The early years of radiation protection: a tribute to Madame Curie

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Education

Éducation

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In 1936, almost 4 decades after the discovery of the x-ray and of radium, the German Röntgen Society erected a monument to commemorate all who had died as a consequence of exposure to x-rays or radium. George W.C. Kaye of the US National Physical Laboratory wrote the inscription: "To the röntgenologists and radiologists of all nations, doctors, physicists, chemists, technical workers, laboratory workers, and hospital sisters who gave their lives in the struggle against the diseases of mankind. They were heroic leaders in the development of the successful and safe use of x-rays and radium in medicine. Immortal is the glory of the work of the dead."

One hundred years ago, on Dec. 26, 1898, Marie Curie, Pierre Curie and Gustave Bémont announced their discovery of a chemical element that would revolutionize medicine: "Les diverses raisons que nous venons d'énumérer nous portent à croire que la nouvelle substance radioactive renferme un élément nouveau, auquel nous proposons de donner le nom de *radium*. La nouvelle substance radioactive renferme certainement une très grande proportion de baryum: malgré cela, la radioactivité est considerable. La radioactivité du radium doit donc être enorme."[1] The discovery of radium came only 5 months after the Curies had announced the existence of another previously unknown element, which they named "polonium, du nom du pays d'origine de l'un de nous."[2]

Four years after the discovery of radium, Marie Curie reported its atomic weight.[3] This was the result of a very labour-intensive endeavour. The isolation of 1 gram of pure radium had required the handling and processing of 8 tons of pitchblende ore. In handling this enormous amount, Marie and Pierre Curie unknowingly exposed themselves continuously to radioactivity; they contaminated their food and clothes with radium and inhaled radon, the gaseous by-product of decaying uranium and radium. It is therefore not surprising that they both complained of fatigue and ill health. In addition, Mme Curie grew thinner by several kilograms. These changes did not go unnoticed by their friends: "J'ai été frappé, en voyant M^{me} Curie à la Société de Physique, de l'altération de ses traits."[4] Nevertheless, Mme Curie gave birth to 2 healthy daughters as well as leaving a remarkable scientific legacy.[5,6] She went on to receive 2 Nobel prizes — one in physics and one in chemistry — and received many honorary degrees from universities all over the world. She also contributed significantly to the development of radiology during World War I.[7] It is interesting that the Curies initially chose to ignore exposure to radioactivity as a health hazard. In 1900, Pierre Curie voluntarily exposed his arm to radium for several hours and as a consequence developed a burn.[8] Eventually, though, Mme Curie not only recognized "that radium was dangerous in untrained hands" but went on to advocate specific training for those who worked with radioactive substances.[9]

On this, the 100th anniversary of the discovery of radium, it is fitting to review the first years of radiation protection, a process that started 3 years before the discovery of radium and that initially was focused on the health hazards of x-ray exposure.

Within a few weeks after the discovery of x-rays by the German physicist Wilhelm Konrad Röntgen,[10] the first published reports of the ill effects of x-ray exposure began to appear. Thomas A. Edison and William J. Morton independently reported that their eyes were affected after exposure to x-rays.[11,12] It is unclear whether this was caused by x-ray exposure or simply by the strain of peering for prolonged periods at a dimly fluorescing screen. Indeed, neither Edison nor

Mme Curie in her laboratory at the Radium Institute, 1921

Morton suggested that x-rays were the cause of their eye trouble. During the same period, Alan Archibald Campbell-Swinton recorded that he and his associates had not experienced ill effects to their eyes after working with Crookes tubes (part of the apparatus used to generate x-rays) for many hours.[19] Nonetheless, as more powerful x-ray equipment was introduced, additional accounts of complications began to appear. Several reports described skin reactions similar to sunburn.

The American physicist Elihu Thomson was the first to prove a direct relation between exposure to x-rays and some of the reported effects. He deliberately exposed his left index finger to an x-ray tube for half an hour a day for several days. The resulting erythema, swelling and pain confirmed the suspected relation.[13] Unequivocal proof of the damaging effects of x-rays came with the reports of William Rollins, who described the fatal results of prolonged x-ray exposure on guinea pigs.[14] On the basis of his observations, Rollins suggested that x-ray users wear radio-opaque glasses, that the x-ray tubes be enclosed in leaded housing and that only areas of interest be irradiated and adjacent areas covered with radio-opaque materials. From 1887 to 1904, Rollins, a true pioneer in radiation protection, made many scientific contributions to the field and developed numerous devices to protect both patients and x-ray operators. Unfortunately, his warnings

X-rays, radiation, radioisotopes and radiation therapy

The first x-rays were produced using a cathode x-ray tube of the type used by the English physicist William Crookes and other pioneers in their early experiments. Subsequently, many changes were made to improve the efficiency of generating x-rays. X-rays are produced when electrons are accelerated across a high potential difference, usually measured in kilo- or mega-volts, and impinge on a suitable target. The energy of the accelerated electrons is dissipated largely through heating of the target material (usually a heavy metal such as tungsten) and through the release of x-rays. These are bundles of energy without mass or charge and are termed photons. There is a wide spectrum of photons, their basic physical properties being the same, but their characteristics varying according to their inherent energy. Radio waves and visible light are made up of photons, for example. When photons, i.e., x-rays, are produced by kilo- or mega-voltage machines, they are very penetrating and can be used for both diagnostic and therapeutic purposes.

Radiographs are produced using x-rays of relatively low voltage. When they strike a sensitive film emulsion they produce a latent image, which is brought out by developing and fixing the film in a process similar to that of black-and-white photography.

X-rays used therapeutically have higher energy, usually in the megavoltage range. These photons can penetrate deeper into the body, where their energy is released and biologic effects are produced through complex interactions with cells. The source of the radiation is at a distance from the patient, and the x-ray beam is channelled so that only the cancer site receives the high-dose radiation. Because the source is at a distance, this technique is termed "teletherapy," from the Greek *tele*, "far off."

So far, we have only described x-rays produced by machines. Naturally or artificially produced radioactive materials (radioisotopes) can also emit photons. Radium and cobalt-60, respectively, are examples of these 2 types. The radiation they produce is often termed "gamma rays." The physical properties of gamma rays are identical to those of x-rays. For practical as well as technical reasons, gamma rays are not used for diagnostic purposes but are employed only for therapy. They are inserted into or applied closely to the cancerous tissue. This technique is known as "brachytherapy," from the Greek *brachy*, "short."

against the dangers of x-rays were initially characterized as overdramatic,[15] and many of his safety innovations went unnoticed. Looking back, it is apparent that Rollins was ahead of his time in the field of radiation protection.

Once a direct relation between x-ray exposure and erythema of the skin was acknowledged, most x-ray operators felt that protecting the skin by means of x-ray filters would likely also provide protection against delayed reactions. George E. Pfahler's introduction of a novel filter that selectively strained the least penetrating rays was felt to be a huge step forward in the protection of patients and operators.[16] Indeed, Pfahler's simple disk of sole leather provided protection because it is the less penetrating rays that burn the skin. However, the filter did not provide adequate protection for those using the same device for therapeutic purposes. In that setting, many physicians used skin protection to increase the dose to the deeper tissues. As a consequence, the risk for delayed nondermatologic effects increased. Unfortunately, the earliest therapeutic use of x-rays was in the treatment not of malignant conditions but of benign disorders such as tinea capitis, acne vulgaris, eczema, lupus, skin tuberculosis and so on.

The issue of radiation protection had become a topic of great concern internationally by 1907. The death of several x-ray operators revealed the serious risks associated with their profession and led to recommendations with regard to the need for adequate training, knowledge and experience.[17] It wasn't until 8 years later, 1 year after the start of World War I, that the Röntgen Society promulgated the first guidelines regarding radiation protection for x-ray operators. It took another 6 years before the British X-ray and Radium Protection Committee issued a preliminary report on radiation protection measures.[18] The committee had been assigned the task of drawing up recommendations for the safe manufacture and use of radium and roentgen ray apparatuses. One year later, similar recommendations were published by the American Roentgen Ray Protection Committee. The recommendations of the British X-ray and Radium Protection Committee were accepted internationally in 1928 after the establishment of the International X-ray and Radium Protection Committee during the second International Congress of Radiology in Stockholm, Sweden. Some radiologists and equipment makers continued to believe that the recommendations were unnecessarily stringent and burdensome,[19] but by the mid-thirties most, if not all, objections had been overcome. No one today denies the need for the greatest care and strictest observance of the recommendations promulgated by international bodies charged with those responsibilities.

Radiation safety measures evolved too late to save the protagonist of this brief note. Upon the death of Mme Curie in 1934, Dr. Tobé reported: "Madame Pierre Curie est décédée à Sancellemoz le 4 juillet 1934. La maladie est une anémie pernicieuse aplastique à marche rapide, fébrile. La moelle osseuse n'a pas réagi, probablement parce qu'elle était altérée par une longue accumulation de rayonnements."[5] Until recently, it was generally believed that the extensive and prolonged exposure to radium caused her final illness.[20] This seems not to have been the case, however. In 1995, Mme Curie's body was exhumed for reburial in France's national mausoleum, the Panthéon. Scientists from the French Office de Protection contre les Rayonnements Ionisants found that the level of radium emanations within the coffin was significantly lower than the maximum accepted safe levels of public exposure.[21] Given these low levels and the very long half-life of radium (1620 years), the Office concluded that Mme Curie's final illness and death were probably not caused by extended exposure to radium. More likely, it was the direct result of her overexposure to x-rays during World War I, when she made significant contributions to military medicine through the establishment of mobile radiographic units.[7] Thus, ironically, Marie Curie became a martyr to the advances in radiography and not to radiation therapy, the clinical specialty that developed from her epochal laboratory research.

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