20% of the case studies were accompanied by patient before-and-after photographs.

While two applicators discussed above employed radioactive elements inserted into the uterus (i.e., the designs of Wickham and Swanberg), another type of applicator was described by Swedish oncologist J. Heyman in 1936 [29]. Heyman had historically treated the uterine cavity using a tube containing between 35-45 mg Ra using a length that fit the cavity; however, surgical evaluation of failed cases identified that the top of the uterine cavity likely received insufficient dose. Heyman designed an alternate method where the uterine cavity was packed with a number of smaller capsules holding less radium. Radium tubes were 20 mm in length and 2.8 mm in diameter, and were encased in an external capsule with an equivalent thickness of 3 mm of lead. Most patient cases could be treated with 8-12 cylinders, although some treatments exceeded 20 cylinders. Treatments were later standardized using approximately 10 capsules, by performing treatment simulations in leather pouches of different size. A strong thread was attached to each capsule for removal, and special attention was necessary for orderly capsule removal. Figure 12 shows a Heyman capsule and the loading tool, that was designed by R. M. Siebert.

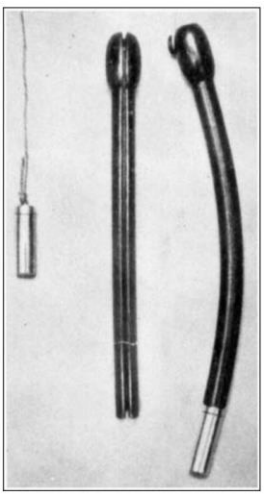

Fig. 12 Heyman capsule (left), empty loading tool (center), and loading tool with capsule (right) [29]

## III. Conclusions

This work explored a selective history of brachytherapy practice in the pre-nuclear era, with a focus on the medical use of radium and radium emanations. The discussion was

divided into two sections, one with a focus on the evolution of clinical practice and another with the intent to examine inventions and equipment that enabled medical advancements during that time. Textbooks and publications from the era were explored to gain insight and more contemporary review papers were also cited. Of note, literature produced during the early 1900s incorporated more and more information (and warning) regarding the risks of radium and radiation exposure, which reflected painful lessons learned through individual sacrifices of pioneers and innovators. This work can be used as a starting point for others to further explore this subject matter.

## ACKNOWLEDGMENT

The authors would like to thank Dr. Geoffrey Ibbott for the invitation to explore this rich topic and present during the History Symposium at the 2026 meeting of the American Association of Physicists in Medicine.

This work would not have been possible without the vast trove of historical documents that have been scanned and stored in digital repositories for the benefit of future generations and academic research. Many of these documents were captured using optical character recognition, improving interpretation of faded source material and allowing subsequent translation of foreign language material. Google AI was used in some instances to translate foreign language text. This technology further allows appreciation of the original subject matter.

Google, Inc. (Mountain View, CA) scanned a number of resources available through the HathiTrust digital library (https://www.hathitrust.org/). Similarly, the Internet Archive, a non-profit corporation, maintains a digital library of numerous historical journals (https://archive.org/), including many volumes of the American Journal of Roentgenology from the early 20th century (https://archive.org/details/pub_ajr-american-journal-of-roentgenology).

These resources and others like them provide access to documents of historical significance to anyone with a computer, an internet connection, a budding interest, and a little free time.

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# THE RISE OF BRACHYTHERAPY SYSTEMS

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***Abstract*—As dosimetry moved from empiricism to physical, treatment planning could also become systematic and several "systems" for designing and controlling interstitial implants, surface applications and intracavitary insertions arose. The principles upon which the systems were based can still provide important guidance for brachytherapy practices today.**

*Keywords*— **Brachytherapy, Brachytherapy Systems, Interstitial Brachytherapy, Cervical Intracavitary Brachytherapy.**

## I. Early brachytherpay treatments

Early brachytherapists quantified treatments as best as they could, specifying the amount of radium used in mg and the duration of the treatment, often in hours. Successful treatments of various diseases using radium, and its emanation, radon, were reported [1,2]. The reports recognized that the amount of radium needed depended on the area or volume to cover, and that the time should vary with that. However, since most of the reports are anecdotal and often include warnings that the values for mg-hrs (the products of mass of radium and duration with the old abbreviation for hours, "hrs," which will be used when using information from historic texts, saving "hr" for modern work) should not be exceeded or reduced, one can infer that each successful treatment regimen probably came with a number of treatment failures. How, exactly the successful values were obtained likely can never be known [3].

By 1914, the need was recognized for specifying dose in terms of radiation received to the target rather than the mg-hrs applied [4]. The new specification was in terms of roentgens (R), based on the work of Villard, and Rutherford and Chadwick, who determined that a 1-mg point source of radium filtered with 0.5mm of platinum produced 8.4 R at 1 cm in air [5-7].

The following will provide an overview of the Manchester Systems, developed at the Christie Hospital and Holt Radium Institute in Manchester, UK, which was the first to incorporate dose to the patient in a consistent and integrated way. The papers and books by the originators of the systems cover many times the number of pages of this review, so the systems provide much more guidance than be covered here. Meredith published a collection of the works from Manchester, and a tutorial can be found in Thomadsen and Hendee [8, 9].

The ends of sections II and III include discussions about how the systems still provide useful guidance in the modern age.

## II. The manchester system for molds and interstitial implants

### A. *Surface molds*

While various approaches to systematic dosimetry were used earlier, the Manchester System was the first that provided simple rules for delivering uniform doses [10]. The system was based on the following:

1. The goal was to deliver a uniform dose to the target, defined as ±10%, although lower doses in the corners of square or cubic implants would be acceptable.
2. The goal would be achieved by using differential radium loading.
3. Attenuation and scatter due to the tissue were ignored, as they were thought to cancel.
4. Radiation from a point source of radium follows the inverse square law.
5. The "dose" to the tissue was actually the in-air exposure, with no conversion to energy absorbed to unit mass of tissue (which did not become common in radiotherapy until the 1970s).

Table 1 Strength and length of British Standard needles and tubes

| **Needles – All filtered with 0.5mm Pt** | | | |
|---|---|---|---|
| Name | Active length [cm] | Half strength [mg] | Full strength [mg] |
| Short | 1.5 | 0.495 | 0.99 |
| Medium short | 2.0 | 0.66 | 1.32 |
| Medium | 3.0 | 0.99 | 1.98 |
| Medium Long | 4.0 | 1.32 | 2.64 |
| Long | 4.5 | 1.485 | 2.97 |
| Add 1.2 cm for physical length. | | | |
| Linear radium density [mg/cm] | | | |
| Full strength | | 0.66 | |
| Half strength | | 0.33 | |
| **Tubes – All filtered with 1 mm Pt** | | | |
| Radium content in mg. (All active lengths 1.35 cm, add 0.65 cm for physical length) | | | |
| 5, 10, 15, 20, 25 | | | |

6. The system was based on the British Standard radium needles, which are described in Table 1. These needles were radium sulfate in tubes of 0.5 mm of platinum, although corrections for various thicknesses of Pt or other

materials are provided. Some sets of needles also include "Indian club" models with double loading in the tip half.

7. Following the radium distribution rules delivers approximately 40 to 50 R/h or about 1000 R per day, which was considered to be biologically equivalent to the typical external-beam dose of 1000 R per week.

The development of the system started with mold treatments, that is, a treatment placing the radioactive material on the skin to treat a target at depth (h) below. In this case, the dose uniformity would be considered in the plane of the target depth. The first case addressed was a circular implant, calculating the dose for various diameter circles and depths. The calculation did not use the actual geometry that needles would form but, rather, uniform activity per centimeter around the circumference. From this, they developed a table of factors $R_A$, the mg-hrs required to deliver 1000 R to the target plane. A sample of the table is shown in Table 2, while the table in their work covered areas to 400cm$^2$ and distances to 5 cm. Keep in mind that these calculations were performed decades before computers were developed.

Table 2 Planar dosimetry table for $R_A$ in (mg-hr)/1000 R for needles with 0.5 mm Pt filtration

| Area in cm$^2$ | Treatment distance in cm | | | | |
|---|---|---|---|---|---|
| | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 |
| 1 | 68 | 171 | | | |
| 4 | 141 | 278 | 462 | 698 | 970 |
| 8 | 206 | 384 | 599 | 855 | 1155 |
| 10 | 235 | 433 | 655 | 923 | 1235 |
| 12 | 261 | 480 | 710 | 990 | 1312 |
| 16 | 315 | 566 | 814 | 1113 | 1460 |
| 20 | 368 | 641 | 910 | 1225 | 1588 |
| 24 | 417 | 707 | 1008 | 1335 | 1712 |
| 28 | 466 | 767 | 1100 | 1438 | 1826 |
| 32 | 513 | 823 | 1185 | 1537 | 1936 |

For an example use of the table, consider treatment of superficial skin cancer that penetrates 0.5 cm deep. The radioactive material should be set on a tissue-equivalent mold, in this case also 0.5 cm, which gives the treatment distance, h=1cm. The target, including margin, has an area of 10 cm$^2$. The prescription dose, D, is 6000 R in a duration, t, 7 days, or 168 hrs. The clinical question becomes how much radium to use in the mold, which comes from the formula:

$$\text{mg} = \frac{\text{D}\cdot R_A}{\text{t}} \qquad (1)$$

$$= \frac{6000\ \text{R} \cdot 433 \frac{\text{mg}\cdot\text{hr}}{1000\ \text{R}}}{168\ \text{hr}} = 15.46\ \text{mg}$$

For cases where the diameter, d, of a circular ring of radium divided by the treatment distance is less than 6, the doses to the target plane proves to be uniform ±8%. For larger ratios of d/h, the dose in the center of the ring of source material decreases, often considerably below the 10% goal. Addressing this problem for larger d/h, the radioactive material is divided between the outer ring, an inner ring with half the diameter, and possibly a source in the center. The distribution of the radium follows the guidelines in Table 3.

Table 3 Source distribution rules for circular mold applications

| d/h | % in outer ring | % in inner ring | % in center spot | % variation |
|---|---|---|---|---|
| 0.5 | 100 | 0 | 0 | ±3 |
| 1 | 100 | 0 | 0 | ±5 |
| 1.5 | 100 | 0 | 0 | ±6.8 |
| 2 | 100 | 0 | 0 | ±5 |
| 3 | 96 | 0 | 4 | ±3.5 |
| 4 | 94 | 0 | 6 | ±2 |
| 5 | 93.5 | 0 | 6.5 | ±5.5 |
| 6 | 80.5 | 16 | 3.5 | ±2.5 |
| 8 | 74 | 23.5 | 2.5 | ±2 |
| 10 | 70.5 | 26.5 | 3 | ±4 |
| 12 | 69 | 28 | 3 | ±7.5 |
| 14 | 69 | 28 | 3 | ±10 |

Circular molds with d/h>14 are not suitable for mold treatments. The authors of the system suggest they could be treated with three rings. Mayneord suggested that such targets could be treated with a combination of a simulated radium disk and a ring, which is more difficult to achieve in practice [11].

In our example, the diameter of the circle with an area of 10 cm$^2$ is 3.6 cm, so d/h=3.6 cm/1 cm=3.6. Interpolating in Table 3 indicates that 95% of the radium (14.69 mg) should be in the ring periphery and 5% (0.77 mg) should be in the center. The mold would look like Figure 1.

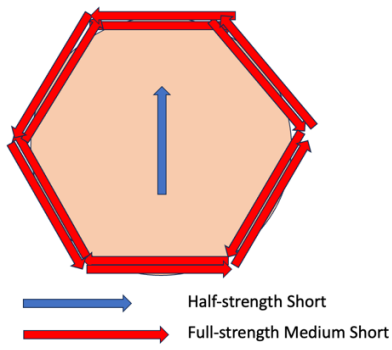


Fig. 1 Layout for the example mold treatment.

Note that the required amount of radium required around the periphery is too great to achieve with a single ring of needles. Longer needles would not conform to the curve of the circle, so placing the medium short needles side by side provides the needed strength.

This configuration has 12 x 1.32 mg = 15.84 mg on the periphery and 0.495mg in the center for a total of 16.335 mg, or 6% more radium than ideal. To compensate, the treatment time should decrease by 6%, becoming 159 hrs. The portions of the radium are 97% on the circumference and 3% in the center, which still falls well within the ±10 uniformity goal.

B. *Interstitial implants*

Lesions that present with a thickness that would lead to either excessive dose at the surface while covering the deep part of the target may benefit from interstitial implants with the needles penetrating the lesion. Such an implant would look like a picket fence, as shown in Fig. 2. The Manchester System handles the dosimetry for such a plane of needles identically to a planar mold except the treatment distance is always taken as 0.5 cm. As seen in Fig. 2, the needles treat to both sides of the needle plane, thus treating a thickness of 1cm. Assume that the needles in Fig. 2 are medium, that is, have an active length of 3 cm. The Manchester System specifies that the needles are placed at centimeter intervals, so the width of the implant is 4 cm and the area is 12 cm$^2$. The dose calculations for a needle implant are the same as for a mold. Rearranging Eq. 1gives

$$D = \frac{mg \cdot t}{R_A}, \qquad (2)$$

showing that for a given mg-hrs, the dose is inversely proportional to $R_A$. From Table 2, for this implant, the ratio of the dose at h=1 cm to that at the 0.5 cm dose specification plane is the ratio of the $R_A$ values, or:

$$\frac{\text{Dose at 1 cm}}{\text{Dose at 0.5 cm}} = \frac{R_A(12\ \text{cm}^2, h = 0.5\ \text{cm})}{R_A(12\ \text{cm}^2, h = 1\ \text{cm})} = \frac{261\frac{\text{mg-hr}}{1000\ R}}{480\frac{\text{mg-hr}}{1000\ R}} = 0.54,$$

well outside of the 10% variation allowed, which is why the treatment thickness is limited to 0.5 cm to each side of the needle plane.

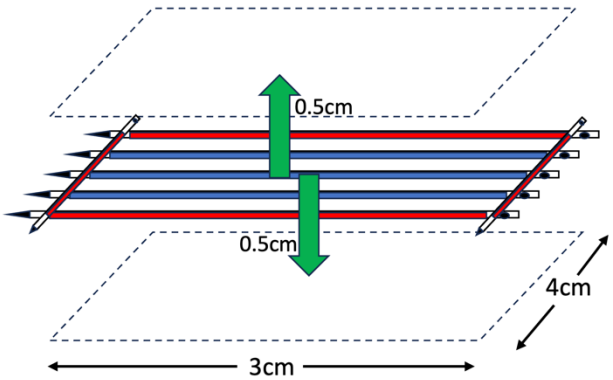


Fig. 2 Example of a single plane implant. The dashed lines outline the boundary of the target volume at the edges of the treatment volume 0.5 cm from the needle plane. Ideally, the red needles are approximately twice the strength of the blue.

At each end of the implant are needles perpendicular to the five main needles, called "crossing needles." These needles serve to square the dose distribution, which would fall between the needles at the ends, were the crossing needles not there, as shown in Fig. 3.

Looking up the $R_A$ value, the area used has to be reduced by using the length correction shown in Fig. 3. In order to treat the volume adequately, longer needles need to be used to compensate for loss from any uncrossed end.

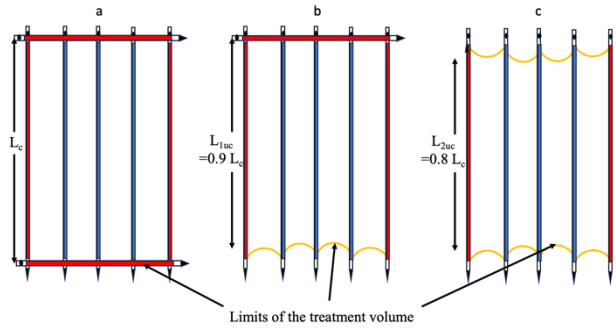


Fig. 3 An illustration of the loss in treatment length due to the lack of crossing needles.

As with molds, there are distribution rules, such as in Table 3, although the rules are simpler because needles have fewer options for changes the weights of the parts. For needle implants the distribution follows Table 4.

Table 4 Distribution rules for planer implants

| Area-> | <25 cm$^2$ | 25-100 cm$^2$ | >100 cm$^2$ |
|---|---|---|---|
| Fraction on periphery | 2/3 | 1/2 | 1/3 |

Assume the small implant in Figure 2 is treating a surgical bed after a complete resection. The prescription for this implant to deliver 4000 R in 72 hrs, the calculation would follow Equation 1, with the $R_A = 261\frac{\text{mg-hr}}{1000R}$. This gives mg $= \frac{D \cdot R_A}{t} = \frac{4000R \cdot 261\frac{\text{mg-hr}}{1000R}}{72\text{hr}} = 14.5\ mg$ of radium. From Table 4, two-thirds of the radium, 9.67 mg, would fall in the periphery, leaving 4.83 mg in the interior. The periphery consists of four needles (2 medium and 2 medium long) with a total active length of (2x3 cm+2x4 cm) = 14 cm. The ideal loading for the periphery would be 9.67 mg/14 cm = 0.69 mg/cm, slightly higher than the linear radium density of the full-strength needles, which would be used. The interior three medium needles ideally would have 4.83 mg/(3x3 cm) = 0.537 mg/cm. This is considerably higher than the half-strength needles' linear radium density and lower than the full strength's. Using three half-strength needles would contain only 2.97 mg, for a total of 12.21 mg, resulting in a treatment duration of 85.5 hrs, which could compromise the biological effectiveness of the treatment. Instead, loading the two outside interior needles as medium full strength and the center as a medium half strength results in 9.24 mg on the periphery (65%) and 4.95 mg (35%) on the interior, for a total of 14.19 mg total and a treatment duration of 73.3 hrs, which all would be biologically the same as prescribed. The adaptation to fit the prescription as demonstrated in this example is very typical for brachytherapy.

For targets thicker than 1cm, or for anatomy such as a tongue, it often is better to sandwich the disease between two planes of needles, such as in Fig. 4.

The case illustrated in the figure has the needles entering the patient from the right. Because the tips of the needles are deep in the patient, the distal end cannot be crossed. This case requires two adjustments compared with the single-plane implant just discussed.

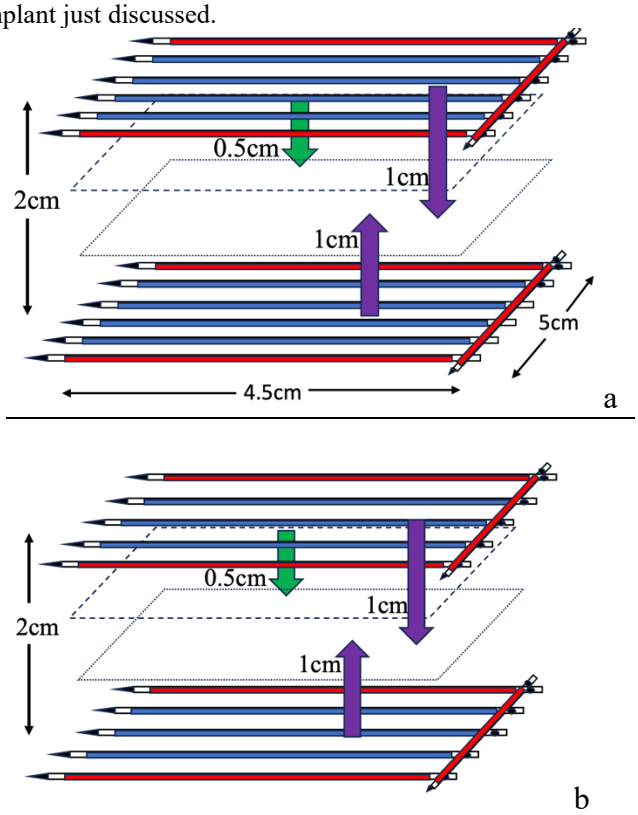


Fig. 4 A two-plane implant with uncrossed ends on the deep end. The dashed line is the dosimetry plane 0.5cm from either needle plane, if the implant is symmetrical (only shown from one). The dotted line represents the midplane, in this case 1cm from either plane. a. As originally conceived. b. As finally planned.

1. Location of dosimetric plane. As discussed in the Manchester papers, the location of the dose is a bit confusing. The calculation always uses the $R_A$ for a distance of 0.5 cm, just as with the single-plane implant. However, the calculation formula includes a "separation factor (SF)," given in Table 5. This factor corrects for the fact that the contribution to the dose from the distal plane, i.e., the opposite plane from the one closest to the 0.5 cm plane, suffers attenuation from the distance to the dashed plane in Fig. 5. This factor also serves to bring the dose in the midplane between the two needle planes to the prescription dose.
2. Correction for lack of crossing. The implant in Fig. 5 has six needles in each plane, thus forming a 5 cm wide implant. Each needle in the "picket fence" is taken as a long needle with an active length of 4.5 cm. Because of the lack of crossing on the deep end, the effective depth of the picket-fence needles, according to Fig. 3, is only 0.9 of the active length, or 4 cm. The effective area of the implant to find the $R_A$ is 0.9 x 4.5 cm x 5 cm=20 $cm^2$. In planning the implant, it is essential to ensure the dose distribution covers the target. While finding the $R_A$, 10% of the active length is discounted, that accounts for the average loss of depth. The maximum loss between needles is closer to 20% of the active length, so deep end of the needles must extend 20% beyond the farthest extent of the target.

Table 5 Separation factors for two-plane implants and the dose to the midplane

| Separation of planes | 1.0 | 1.5 | 2.0 | | 2.5 | |
|---|---|---|---|---|---|---|
| Separation Factor (SF) | 1.0 | 1.25 | 1.4 | | 1.5 | |
| Area of planes | | | 0-25 $cm^2$ | 25-50 $cm^2$ | 0-25 $cm^2$ | 25-50 $cm^2$ |
| Dose low at midplane | | | 20% | 10% | 30% | 20% |

Calculations for the implant in Fig. 4 use the $R_A$ for 20 $cm^2$, h of 0.5 cm and the separation factor of 1.4, giving:

$$mg = \frac{SF \cdot D \cdot R_A}{t} \quad (3)$$

In this case, assume we want a dose rate of 50 R/hr.

$$mg = 1.4 \cdot 368 \frac{mg \cdot hr}{1000\ R} \frac{50\ R}{hr} = 25.76\ mg$$

Of the 25.76 mg, each plane will have half, or 12.88 mg.

The interior four needles should carry one third of the radium in the plane, or 4.29 mg. Dividing this into four needles gives 1.07 mg per needle, which is considerably lower than the half strength long needles. However, if this were divided between three needles, that would be 1.43 mg per needle, just 3.7% lower than the radium in a half-strength, long needle. The periphery consists of the two outside needles and the crossing needle, all of which would be long needles. Since the periphery should carry two-thirds of the radium on the plane (8.59 mg), that would be 2.86 mg per needle, again 3.7% lower than a full-strength long needle. The replanned implant is shown in Fig.4b as two planes, each with the three full-strength long needles on the periphery and three half-strength long needles in the interior. All the needles in the picket fence are separated by 1.25 cm. With the new total of 26.73 mg, the final dose rate is 51.9 R/hr.

B. *Volume implants*

Because the dose in the center of two-plane implants falls below the ±20% limit on uniformity for typical clinical cases that would require planes separated by more than 2.5 cm, the Manchester System recommends using volume implants [12, 13]. Volume implants in their system come in several configurations: spherical, cylindrical, box and multiplane. In practice, the spherical would mostly be used in radon-seed permanent implants; the box approach was infrequently used.

The dose calculations were similar to planar implants but instead of a two-argument $R_A$, they use a single-argument $R_V$ based only on volume of the implant. Table 6 shows a sample of the $R_V$ values.

The distribution rules for volume implants are very different from molds and planar implants. Because of the length limitation of this article, we will only consider cylindrical volume implants, with a brief mention of multiplanar. A multiplanar implant consists of the outer planes on each side of the target that define its limits and the inner planes that fill the interior, with all planes between 1-1.5 cm apart. Cylindrical implants have a cylindrical belt that circumscribes the target, a core in the interior, and sometimes crossing planes that form a lid to the belt. The radium is portioned the different constituents based on its parts:

- For multiplanar implants, each outer plane carries three parts, and the inner planes carry two parts each.
- For cylindrical implants, the belt receives four parts, the core two parts and each end, when present, one part.

Table 6 Volume dosimetry table for $R_V$ in (mg-hr)/1000 R for needles with 0.5mm Pt filtration

| Volume in $cm^3$ | $R_v$ |
|---|---|
| 4 | 85.9 |
| 5 | 99.7 |
| 10 | 158.3 |
| 15 | 207 |
| 20 | 251 |
| 30 | 329 |
| 40 | 399 |
| 60 | 523 |
| 80 | 633 |
| 120 | 830 |
| 160 | 1005 |

An example clarifies how this works. Fig. 5 shows an example of a cylindrical, volume implant treating a target 5.5cm in diameter and from the skin going 5cm deep. The desired dose rate is 45 R/hr. Because the active length of the long needles is only 4.5 cm, the crossing occurs at the physical end of the needles with the eyelet at the skin. Contrary to the rule that needles cross at each active end, this is allowed for volume implants but the distribution rule changes:

- For cylindrical implants with crossing at the physical end of the belt, the belt receives four parts, the core two parts and end two parts.

As with planar implants, correction is required for uncrossed ends. Particularly for volume implants, the deep end cannot be crossed. As a correction for each uncrossed ends, for volume implants the active length is reduced by a factor of 0.925, instead of the 0.9 for planar implants. While the depth from the surface crossing needles to the active ends of the picket-fence needles, because of the uncrossed deep end, the length is reduced to (1-0.075) x 5 cm = 4.63 cm. The volume becomes $\pi r^2 L_{eff} = \pi(2.75\ cm)^2 \times 4.63\ cm = 110\ cm^3$. Interpolating from Table 6 gives $R_V = 781 \frac{mg \cdot hr}{1000\ R}$.

The $R_V$ may require an elongation correction (EC) based on the elongation factor (EF), that is, the ratio of the longest dimension to the shortest, orthogonal dimension. Table 7 gives these corrections. This correction increases the required mg-hrs due to the reduced efficiency of the dose delivery as the implant stretches because of increased distances from the extremes of the needles.

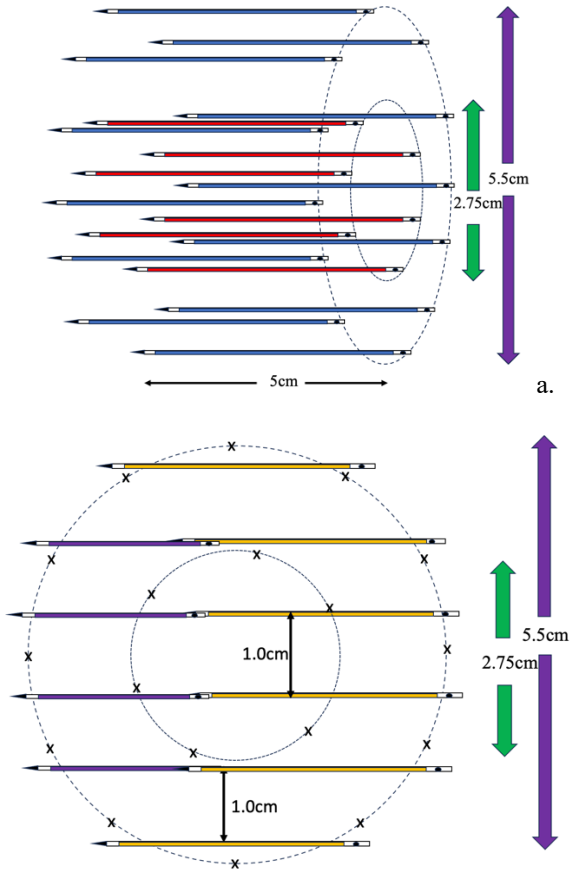


Fig. 5 An example cylindrical implant as described below. a. A view along the needles going deeper into the patient towards the left. All the needles are of the "long" type. The blue needles indicate the belt and the red indicate the core. b. The view looking at the implant on the skin. An "x" marks where the needle location in the core and belt, with the needles on the skin superimposed. In b., the yellow needles are "medium" and the purple are "medium short."

Table 7 Elongation corrections (EC) for volume implants $R_V$, based on the elongation factor (EF)= longest dimension to the shortest dimension.

| EF | EC |
|---|---|
| 1.5 | 3% |
| 2 | 6% |
| 2.5 | 10% |
| 3 | 15% |

In this case, the EF = 1.1 no EC is required.

Calculating the total mg of radium follows equation 4:

$$mg = \frac{D \cdot R_V (1+EC)}{t} \quad (4)$$

$$= 781 \frac{mg \cdot hr}{1000\ R} \cdot \frac{45\ R}{hr} = 35.15\ mg.$$

With the belt having four parts, the core having 2 parts and the end having 2 parts, that is a total of 8 parts, so the distribution

will be 4 parts/8 parts = 50% (17.57 mg) on the belt, 2 parts/8 parts = 25% (8.79 mg) in the core and on the end.

The radium for the core is dived among 12 needles, or 1.46mg/needle, which is happily very close to the half-strength long needle. Since the percentage of radium in the core is half that for the belt, and the number of needles is also half, the same needles would be used in the core. This is usually the case. The end has six medium and 4 medium short needles, for a total length of 26 cm for the 8.79 mg, or 0.34 mg/cm, so again matching well the half strength.

### C. *Applicability to the modern practice.*

Obviously, radium is no longer in use, and prescriptions are in gray. What is useful still is using the guidance for needle layout and general distribution of source dwell times for initial starting points in treatment planning. Using rules from the Manchester System, or other systems such as the Paris System, as starting points helps current, computer-based optimization programs generate more uniform plans.

The Manchester System designed implants with the target fully enclosed within the needles. In most Manchester implants, the 90% extends about 0.5 cm outside needle volumes, which can shrink the implanted volume, and make it approximate a Paris System implant.

Manchester calculations can be useful for quick quality control for brachytherapy implants. Use with modern, high-dose-rate (HDR) cases requires several changes:

1. Correction for the exposure rate constant – In 1934 the accepted value was 8.4 $\mathrm{R}\cdot\mathrm{cm}^2/\mathrm{mg}\cdot\mathrm{hr}$, while now the value of 8.25 $\mathrm{R}\cdot\mathrm{cm}^2/\mathrm{mg}\cdot\mathrm{hr}$ is assumed.
2. Specify the dose in Gy. Correcting from exposure to dose to tissue while also expressing the table in Gy instead of R.
3. Correction for oblique filtration.
4. Correction for tissue attenuation and scatter.

Because the last two tend to cancel, a constant factor of 0.80 can be used to convert the original tables in $\frac{\mathrm{mg\cdot hr}}{1000\mathrm{R}}$ to $\frac{\mathrm{U\cdot h}}{\mathrm{Gy}}$ [9].

## III. The Manchester System for Intracavitary Cervical Brachytherapy

Shortly after clinics received radium sources, they tried treating cervical carcinoma with intracavitary application. The treatments used variously designed applicators and used ranges between 1200-5000 mg-hrs [14]. Reports in these early years included successes, failures and many complications. Because the applicators mostly were made in house, there was no uniformity in therapy. Mourya et al. published a review of the development of intracavitary brachytherapy applicators [15].

The main advantage of the Manchester System for cervical cancer was that it was reproducible, if the practitioner had the same apparatus as used in Manchester, and the calculations were simple [16, 17]. This was a definite advantage for an empire with patients in developing countries.

### A. *System Principles*

Much of the Manchester System for cervical cancer is particular for treatment based on the stage and extent of disease. This paper only focuses on the physical aspects of the treatments. As did the Manchester System for interstitial implants, the approach moved from treatments based on mg-hrs to "dose" in R. The system *only* applied to the Manchester applicator, which had three parts:

1. The tandem that went into the uterine canal. The tandem was a thin rubber tube that could flex with the canal. A flange on the open end of the tube kept it from sliding deeper into the canal than desired. The tube accommodated tube type sources listed in the bottom of Table 1. To fit the patient's anatomy, the tandem came in three sizes to fit one, two or three radium sources.
2. The ovoids that fit into the vaginal fornices. The ovoids are not flexible and each would hold a single radium source. The ovoids came in three diameters: 2, 2.5 and 3 cm.
3. The hard rubber spacer or washer that separate the ovoids. The spacer fits between the ovoids keeping them 1cm apart, while using the washer allowed the ovoids to almost touch.

The goal of the three components was to make a stable unit that allows for a consistent dose to be delivered to all patients.

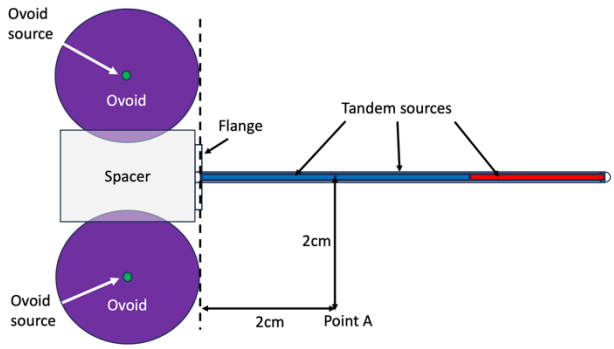


Fig. 6 The schematic geometry for the Manchester applicator, this one with a three-source tandem and two medium ovoids. This also shows the location of Point A. The strengths of radium in this example are a very common combination: Red is 15 mg, blue is 10 mg, green is 20 mg.

Much of achieving consistent doses required specification of a reproducible point at a relevant anatomical site. They based the dose control location on observations that the initial site of radiation necrosis in cervical intracavitary brachytherapy occurred from high doses to "the medial edge of the broad ligament where the uterine vessels cross the ureter." They called this area the "paracervical triangle" and considered it the dose limiting location. They named this spot Point A and specified it as 2 cm lateral to the center of the uterine canal and 2 cm cephalad of the mucous membrane of

the lateral fornix in the plane of the uterus [16]. Fig. 6 shows the geometry of the applicator and the location of Point A. The applicator with the loading patterns they give produces a "pear" shaped dose distribution.

In addition to limiting the dose to Point A, they identified the location they thought the obturator node to be, calling it Point B, and used it to evaluate the "lateral throw" of the application. Point B was found by starting at the same place as for Point A, moving 2cm directly cephalad but then going 5 cm lateral. Fig. 7 illustrates the location of Point B. The figure also shows that with a tipped uterus, Point A follows the uterus, while Point B is independent of any angulation of the uterus.

The standard dose to Point A would be 8000 R in 144 hrs, which translates to 55.5 R/hr. The actual delivery was in two 72-hr sessions separated by three days. The brachytherapy would be supplemented with external beam for stages III and IV.

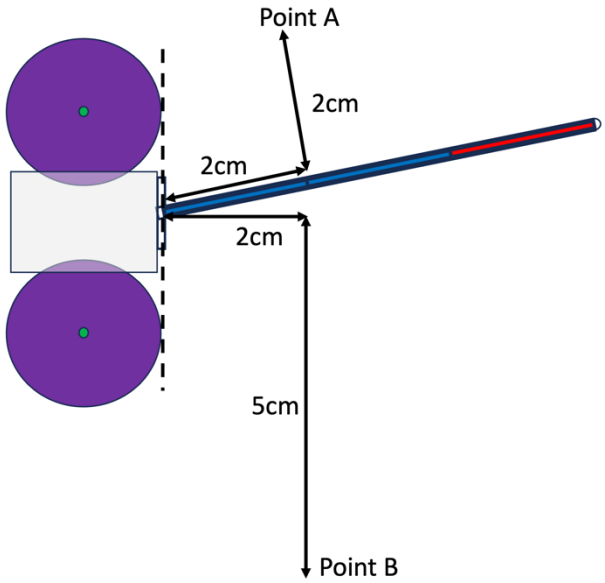


Fig. 7 An illustration of the location of Point B, also showing how Point A follows a tipped uterus while Point B remains related to the whole body.

The 1953 revision to the system addressed the ability to perform individualized dosimetry based on radiographic imaging [17]. Because the ovoids do not show the vaginal fornix mucosa clearly, the method to find Point A changes very slightly, starting at the physical bottom of the inferior-most source in the tandem rather than the intersection of the line connecting the cephalad-most aspect of each vaginal fornix with the cervical os. Fig. 6 shows that for the Manchester applicator, both definitions yield the same point.

### B. *Applicability to the modern practice*

Even more than with interstitial implants, modern cervical intracavitary brachytherapy carries many remnants of the Manchester System. New applicators had to adapt to allow afterloading of sources [18, 19]. The new applicators often lost the physical connection between the tandem and the ovoids, yet continued to use the revised Manchester definition for finding Point A, starting at the bottom source in the tandem. Figure 8 shows the difference.

Point A as defined in the Manchester System sits in a portion of the isodose surfaces where small errors in locating Point A have little effect on the calculated dose. On the other hand, Point A' as located in Fig. 8 falls where the dose from the ovoids pushes the isodose into the fatter part of the "pear." In that location, small errors in the craniocaudal direction can make much larger differences in the calculated dose.

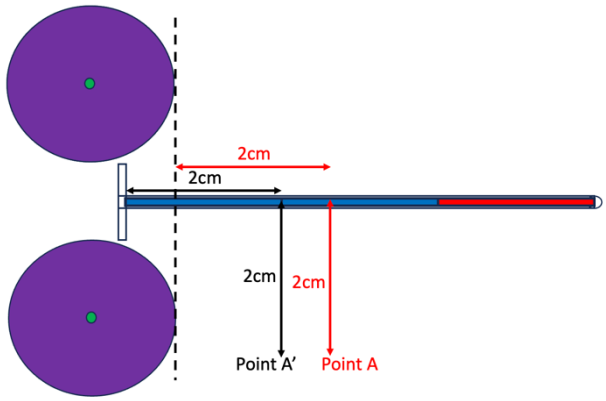


Fig. 8 This figure show an afterloading applicator where the tandem and ovoids move independently, which gives Point A'. Point A' could be cephalad of Point A if the tandem is pushed in deeper than the ovoids, but more often it falls inferior to Point A because the tandem comes between the ovoids.

Manchester's use of three sources in the tandem, with the cephalad source being particularly active, formed the well-know "pear shaped" dose distribution. The target for cervical cancer brachytherapy, does not conform to that shape. However, given the sources available at the time, in order to project the dose sufficiently lateral in the cervix, they needed to use the strong source above the cervix. HDR brachytherapy allows much more control over the shape of the dose distribution, and magnetic-resonance imaging gives a clearer picture of the disease. Report 89 from the International Commission on Radiation Units and Measurements provides guidance for brachytherapy in the 21st Century, but has its roots firmly planted in the Manchester System [20].

## VI. Conclusion

The Manchester Systems brought uniformity and consistency to brachytherapy, basing treatments on dose to a patient (albeit, in roentgens). Because of the careful thought and calculations (all before computers), the systems formed the general patterns for much that followed, and their foundations can still be seen in what we do today.

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# THE *PHYSICS OF RADIOLOGY* BY JOHNS AND CUNNINGHAM A HISTORICAL PERSPECTIVE AND INPACT ON THE PRACTICE OF MEDICAL PHYSICS

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## Introduction

The book series, The Physics of Radiology by Harold Johns and Jack Cunnigham, was, and continues to be, a major resource for educating medical physicists and related professionals and a reference for clinical practice, especially in radiation therapy. Over a period of 68 years five (5) editions were published. Each documented the state of the science/physics and technology that existed at that time. This establishes it as a valuable historical record of the development of medical physics and related clinical applications throughout that time. The first two editions were authored by Johns, the third and fourth editions by Johns and Cunningham, and the fifth edition by different authors.

For someone studying the history of radiation therapy, the book provides a remarkable record of how the field evolved from simple X-ray and radium treatments in the 1950s to today's computer-controlled, image-guided, and particle-beam therapies.

## The Authors

Harold E. Johns, PhD, the first full-time cancer care-focused medical physicist in Canada, has been called the father of megavoltage radiation and the educator of generations of radiation oncologists, diagnostic radiologists, nuclear medicine physicians and medical physicists. (Ref. 1)

John Robert “Jack” Cunningham was a Canadian medical physicist best known as the co-author, with Harold E. Johns, of The Physics of Radiology and as a pioneer in computerized radiation-treatment planning. (Ref. 2, 3).

*Their Relationship, as Reported by Cunningham*

The Second Edition was prepared after Dr. Johns had moved to Toronto in the late 1950's. My role in working on this manuscript was mainly to act as a sounding board for some of the chapters, and to check the solutions to some of the problems that are found at the end of the chapters. I became a full co-author for the Third Edition, which was prepared during the years 1966-69. I was responsible for the initial drafts of some of the chapters on basic Radiation Physics.

For the Fourth Edition I played a much greater role. I wrote the first drafts for about half the chapters and set up most of the tabular data in the Appendix. For this latter task I wrote several computer programs and compiled and organized the data. I also calculated the data for several of the dose distributions that are included.

The Fourth Edition was first published in 1983 ft takes two or three years of intense work to produce a textbook of this sort. The book sells for somewhat more than $ I00 (US) per copy and the Royalties an approximately 5%, split between the two of us. Sales were a thousand or so copies, during the first year, tapering off considerably as the years go by. I have estimated that the income on an hourly basis would be well less than $1.00 Clearly it is not the kind of activity one would undertake in the hopes of making money. That being said, I know both of us would say it was very worthwhile. It has established itself as the standard textbook in the radiological physics field and is used worldwide.

**First Edition 1953**

Established medical physics as a quantitative scientific discipline.

The first edition of the book was titled: The Physics of Radiation Therapy and was authored by Harold E. Johns. The origin and general content are described in the Preface by Dr. Johns.

*From the Preface*

This book is an expansion of a set of notes, The Physical Basis of Radiotherapy, which was printed privately and in limited numbers by the Saskatchewan Cancer Commission. It is written with the object of supplying students and physicians with the fundamental physical principles basic to an understanding of radiotherapy.

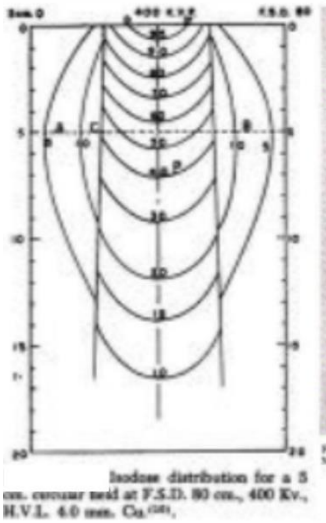
A detailed discussion of the methods by which an x-ray beam can give up its energy to tissue has been included. Special emphasis has been placed, throughout, on the concept of energy absorption in tissue, which I feel is fundamental. The nature of the distribution of radiation in space has been emphasized and a number of practical examples in radiotherapy have been included. The methods by which depth dose data and isodose distributions may be used in clinical work are indicated. In addition, a discussion of energy absorption in bone, fat and muscle has been included. Description of radium dosage has followed closely _the Manchester system. A section on high energy devices (in particular, the betatron) and the use of radioactive isotopes has been added.

To increase the practical application of this book, I have added an appendix. This includes depth dose data based upon a comprehensive experimental survey of the depth dose which has been obtained from a variety of types of radiations. Great care has been taken in compiling this data to determine how the depth dose depends upon focal skin distance and area. A number of isodose distributions for the more commonly used types of radiation have been included. Experimentally determined spectral distributions of radiations are also presented.

Harold E. Johns.

The development of the book started in 1946 when W. V. Mayneword from England was in Canada participating in a program concerning the development of nuclear weapons. He was lecturing in Toronto and Harold Johns attended the lectures. Johns, who was a senior physicist, was designated to prepare the notes for the class. Using these notes, he continued to develop the text for the book. In 1948 Jack Cunningham was one of his students majoring in engineering and with experience in drafting was co-opted to produce some of the illustrations.

A major focus of the book was providing methods and data that could be used for planning radiation therapy procedures. This was with depth dose and isodose curves that were provided in the appendix. An example is shown here.



Isodose distribution for a 5 cm. circular field at F.S.D. 80 cm., 400 Kv., H.V.L. 4.0 mm. Cu.[123].

Figure VII-7. Photograph of a contour projector similar in design to that of Mayneord[27].

**The** book can be read at: **The physics of radiation therapy : Johns, Harold Elford. : Free Download, Borrow, and Streaming : Internet Archive**

**Second Edition 1960s**

Reflected rapid growth of cobalt therapy and radiation measurement.

The Second Edition, The Physics of Radiology, 767 pages, was also authored by Johns and was expanded to include the physics of medical imaging and more on radiation protection. The content of each chapter is based on many publications by other professionals and are referenced. This enhances its value to other researchers.
With its expansion beyond just the basic physics of radiation and the physics of radiation therapy, there was a considerable emphasis on the hazards of radiation. Some justification for this was said to be the many other sources of radiation beyond medicine that the public might be exposed to, including reactors and bombs. The chapter on Imaging opens with a discussion of the hazards of radiation and the statement that patients undergoing an examination is "also receiving a treatment".

The book serves two major purposes, as an education resource and a reference and handbook for clinical practice.

*Education*

The series, and especially beginning with the Second Edition, was developed to be a major textbook for medical physicists and related medical professionals.

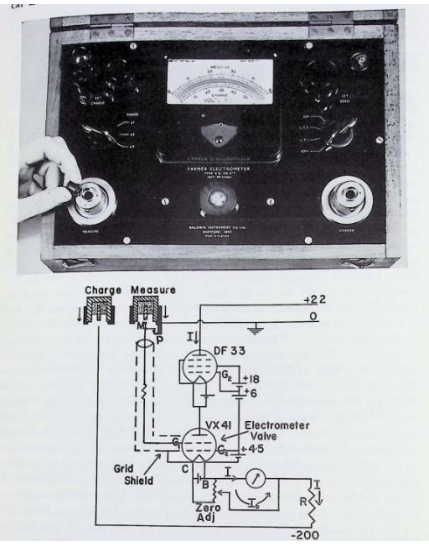
The comprehensive and detailed text with understandable explanations and the necessary quantitative and mathematical components was coupled with illustrations that connected the theory to practical applications.

This is an illustration that shows both the circuitry and use of the electrometer for charging and reading the small condenser chambers that were used to measure radiation exposure at that time…. bridging the theory to the practical applications.

Perhaps the content that stimulated learning was the set of questions at the end of each chapter. The correct answers were in a section near the end of the book.

At that time in history, many, including myself, were entering the field of medical physics not having graduated from medical physics programs. My graduate work was in nuclear physics with a good understanding of radiation interactions but not medical physics applications. For us, the Johns and Cunningham books were our introduction and continuing learning resource for medical physics.

An example is show here.



*Clinical Practice of Medical Physics*

Throughout the series, the physics of radiation therapy has been the major topic. It is the field that both Johns and Cuningham were major contributors to with their research and developments and used their knowledge and experience to support other physicists practicing in that field.

It was the time before the more contemporary treatment planning methods with computers was available and it was generally done manually with published tables and charts.

**Third Edition 1970s**

Added modern dosimetry and computer-assisted calculations.

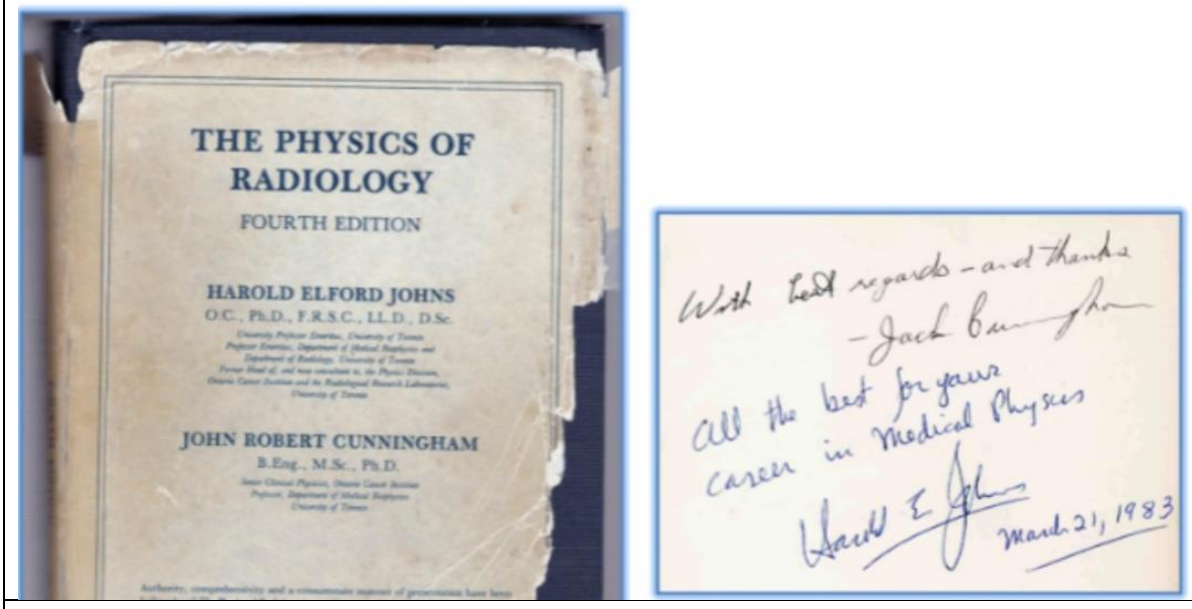
This was the first edition to be authored by both Johns and Cunningham. It added more on modern dosimetry and computer-assisted calculations that was Cunninghams' specialization.

The Appendixes were updated. Appendix A. provided absorption coefficients and absorption data for a large range of photon energies. Appendix B provided depth dose data for the various radiation sources, field sizes, shapes, and distances that were being used at that time.

**Fourth Edition 1983**

Became the standard reference text for medical physics education worldwide.

It was the last to be authored by Johns and Cuningham and remained the standard version for almost four decades.




Autographed Copy to Jake Van Dyke

**Fifth Edition 2021**

Complete modernization while preserving the original educational style

The 5th edition was published in 2021 as Johns and Cunningham's Physics of Radiology but was not written by Johns and Cunningham themselves. It preserves their names in the title because the book continues the classic textbook tradition begun by Harold Elford Johns and John Robert Cunningham. The 5th edition authors are Eva Bezak, Alun H. Beddoe, Loredana G. Marcu, Martin Ebert, and Roger Price.

The 5th edition was important because it updated the classic 1983 fourth edition after nearly four decades. During that period, radiology and medical physics changed greatly with the growth of CT, MRI, PET, molecular imaging, digital x-ray detectors, modern radiation therapy planning, proton and heavy-ion therapy, molecular radiotherapy, and computer-based dose calculations.

**Conclusions**

The series of textbooks, four editions, published over a period of 30 years, authored by Harold Johns and Jack Cunningham, was a major educational resource for medical physicists and provided data for general medical physics applications and especially treatment planning in radiation therapy. The value of each edition was providing updates on current medical physics issues, like radiation quantities and units, and the clinical technology and methods being used at that time.

**Acknowledgement**

Jacob (Jake) Van Dyk, Professor Emeritus, Departments of Oncology and Medical Biophysics
Western University, London, Ontario, Canada, has been a major resource providing detailed information for this article. He joined the staff with Johns and Cunningham in 1971 and was a colleague and friend throughout their lifetime.

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**Author:** Perry Sprawls

Perry Sprawls is a clinical medical physicist and educator, Distinguished Emeritus Professor, Emory University School of Medicine and the Sprawls Educational Foundation, www.sprawls.org . Major interest and activity are the history of medical physics and related clinical applications.

# THE NEED OF REGULAR ASSESSMENT OF THE MEDICAL PHYSICS EDUCATION STATUS FOR SUPPORT OF THE PROFESSIONAL GROWTH

Prof. Slavik Tabakov,
Emeritus President IUPESM, Past President IOMP (2015-2018)

**Abstract**

The development of medical physics education is directly related to professional growth and from there to the healthcare provision today. Regular assessment of this educational development is necessary in order to establish the trend and stability of this process. Before the launch of the MPI Journal two books were published on this subject and several conferences were held in different parts of the world. Further activities and publications additionally supported the medical physics global professional growth. These activities are necessary to continue and accelerate in order to reach the needed number of medical physicists by 2035 (as per the GTFRC predictions).

## The 1995 book "Medical Radiation Physics – A European Perspective"

This book was published after the European Conference on Medical Physics Education and Training, organised in Budapest 1994. The book collected papers from the Conference delegates (senior medical physicists from various European countries) and from other countries and institutions: Austria; Belarus, Belgium; Bulgaria; Croatia; Cyprus; Czech Rep; Denmark; Estonia; Finland; France; Germany; Greece; Hungary; Ireland; Italy; Latvia; Lithuania; Netherlands; Poland; Portugal; Romania; Russia; Slovakia; Spain; Sweden; Switzerland; Turkey; Ukraine; United Kingdom; EFOMP (European Federation of Organisations for Medical Physics) ; IFMBE (International Federation of Medical and Biological Engineering); IAEA (International Atomic Energy Agency).

There were 13 Central/Eastern European countries present at the Budapest Conference. Later most of them developed their own medical physics educational programmes. It is interesting to note that this book was published in 1995 both as paper book and as e-book on a diskette (thus becoming one of the first e-books published on this medium) [3]. The latter aimed at better distribution in Europe and other continents.

In an MPI paper from 2020 we described this activity and its impact in Central and Eastern Europe [1]. The book itself was annexed to the MPI – History Editions No.10 , 2024 ("Medical Radiation Physics – A European Perspective" editors C Roberts, S Tabakov, C Lewis, King's College London, 1995) for free use [2].

This book was followed by other activities and books on the subject of medical physics and engineering education:

- "Towards a European Framework for Education and Training in Medical Physics and Biomedical Engineering", (2001), ISBN 1 58603 151 1, IOS Press, Amsterdam
- The materials of the project BIOMEDEA and its associated Conferences (2004-2005), available from www.biomedea.org.
- The special issue "e-Learning in Medical Engineering and Physics", Journal of Medical Engineering and Physics, 2005, vol.27, N.7
- El Fisico Medico: Criterios y Recomendaciones para su Formación Academica, Entrenamiento Clinico y Certificacion en America Latina, OIEA, VIENA, 2010, STI/PUB/1424, ISBN 978-92-0-311209-3

Additionally over 40 educational activities, seminars and courses were co-organised by the IOMP Education and Training Committee (ETC) in the period 1997 to 2006, as per the reports in the IOMP Newsletter Medical Physics World [4]. In the same period was opened the first educational web site in the profession and e-learning was introduced [5].

**The 2011 book Medical Physics and Engineering Education and Training**

About 15 years after the book from 1995 another book on the subject was published in 2011 [6]. It was based on contributions from the attendees of the ICTP College on Medical Physics in the period 2002-2010, as well as specific events organised by the IOMP Education and Training Committee (ETC) at our professional World Congresses in Sydney (2003), Seoul (2006) and Munich (2009). From these we have to specially mention the large Workshop "Medical Physics and Engineering Education and Training – a global perspective", held at WC2006, Seoul, 29 August 2006, co-organised by the Editors of the 2011 book and specialists from AFOMP (Asian Federations of Organisations for Medical Physics) and SEAFOMP (South-East Asian Federations of Organisations for Medical Physics).

The 2011 book included papers from Australia and New Zealand; PR China; Hong Kong, China; India; Shi Lanka; Nepal; Pakistan; Indonesia; Malaysia; Philippines; Thailand; Bangladesh; Russia; Turkey; Estonia; Romania; Bulgaria; Czech Rep.; Brazil; Cuba; Morocco; Ethiopia; Sudan; Ghana; United Kingdom; IOMP (International Organisation for Medical Physics); ICTP (International Centre for Theoretical Physics, Trieste, Italy); IAEA (International Atomic Energy Agency); AFOMP (Asian Federations of Organisations for Medical Physics); Emerald project; Biomedea project; Emitel Encyclopaedia project; Sprawls Foundation.

The book included also the IOMP project for development of a Model Curriculum for Medical Physics MSc programmes. This activity was further developed by the IAEA, who published in 2013 their TCS-56 Postgraduate Medical Physics Academic Programmes [7]. The latter was updated in 2021 [8]. In parallel with IOMP and various projects, IAEA was very active in the field of building and supporting educational activities [9].

The materials from the 2011 book also included information about the GDP (Gross Domestic Product) of the countries, what presented a very interesting information – Fig.1.

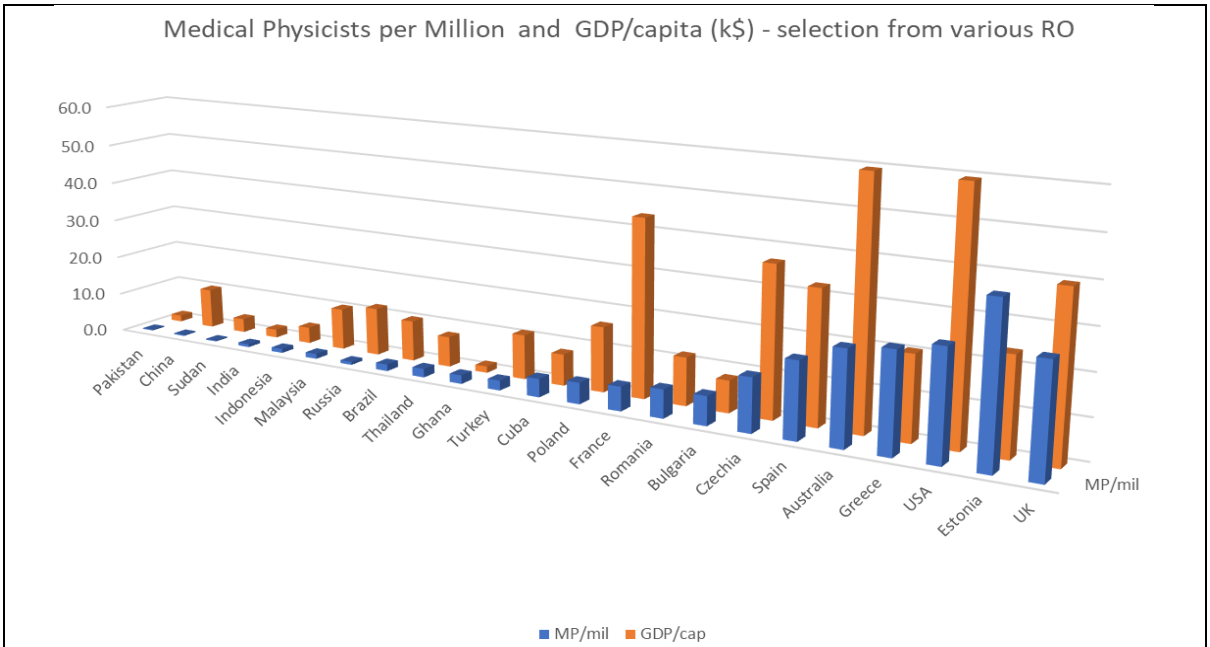


Fig.1 Statistics for number of medical physicists in different countries as per 2010 - Medical physicists per million population (blue bars) and Gross Domestic Product per capita in 1000 USD (orange bars – back row).

It appeared that the number of medical physicists is not directly related to the GDP of a given country at the time of the book publication. Some large countries have significant capacity for educating more medical physicists, while other small countries have a very good number of medical physicists, despite their lower GDP. This led to the conclusion that publicity in a given country (at various levels) is more important for increasing the number of medical physicists. This result was an additional catalyst for the introduction of the International Medical Physics Day (IDMP) in 2013 [10], aiming to publicise more widely our profession, as well as the related IDMP Award in 2015 (these award colleagues from each continent for their excellence in promoting the profession and highlighting our contribution to patient care).

The book from 2011 is available free and is attached as a free ANNEX to this issue of MPI-History Editions.

**Further assessments of the Medical Physics Education Status**

Following the activities in 2003, 2006 and 2009, later World Congresses and International Medical Physics Conferences included also specific topics and Workshops on medical physics and engineering education – Beijing (2012); Brighton (2013); Toronto (2015); Bangkok (2016); Prague (2018). The activities co-organised with IUPAP, IAEA and WHO were specially important for assessing the current status of medical physics education and planning new activities in LMI countries – Fig.2.

Attendees at the Seminar for Medical Physics Education and Professional Development in Low and Middle Income (LMI) countries, at WC2018, Prague, Czech Rep

Additionally in 2018 the IOMP Medical Physics International (MPI) Journal organised the publication of series of papers from each of the 6 IOMP Regional Organisations (Federations per continent):

-MPI 2019 (vol7) No.1 - Latin America (ALFIM), related also to the ICMP 2019 in Chile. This issue also presented a paper about the North America professional development [11];

-MPI 2019 (vol7), No.2 – Africa (FAMPO), Contributing Co-Editors: T Ige and F Hasford [12];

-MPI 2020 (vol.8), No.1 – South-East Asia (SEAFOMP), Contributing Co-Editors: Kwan Ng and A Krisanachinda [13];

-MPI 2020 (vol.8) No.2 – Asia-Oceania (AFOMP), Contributing Co-Editors: A Chougule, E Bezak, A Azhari [14];

-MPI 2021 (vol.9) No.1 – Middle East (MEFOMP), Contributing Co-Editors: H al-Naemi and M H Kharita [15];

-MPI 2021 (vol.9) No.2 – Europe (EFOMP), Contributing Co-Editors: D Lurie, E Koutsouveli and P Gilligan [16].

These MPI issues included papers from 65 countries from all continents: Belize; Costa Rica; El Salvador; Guatemala; Honduras; Nicaragua; Panama; Chile; Brazil; USA and Canada; South Africa; Zimbabwe; Nigeria; Ghana; Morocco; Algeria; Tunisia; Egypt; Zambia; Rwanda; Kenya; Vietnam; Indonesia; Thailand; Philippines; Myanmar; Lao PDR; Australia and New Zealand; Bangladesh; Japan; India; Korea; Malaysia; Mongolia; Nepal; Philippines; Singapore; Thailand; Pakistan; Iraq; Jordan; Kuwait; Lebanon; Oman; Palestine; Qatar; Saudi Arabia; Syria; Yemen; Denmark; France; Bulgaria; Hungary; Lithuania; Malta; Norway; Poland; Spain; Serbia; Sweden; Ukraine.

**Discussion and Conclusion**

Using the previous assessments of our professional growth [17] and the current number of medical physicists we can see that at the moment the trend of this growth presents growth, which is lower than needed – Fig.3.

The initial professional growth (in the three decades after IOMP establishment (1965-75; 1975-85; 1985-95) of the profession has a linear growth (with a growth of about 2000 medical physicists per decay). The following 3 decades (1995-2005; 2005-2015; 2015-2025) there is almost exponential growth, but it slows by 2025. This means that we shall not be able to achieve even a linear growth from 2015 to 2035 (the red line on Fig.2). The latter will not create conditions allowing the profession to reach the predicted workforce requirements of the Global Task Force on Radiotherapy for Cancer (GTFRC) and further discussions on the subject [18,17] - about 60,000 to serve both Radiotherapy and Medical Imaging plus Radiation Safety.

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Together with the above, the profession has currently a new challenge – the introduction of Artificial Intelligence (AI), which should be included in the new medical physics curricula. Most of the Conferences and Workshops now address AI related research, but it is necessary to address also new educational programmes, which will introduce AI in the education of young medical physicists. The current ICTP College on Medical Physics will pilot such an activity in 2026, what could be a good starting point for future activities on this subject. In future proper introduction, exploitation and assessment of AI in medicine (including medical physics) will be paramount element of patient safety. Undoubtedly this will increase the expected numbers of medical physicists by 2035 – staff whose responsibility for patient safety will further increase.

The regular assessment of the medical physics education status must continue in the future years. New Workshops and other activities on the subject are necessary in order to have strong development of our education programmes and from there – further increased global professional growth of medical physicists.

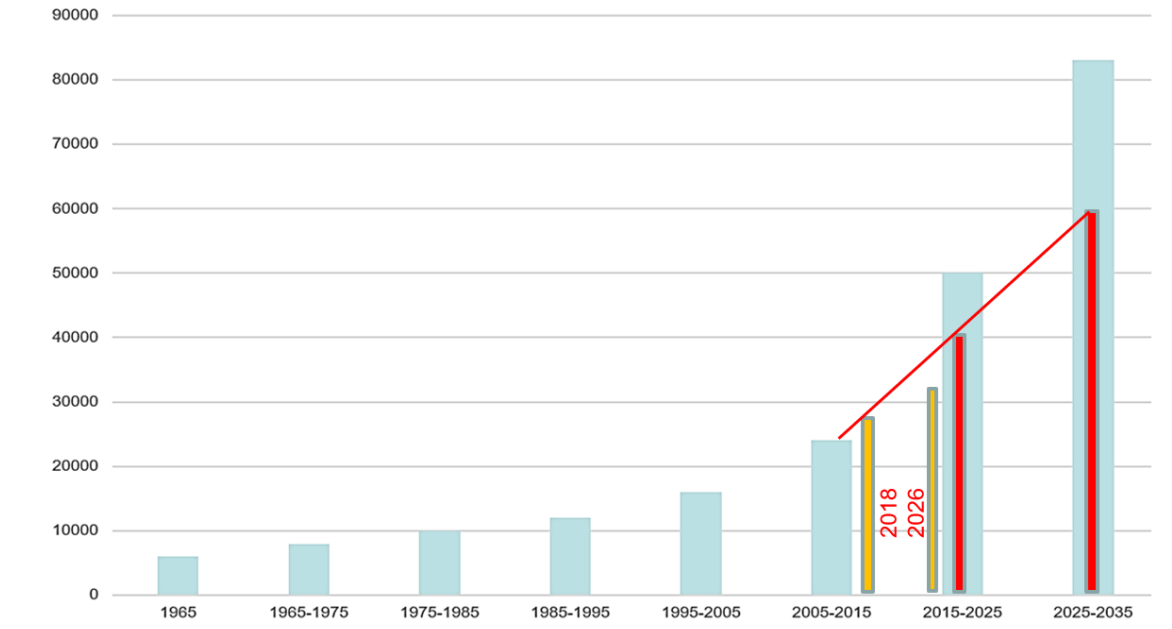


Fig.3 Global growth of the profession from 1963 to 2026 and prediction for the necessary growth by 2035. The blue bars show the growth in case if exponential growth would have been sustained (which is not the case now); the yellow bars show the real figures from 2018 and 2026; the red bars show the necessary growth to be achieved by 2035 in case of linear growth after 2018.

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**Author:** Slavik Tabakov

Slavik Tabakov, PhD, Dr h.c.,FIPEM, FHEA, FIOMP, FIUPESM is a British-Bulgarian medical physicists, who has served in the IOMP ETC from 1997 to 2018 (incl. Chair ETC from 2000 to 2006). He has been part of IOMP ExCom from 2009 to 2022 (including President from 2015 to 2018). He has worked extensively to support global medical physics education and has supported the establishment of 18 MSc courses. He has also coordinated the large projects EMERALD and EMIT, which introduced e-learning in the profession, as well as EMITEL – establishing the first e-Encyclopaedia of Medical Physics. He has been MSc Director at King's College London and ICTP Trieste.

# THE 100TH ANNIVERSARY OF PROF. ABDUS SALAM – A BRIGHT MIND AND A GLOBAL LEGACY

Magdalena Stoeva[1,3] and Slavik Tabakov,[2,3]
[1] IOMP Secretary General, [2] IOMP Past President (2015-2018), [3] Co-Directors ICTP Medical Physics College

2026 marks another milestone in the development of modern physics – Abdus Salam's 100th anniversary. It is a moment to honour Prof. Salam as one of the 20th century's most influential theoretical physicists, celebrated for unifying the weak and electromagnetic forces — work that earned him the 1979 Nobel Prize in Physics. Today, Salam's 100th anniversary highlights his impact on global science, international collaboration, and pioneering role in global research.

Abdus Salam is a pioneering Pakistani theoretical physicist, who spent the main part of his professional life in the United Kingdom. His work reshaped modern particle physics. Born in 1926, he became world-renowned for co-developing the electroweak theory, unifying the weak nuclear force and electromagnetism — a breakthrough that earned him the 1979 Nobel Prize in Physics. Salam taught at Cambridge and Imperial College London, where he built a leading research group and mentored future Nobel laureates.

Although Prof. Salam's primary scientific contributions are not directly related to the medical physics, a further development of his career set a standard for education in the field theoretical physics extending his legacy far beyond his scientific achievements: in 1964 he founded the International Centre for Theoretical Physics (ICTP) in Trieste, Italy - dedicated to advancing research and supporting scientists from developing countries.

By coincidence Prof. Abdus Salam received his Nobel Prize in Physics in 1979, the same year when two medical physicists - Godfrey Hounsfield and Allan McLeod Cormack - received the Nobel Prize for Physiology or Medicine. Their discovery of the X-ray Computed Tomography transformed totally medical diagnostic imaging and opened the ways for the discovery and medical implementation of many new medical imaging methods.


Nobel Prize winners 1979, including Abdus Salam (3rd from right), Godfrey Hounsfield and Alan Cormac (1st and 3rd from left) – image courtesy to ICTP Archives.

Prof. Abdus Salam supported further medical physics when approving in 1988 the First ICTP Medical Physics College – an activity initiated by Dr Anna Benini and Prof. Luciano Bertocchi (who was ICTP Deputy Director). From this time now 38 years this College is the beacon of medical physics for many students from the Low-and-Middle Income (LMI) countries. Over 1500 students from nearly 90 LMI countries have attended this College over the years. Many of them becoming leading professionals for their countries and regions.

This way the legacy of Prof. Abdus Salam extends not only in theoretical physics, but also in physics applied to medicine, and from there to healthcare provision in all LMI countries. Further, in 2014 ICTP established the unique Master programme in Advanced Medical Physics – a join activity with the University of Trieste and the International Atomic Energy Agency (IAEA). The ICTP Award "Spirit of Salam" was presented to Prof. Bertocchi in 2015 (one year after the establishment of the Award), while in 2025 this ward was presented to the MSc Coordinator Prof. Renato Padovani.

The ICTP Medical Physics College will celebrate its 40th anniversary in 2028 which in turn will become another important occasion to appreciate Abdus Salam's contribution to our profession. The growing demand for and interest in medical physics, the achievements of our colleagues worldwide, the sustainable progress of the profession in the LMICs would be unthinkable without the cornerstone set by Abdus Salam and the continuous support of the ICTP which proudly carries his name.

First ICTP College on Medical Physics, 1988

Two photos of ICTP College on Medical Physics 2024 – with all students and Faculty

# INFORMATION FOR AUTHORS


## PUBLICATION OF DOCTORAL THESIS AND DISSERTATION ABSTRACTS

A special feature of Medical Physics International (on line at www.mpijournal.org ) is the publication of thesis and dissertation abstracts for recent graduates, specifically those receiving doctoral degrees in medical physics or closely related fields in 2010 or later. This is an opportunity for recent graduates to inform the global medical physics community about their research and special interests.

Abstracts should be submitted by the author along with a letter/message requesting and giving permission for publication, stating the field of study, the degree that was received, and the date of graduation. The abstracts must be in English and no longer than 2 pages (using the MPI manuscript template) and can include color images and illustrations. The abstract document should contain the thesis title, author's name, and the institution granting the degree.

Complete information on manuscript preparation is available in the INSTRUCTIONS FOR AUTHORS section of the online journal: www.mpijournal.org.

# INSTRUCTIONS FOR AUTHORS

The goal of the new IOMP Journal Medical Physics International (http://mpijournal.org) is to publish manuscripts that will enhance medical physics education and professional development on a global basis. There is a special emphasis on general review articles, reports on specific educational methods, programs, and resources. In general, this will be limited to resources that are available at no cost to medical physicists and related professionals in all countries of the world. Information on commercial educational products and services can be published as paid advertisements. Research reports are not published unless the subject is educational methodology or activities relating to professional development. High-quality review articles that are comprehensive and describe significant developments in medical physics and related technology are encouraged. These will become part of a series providing a record of the history and heritage of the medical physics profession.

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Manuscripts shall be in English and submitted in WORD. Either American or British spelling can be used but it must be the same throughout the manuscript. Authors for whom English is not their first language are encouraged to have their manuscripts edited and checked for appropriate grammar and spelling. Manuscripts can be up to 10 journal pages (approximately 8000 words reduced by the space occupied by tables and illustrations) and should include an unstructured abstract of no more than 100 words.

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The use of high-quality color visuals is encouraged. Any published visuals will be available to readers to use in their educational activities without additional approvals.

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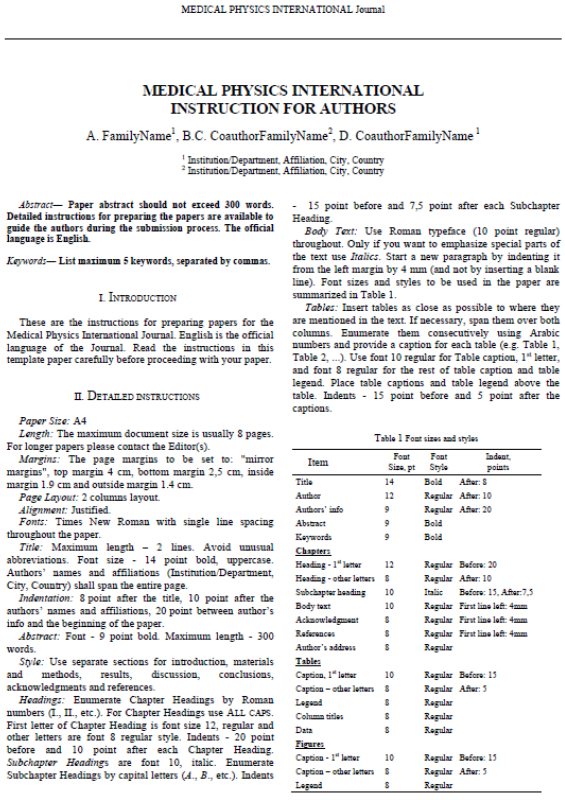

MEDICAL PHYSICS INTERNATIONAL Journal

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*Keywords*— **List maximum 5 keywords, separated by commas.**

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*Abstract:* Font - 9 point bold. Maximum length - 300 words.
*Style:* Use separate sections for introduction, materials and methods, results, discussion, conclusions, acknowledgments and references.
*Headings:* Enumerate Chapter Headings by Roman numbers (I., II., etc.). For Chapter Headings use ALL CAPS. First letter of Chapter Heading is font size 12, regular and other letters are font 8 regular style. Indents - 20 point before and 10 point after each Chapter Heading. *Subchapter Headings* are font 10, italic. Enumerate Subchapter Headings by capital letters (*A.*, *B.*, etc.). Indents - 15 point before and 7,5 point after each Subchapter Heading.
*Body Text:* Use Roman typeface (10 point regular) throughout. Only if you want to emphasize special parts of the text use *Italics*. Start a new paragraph by indenting it from the left margin by 4 mm (and not by inserting a blank line). Font sizes and styles to be used in the paper are summarized in Table 1.
*Tables:* Insert tables as close as possible to where they are mentioned in the text. If necessary, span them over both columns. Enumerate them consecutively using Arabic numbers and provide a caption for each table (e.g. Table 1, Table 2, ...). Use font 10 regular for Table caption, 1st letter, and font 8 regular for the rest of table caption and table legend. Place table captions and table legend above the table. Indents - 15 point before and 5 point after the captions.

Table 1 Font sizes and styles

| Item | Font Size, pt | Font Style | Indent, points |
|---|---|---|---|
| Title | 14 | Bold | After: 8 |
| Author | 12 | Regular | After: 10 |
| Authors' info | 9 | Regular | After: 20 |
| Abstract | 9 | Bold | |
| Keywords | 9 | Bold | |
| **Chapters** | | | |
| Heading - 1st letter | 12 | Regular | Before: 20 |
| Heading - other letters | 8 | Regular | After: 10 |
| Subchapter heading | 10 | Italic | Before: 15, After: 7.5 |
| Body text | 10 | Regular | First line left: 4mm |
| Acknowledgment | 8 | Regular | First line left: 4mm |
| References | 8 | Regular | First line left: 4mm |
| Author's address | 8 | Regular | |
| **Tables** | | | |
| Caption, 1st letter | 10 | Regular | Before: 15 |
| Caption – other letters | 8 | Regular | After: 5 |
| Legend | 8 | Regular | |
| Column titles | 8 | Regular | |
| Data | 8 | Regular | |
| **Figures** | | | |
| Caption - 1st letter | 10 | Regular | Before: 15 |
| Caption – other letters | 8 | Regular | After: 5 |
| Legend | 8 | Regular | |

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*Figures:* Insert figures where appropriate as close as possible to where they are mentioned in the text. If necessary, span them over both columns. Enumerate them consecutively using Arabic numbers and provide a caption for each figure (e.g. Fig. 1, Fig. 2, ...). Use font 10 regular for Figure caption, 1st letter, and font 8 regular for the rest of figure caption and figure legend. Place figure legend beneath figures. Indents - 15 point before and 5 point after the captions. Figures are going to be reproduced in color in the electronic versions of the Journal, but may be printed in grayscale or black & white.




Fig. 1 Medical Physics International Journal

*Equations:* Write the equation in equation editor. Enumerate equations consecutively using Arabic numbers

$$A + B = C \quad (1)$$

$$X = A \times e^{at} + 2lkt \quad (2)$$

*Items/Bullets:* In case you need to itemize parts of your text, use either bullets or numbers, as shown below:

- First item
- Second item

1. Numbered first item
2. Numbered second item

*References:* Use Arabic numbers in square brackets to number references in such order as they appear in the text. List them in numerical order as presented under the heading 'REFERENCES'. Examples of citations for Journal articles [1], books [2], the Digital Object Identifier (DOI) of the cited literature [3], Proceedings papers [4] and electronic publications [5].

III. CONCLUSIONS

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