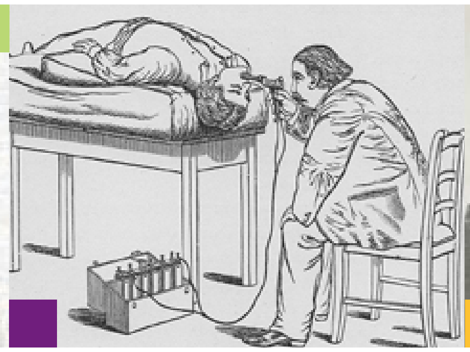
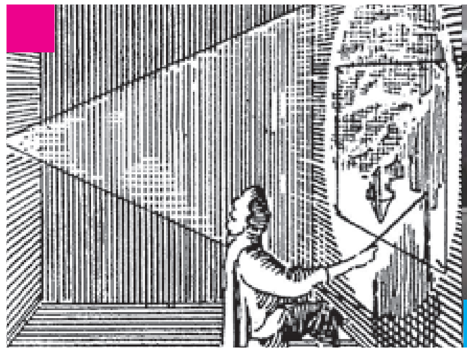
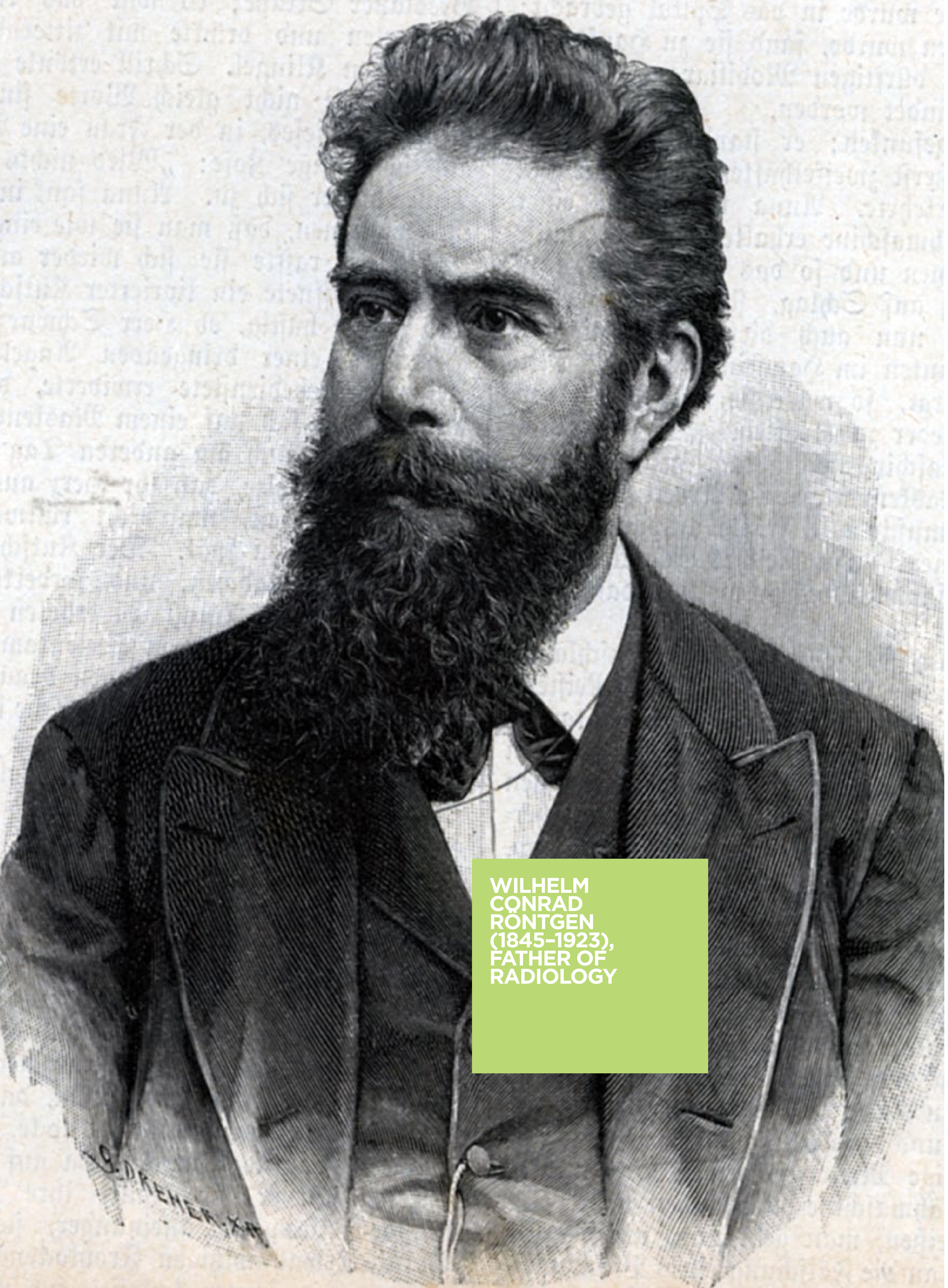
European Society of Radiology

THE STORY OF RADIOLOGY

Volume 3

WILHELM CONRAD RÖNTGEN (1845–1923), FATHER OF RADIOLOGY

THE STORY OF RADIOLOGY

On November 8 each year, radiologists, radiographers, medical professionals and scientists from all over the world get together to celebrate Wilhelm Conrad Röntgen's discovery of the x-ray. The International Day of Radiology has become a major occasion since its launch three years ago, helping to promote the importance of radiology in modern healthcare to the general public.

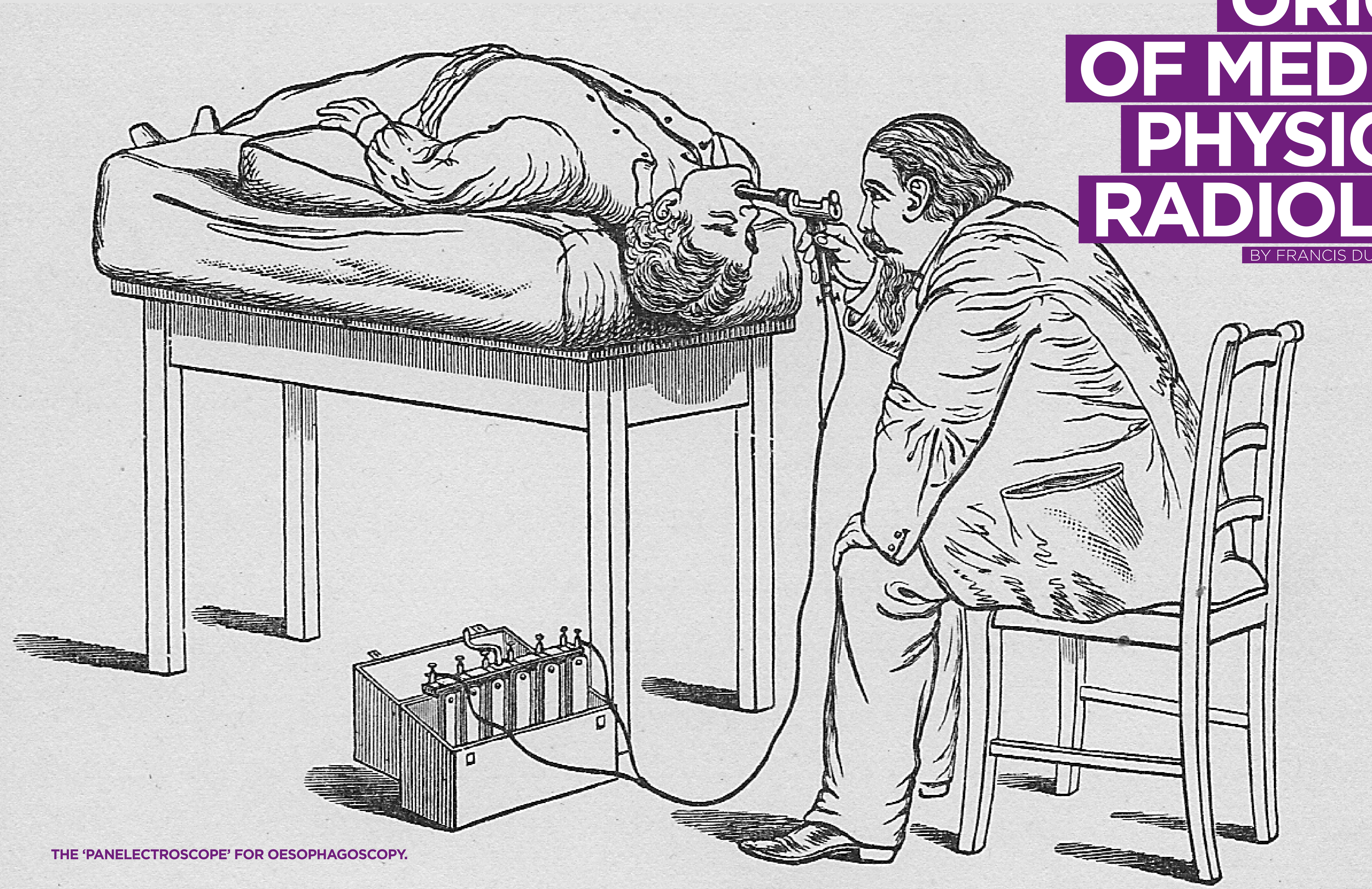
But no International Day of Radiology would be complete without another chapter in the great *Story of Radiology*. This year you will learn about the use of medical imaging during the First World War, as we observe the 100th anniversary of that brutal moment in history. You will also get an insight into the life of one of the most famous scientists in history, Marie Curie, whose groundbreaking research and discoveries paved the way for the modern science of radiology. The development of MRI, the relationship between photography and radiology, as well as the origins of medical physics, are also explored in this year's edition.

Once again, this book was only possible through the generous support from the International Society for the History of Radiology and the German Röntgen Museum, who provided the content. As the world remembers the bloody battles of the First World War, it is really worth reflecting on how medical imaging adapted to treat war casualties on the front. Meanwhile, scientists like Curie strived to use this emerging technology to save lives while Europe's armies introduced new technology to take lives.

This book covers a brief but significant period in the history of radiology, and adds to the story already told in the previous two volumes. Given the wide range of scientific discoveries and pioneers responsible for making modern medical imaging possible, you can expect to see many more volumes of the *Story of Radiology* in the future.

ORIGINS OF MEDICAL PHYSICS IN RADIOLOGY

BY FRANCIS DUCK AND UWE BUSCH



THE ‘PANELECTROSCOPE’ FOR OESOPHAGOSCOPY.

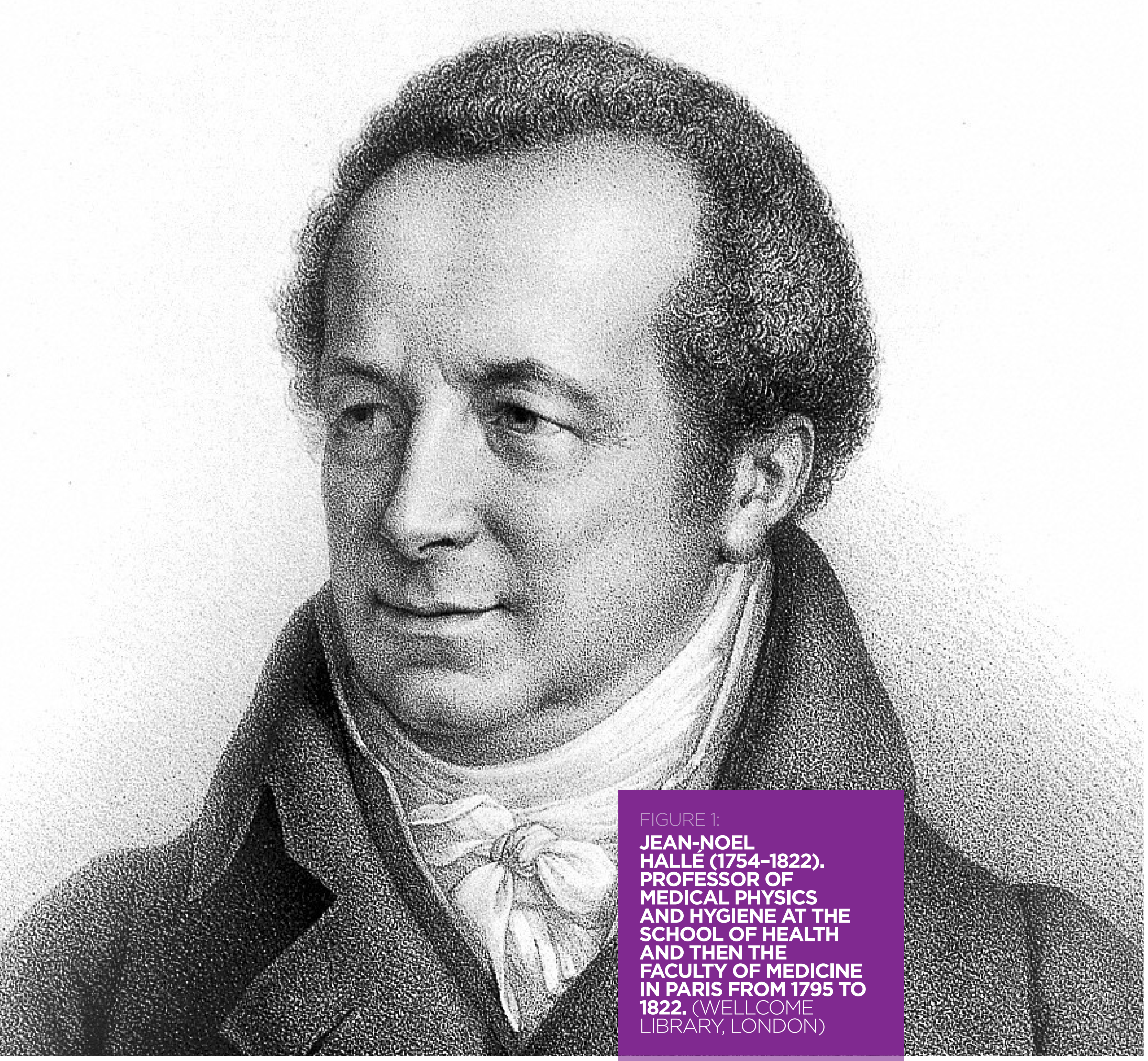


FIGURE 1:
JEAN-NOEL HALLÉ (1754–1822). PROFESSOR OF MEDICAL PHYSICS AND HYGIENE AT THE SCHOOL OF HEALTH AND THEN THE FACULTY OF MEDICINE IN PARIS FROM 1795 TO 1822. (WELLCOME LIBRARY, LONDON)

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A DEFINITION OF MEDICAL PHYSICS

The modern practice of medical physics is largely concerned with the application of ionising radiation. It was not always so. A medical dictionary from 1814 defined medical physics much more broadly as 'physics applied to the knowledge of the human body, to its preservation and to the cure of its illnesses.[1]

This concise definition was almost certainly created by Jean Hallé (1754–1822) (Fig. 1). He was appointed in 1795 as the first chair of medical physics and hygiene in the post-revolutionary *École de santé* in Paris. This appointment constituted a firm endorsement of physics in medical training, summed up by the leading politician, chemist and doctor the Comte de Fourcroy (1755–1809) who, in 1791, declared that "The study of medicine always starts with the study of physics. It is not possible to be a doctor without being a physicist."

For those who associate medical physics only with radiology and radiotherapy, this historical perspective may be surprising. But even the emergence of medical physics as a formal subject in France at the end of the eighteenth century was preceded by many examples of physical scientists contributing to medical understanding. Examples are the biomechanics of Giovanni Borelli (1608–79), Johannes Kepler's description of the eye in 1600 as no more than an optical instrument, the application of Newtonian aether to neuro-muscular actions, and the analysis of the work of the heart by Daniel Bernouilli (1700–1782) in 1753. Details of these and many other stories in the history of medical physics may be found elsewhere.[2, 3]

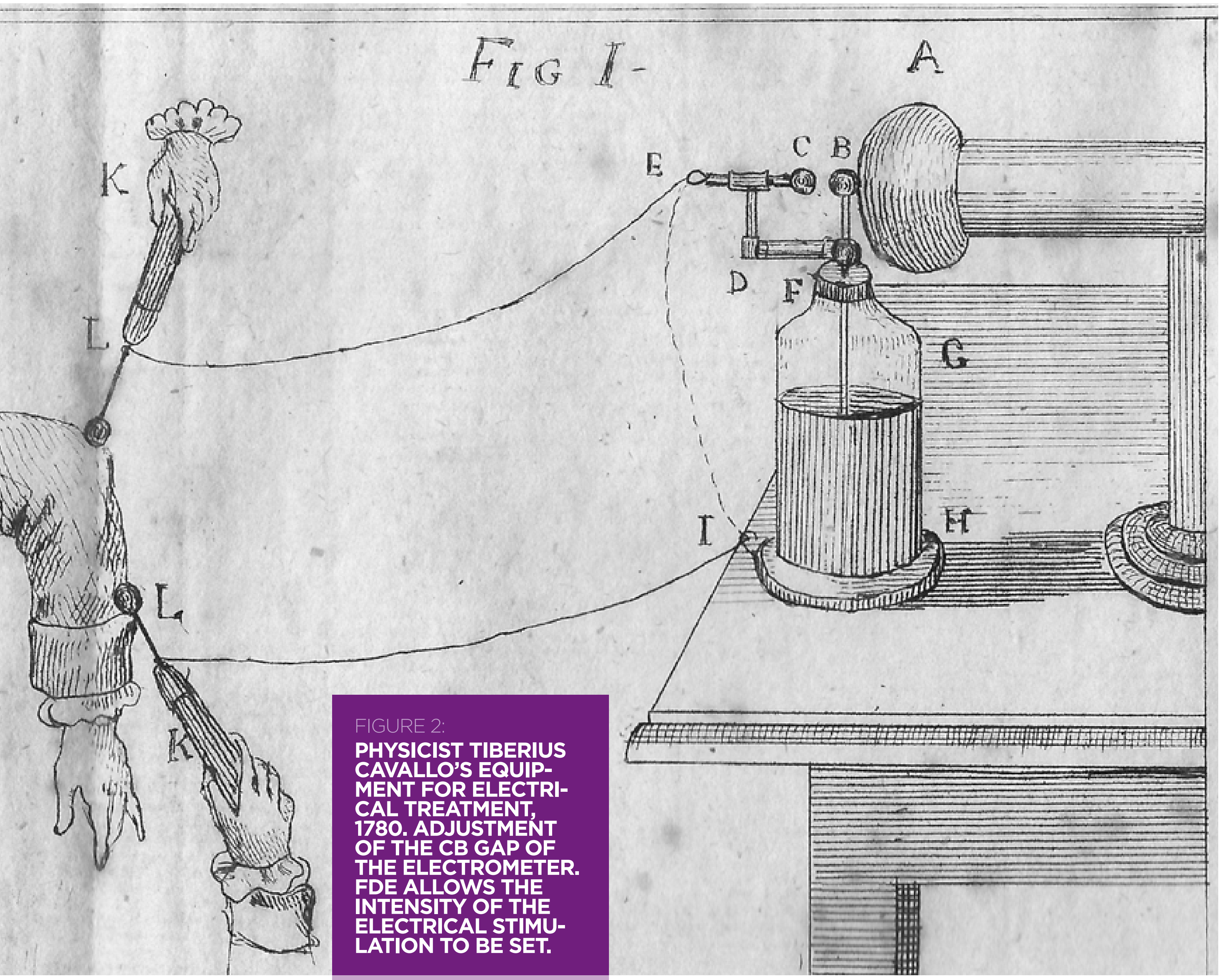

FIGURE 2:
PHYSICIST TIBERIUS CAVALLO'S EQUIPMENT FOR ELECTRICAL TREATMENT, 1780. ADJUSTMENT OF THE CB GAP OF THE ELECTROMETER. FDE ALLOWS THE INTENSITY OF THE ELECTRICAL STIMULATION TO BE SET.

When Hallé became professor of medical physics there was much emphasis on the health effects of the environment and the weather, resulting in the development of standards for measuring temperature, barometric pressure and humidity. Soon a new direction emerged through Galvani's demonstrations of medical electricity, and Volta's subsequent demonstration, in 1800, of the first electric battery. These developments initiated renewed medical interest in electro-therapeutics, known as galvanism. Medical electricity was then relatively new, following the demonstration of charge storage by Peter Musschenbroek (1692–1761) in Leyden in 1746. Physicists quickly started to explore its possible medical applications. In Paris, Abbé Jean-Antoine Nollet (1700–1770) published his observations on the biological effects of electricity.[4] Jean Jallabert (1712–1768), professor of mathematics and philosophy in Geneva, was among several who reported successful treatment of paralysis using electric shocks.[5] These techniques had become well established by the end of the 18th century (Fig. 2).

PHYSIOLOGICAL PHYSICS

Nineteenth century medical physics became dominated by physiological physics. It was only in the twentieth century that the emphasis moved towards the use of physical techniques in the diagnosis and treatment of illness, most notably stimulated by the discovery of x-rays. Early books on medical physics appeared, the first in 1844 by the professor of physics in Pisa, Carlos Matteucci (1811–1868),[6] and then by the better-known German physiologist Adolf Fick (1829–1901).[7] Not long after he joined Carl Ludwig (1816–1895) in Zurich, Fick wrote a

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supplement on medical physics for a widely-used physics text book. He covered diffusion, skeletal mechanics, haemodynamics, acoustics, animal heat, physiological optics and bio-electricity, with each chapter including contributions from his own research. In Fick's last chapter he described nine instruments for physiological measurement: the planimeter, Ludwig's kymograph (Fig. 3), the sphygmograph, the microscope, Helmholtz's ophthalmoscope and chronometer, the stereoscope, du Bois-Reymond's galvanometer, and his induction apparatus for inducing tetanus. These physical instruments revolutionised physiological measurement, giving doctors tools for measurement that would alter diagnostic medicine forever. Fick is also remembered for his method of estimating cardiac output from measurements of pulmonary arterio-venous oxygen difference and lung oxygen consumption. He presented this proposal to the Würzburg Physical-Medical Society on July 9, 1870. Wilhelm Röntgen was present, as a new member, while working as August Kundt's young assistant. Twenty-five years later he would present his new kind of rays to the same Würzburg society.

Arguably the most important contribution to medicine from physics during this period was to show that vitalism was a false paradigm. Physiological thinking had asserted that there were laws governing life processes that were not dependent on the laws of physics and chemistry of non-living matter. Specifically, living tissues had innate attributes of sensibility and contractility, properties that were intrinsic and unique to life. During the middle decades of the century the concept of energy, its conservation and its variety of forms, slowly took hold. By 1866, Jules Gavarret (1809–1890), professor of medical physics at the

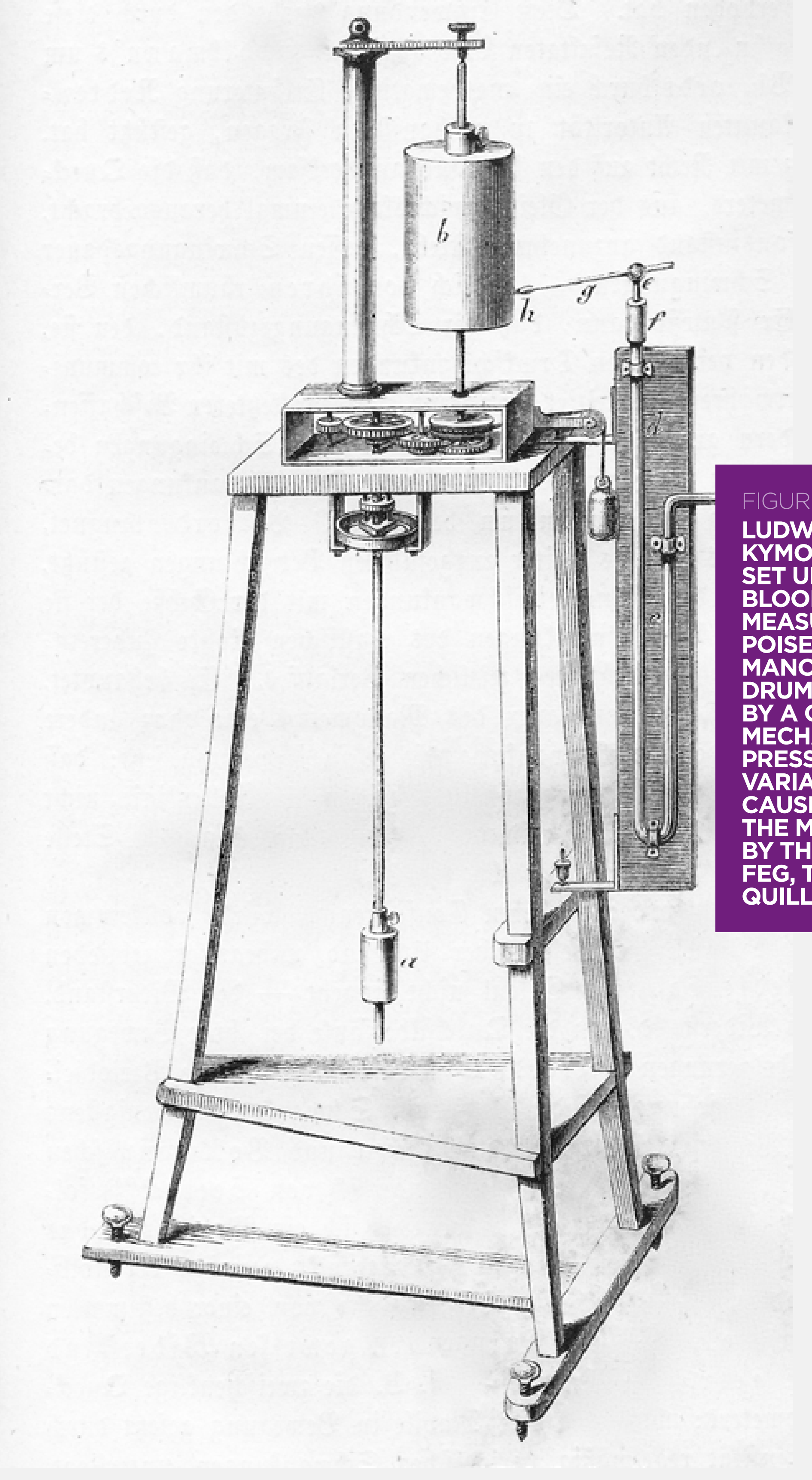

FIGURE 3:
LUDWIG'S KYMOGRAPH SET UP FOR BLOOD-PRESSURE MEASUREMENT, USING POISEILLE'S MERCURY MANOMETER. THE DRUM, B, IS ROTATED BY A CLOCKWORK MECHANISM. PRESSURE VARIATIONS AT I CAUSE MOVEMENT OF THE MERCURY LINKED BY THE LEVER ARM, FEG, TO THE MARKER QUILL, H.

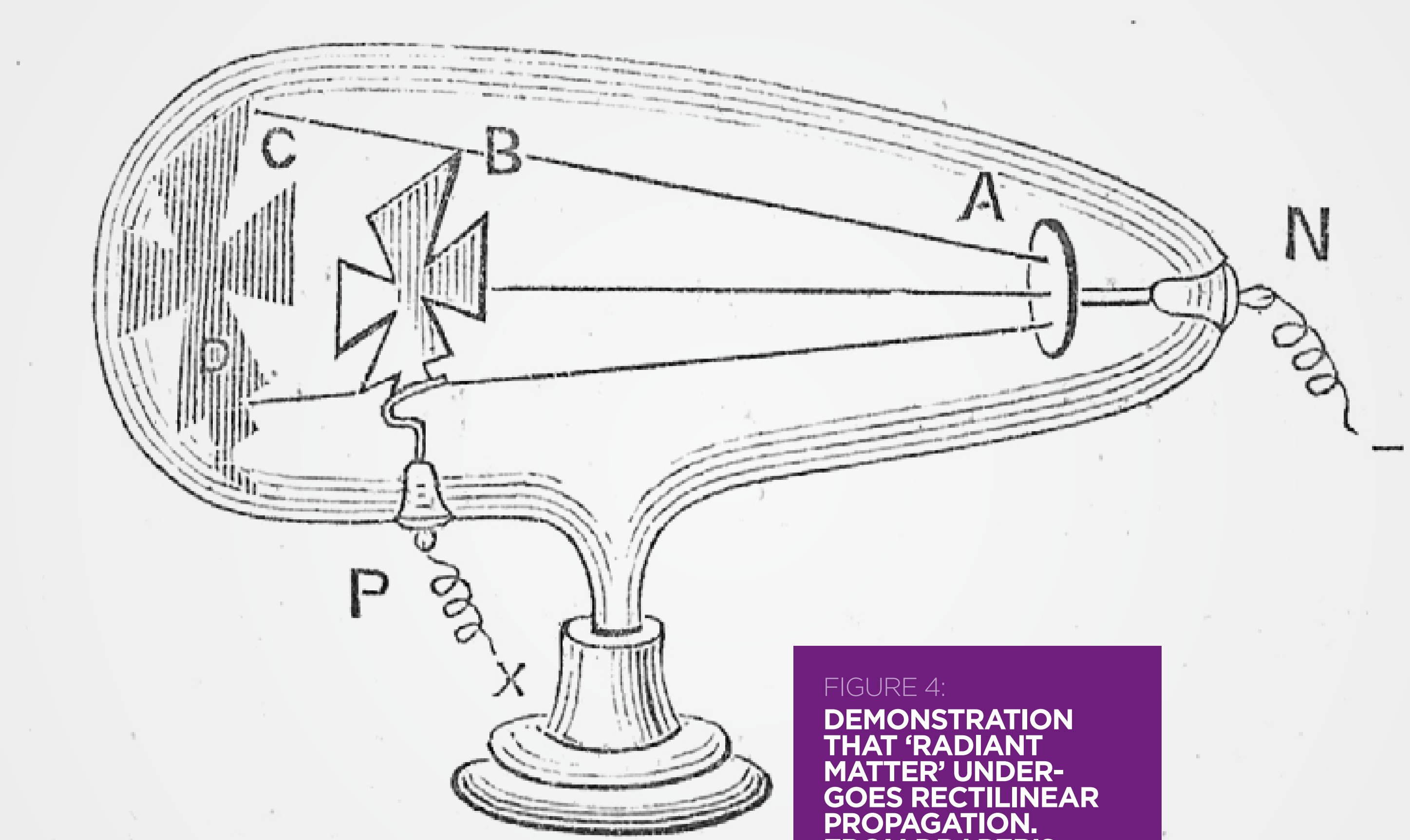

FIGURE 4:
DEMONSTRATION THAT 'RADIANT MATTER' UNDER-GOES RECTILINEAR PROPAGATION. FROM DRAPER'S *MEDICAL PHYSICS* (1885)

faculty of medicine in Paris, further developed these ideas in the context of living bodies in his advanced course *Physique biologique*.[8] Here he marshalled arguments from energetics for a final push against the "mere useless hypothesis … that the vitalist school invoke to explain the phenomena of nutrition and development."

Medical physics failed to gain as much influence in Britain and the USA during this period. In 1827, Neil Arnott was the first to use the term medical physics in English in his international best-selling book on popular science.[9] The first medical physics book in English was not published until 1885, by John Christopher Draper (1835–1885), a New York professor.[10] Draper starts his preface, "The fact that a knowledge of physics is indispensable to a thorough understanding of medicine has not yet been as fully realised in this country as in Europe." A review for the American Medical Association reported, "Thus far our colleges may, with but few exceptions, be said to have 'thrown physics to the dogs'." Nevertheless, Draper's book included a prescient and well-illustrated chapter on 'radiant matter' (Figs. 4 and 5). Ten years later, any medical student who trained at that time was aware that the tubes might emit x-rays.

MEDICAL ELECTRICITY

In the clinic, medical electricity had never become fully accepted, remaining on the fringes of medicine, primarily in the diagnosis and treatment of paralysis, palsy and other neuro-muscular conditions (Fig. 6). Nevertheless, by the end of the nineteenth century, new electrical applicati-

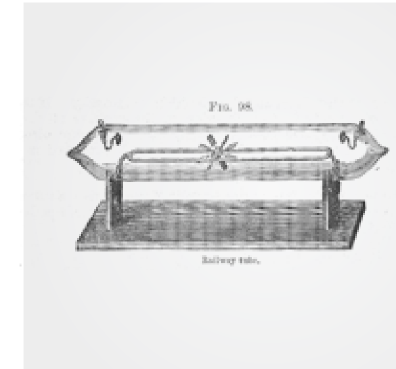

FIGURE 5:
RAILWAY TUBE, ANOTHER ILLUSTRATION OF RADIANT MATTER, FROM DRAPER'S *MEDICAL PHYSICS*

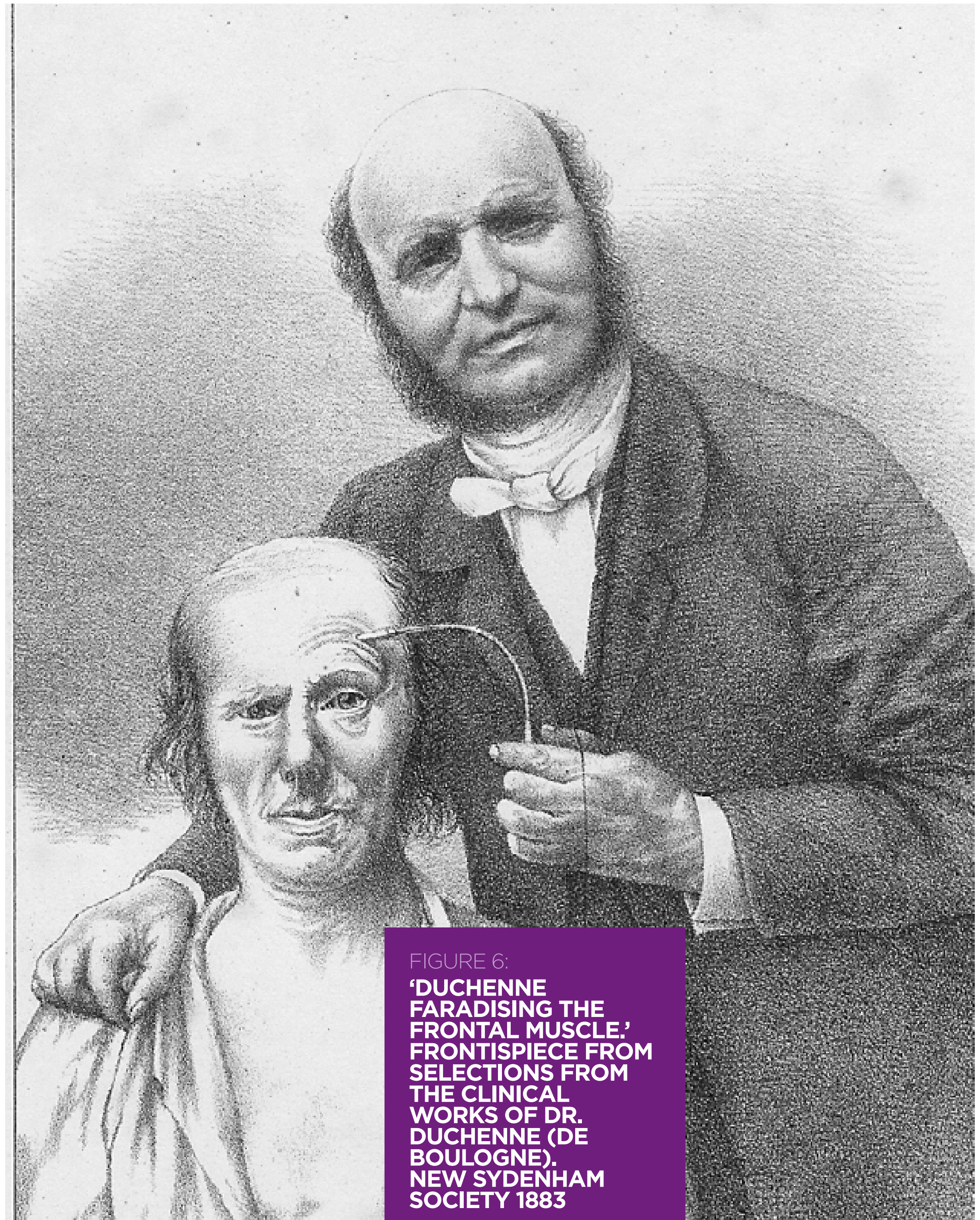

FIGURE 6:
'DUCHENNE FARADISING THE FRONTAL MUSCLE.' FRONTISPIECE FROM SELECTIONS FROM THE CLINICAL WORKS OF DR. DUCHENNE (DE BOULOGNE). NEW SYDENHAM SOCIETY 1883

ons were introduced as electrical technology developed. Electro-cautery was introduced, and Edison's carbon filament bulbs opened a new era of endoscopic investigations (Fig. 7, see page 6) replacing hazardous heated platinum wires. Resonant coils enabled foreign bodies to be located, and electromagnets were used to remove ferrous objects.

During the last decade of the nineteenth century, there were further developments from physics applied to medical treatment. The therapeutic use of infrared and ultraviolet radiation was pioneered by the Nobel prize-winning Danish doctor Niels Finsen (1860–1904).[11] In 1893, he introduced 'red room' treatment for smallpox lesions, and in 1895 he showed that *lupus vulgaris,* a disfiguring form of tuberculosis, responded to treatment with UV (Fig. 8). Thus, photo-therapy was born. A second new therapy arose from the demonstration of radio waves in 1888 by Heinrich Hertz (1857–1894). Arséne d'Arsonval (1851–1940), professor of biophysics at the *Collége de France* in Paris, was investigating the biological responses to direct and alternating currents and the problem of industrial deaths from electrocution. From the knowledge he gained, he introduced the first clinical high-frequency heat therapy unit, in the *Hôtel Dieu,* in 1895. Thus, modern electrotherapy was born.

THE DISCOVERY OF X-RAYS

Nevertheless, the true re-emergence of medical physics came from a discovery made at the University of Würzburg in 1895. Here, six years earlier, Wilhelm Conrad Röntgen (1845–1923), from Lennep, Rhineland, had returned to the chair of physics as the successor to Friedrich Kohlrausch (1840–1910).

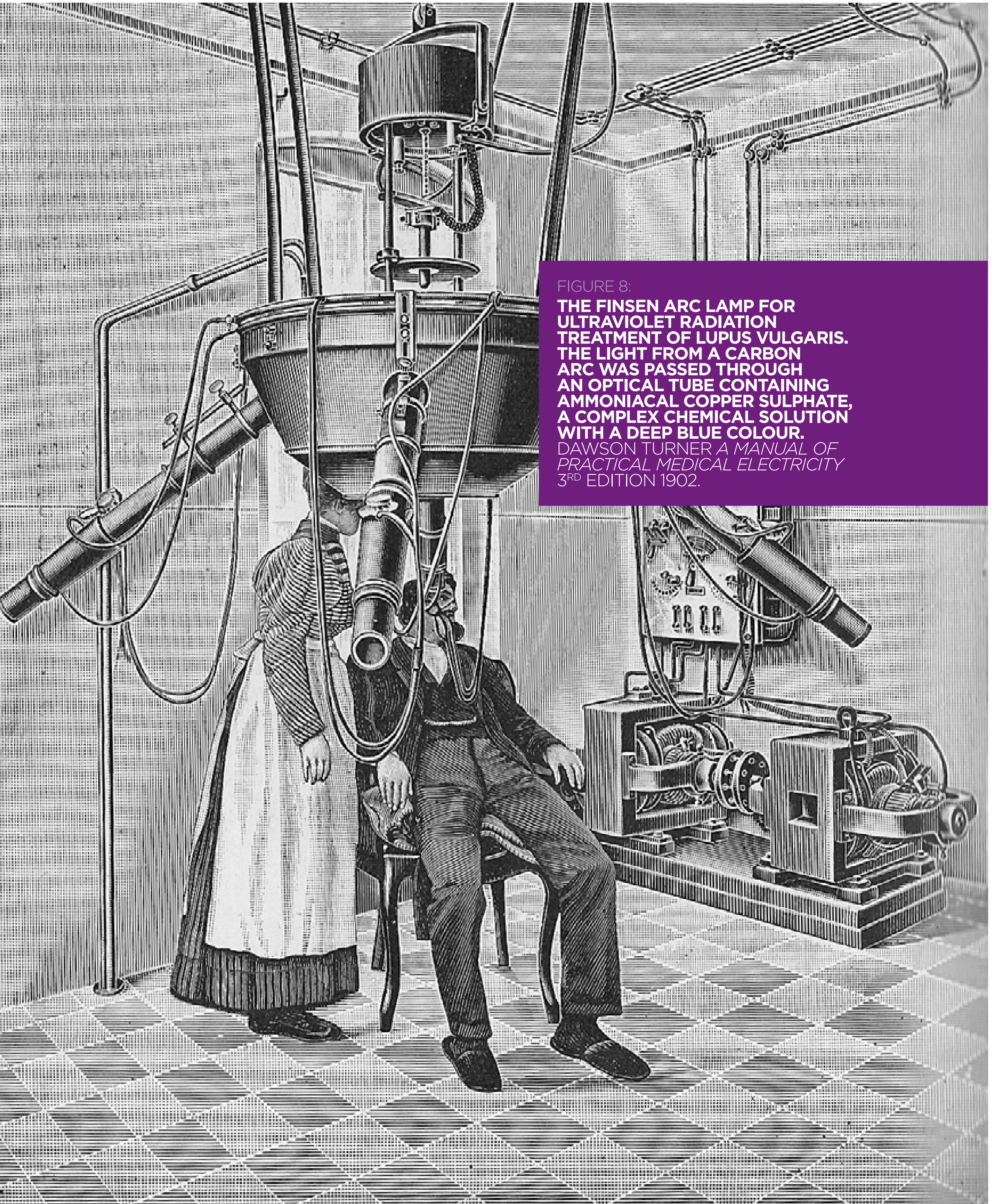

FIGURE 8:
THE FINSEN ARC LAMP FOR ULTRAVIOLET RADIATION TREATMENT OF LUPUS VULGARIS. THE LIGHT FROM A CARBON ARC WAS PASSED THROUGH AN OPTICAL TUBE CONTAINING AMMONIACAL COPPER SULPHATE, A COMPLEX CHEMICAL SOLUTION WITH A DEEP BLUE COLOUR.
DAWSON TURNER *A MANUAL OF PRACTICAL MEDICAL ELECTRICITY* 3RD EDITION 1902.

Before his discovery, and like many other physicists in the 19th century, Röntgen was interested in the main fields of classical physics. These included the physics of solid and fluid bodies, the work of Rudolf Clausius (1822–1888) on the second law of thermodynamics and Lord Kelvin's (1824–1907) definition of the absolute temperature. Van der Waals' (1837–1923) mathematical description of real gases and the universal formula for radiation from black surfaces by Max Planck (1858–1947) were also of great interest. Electrodynamic theory had developed from the work of Hans Oersted (1777–1851), André Marie Ampére (1775–1836), Michael Faraday (1791–1867) and Georg Ohm (1787–1854), leading to a second classic theory in physics, after Newton's theory of gravitation, by James Clark Maxwell (1831–1879). Using Maxwell's theory George Fitzgerald (1851–1901) predicted electromagnetic radio waves, and Heinrich Hertz (1857–1894) demonstrated their properties. There was widespread interest in phosphorescence and fluorescence.

By early 1894, Röntgen had become interested in the physical nature of cathode rays produced in evacuated gas tubes. These had been widely studied by many physicists, particularly following improvements in mercury vacuum pumps in the early 1870s. During the summer of 1895, he assembled his equipment, including a large induction coil and suitable discharge tubes. It was already known that cathode rays were absorbed in air, gases, and in thin metal foils roughly according to the total mass of the matter traversed. It was also known that fluorescence was excited in fluorite or barium platinum cyanide crystals.

Röntgen never reported what measurements he intended to make. The question of whether he was interested in the law of absorption of cathode rays or in the excitation of fluorescence in different media remains unanswered. The fact is that he noticed that a barium platinum cyanide screen lying on the table at a considerable distance from the tube showed a flash of fluorescence every time a discharge of the induction coil went through the tube. This flash could not be due to cathode rays because these would have been fully absorbed by the black cardboard with which Röntgen covered the tube. He concluded that the fluorescence was caused by something, the unknown agent X, that travelled in a straight path from the spot where the cathode rays in the tube hit the glass wall; and that the phenomenon could cast a shadow in the fluorescent area of the screen. He therefore spoke of 'x-rays'. Roentgen also noticed that x-rays were able to expose photographic plates, "without removal of the shutter of the dark slide or other protecting case, so that the experiment need not be conducted in darkness."

He examined the character of absorption in different materials and was able to determine an attenuation law analogous to light. In other ways, however, x-rays did not seem to behave like light, and by using prisms and mirrors he found no evidence for their reflection or refraction. A strong magnetic field failed to cause any deviation in the beam, prompting Röntgen to deny a close relationship between cathode rays and x-rays. Left without strong evidence, he could only speculate as to the physical nature of the x-rays. It was only in 1912 that Max von Laue, Walter Friedrich and Paul Knipping were able to describe the wave character of x-rays.

Röntgen was able to take radiographs of his laboratory door that was painted with lead paint, a metal spiral in a wooden box and his laboratory set of weights. These impressive shadow pictures clearly justified the use of the term 'rays'. On December 22, 1895, Röntgen asked his wife Anna Bertha if he could make a radiograph of her hand. On the photographic plate the bones of her hand and two rings can be seen distinctively. This picture became a historic document and December 22, 1895 became the true birthday of radiology as a medical speciality.

A few days later, on December 28, 1895 Röntgen sent the manuscript of the first communication on x-rays 'Über eine neue Art von Strahlen (Vorläufige Mittheilung)' to the secretary of the Würzburg Physical-Medical Society for publication in the official journal of the society. It was printed in the first week of 1896, and Röntgen sent reprints and enclosed nine photographs to prominent scientists. Among them were Franz Exner (Vienna), August Voller (Hamburg), Emil Warburg (Berlin), Otto Lummer (Berlin), Ludwig Zehnder (Freiburg), Friedrich Kohlrausch (Strassburg), Hendrik A. Loretz (Leiden), Lord Kelvin (Glasgow), Arthur Schuster (Manchester), Henri Poincaré (Paris) and others.

PHYSICISTS AND THE ORIGINS OF RADIOLOGY

Why had others not recognised the existence of x-rays before Röntgen? Plenty of other physicists were experimenting with discharge tubes at that time and certainly in a number of cases x-rays would have been generated. As the Cambridge physicist J.J. Thomson remarked of someone (possibly Crookes) who had noticed that his photographic plates had become fogged: "All he did was to move the plates further away; he saved the plates but lost the Röntgen rays."[12] The view of Arthur Schuster, German by birth and by then professor of physics in Manchester, was that few laboratories were equipped to be able to achieve the appropriate vacuum, and "English lead glass is much less suitable than the soft German glass to excite and transmit the rays."[13] Sylvanus P. Thompson blamed the situation in London on its university, which was an examining body only and received no state funding. As a result "the physical laboratories of the university are practically non-existent."[14] For whatever reason, it was Röntgen who had the perception to observe what had been missed by others, and then the scientific integrity to investigate fully this new form of radiation that he had discovered.

The medical interest was immediate and, where there were strong local links between experimental physicists and medical practitioners, the first clinical radiographs were carried out very soon after Röntgen's announcement. Two distinct circumstances can be recognised. In the first, a hospital department of medical electricity was already equipped with several sources of electricity, including frictional machines, batteries and generators, along with induction coils and interrupters and an enthusiast who understood this technology. This pattern was common in the London hospitals. Where there was no local department of medical electricity, x-ray equipment was typically set up in the physics laboratory of the local university, where patients were sent by their doctors to be examined.

University-based medical education was established much later in Britain than was the case in other European countries, and physics was typically taught, not by a member of the medical faculty, but by the local professor of physics. Amongst others, Lord Kelvin in Glasgow, George Fitzgerald in Dublin, Peter Tait in Edinburgh, Oliver Lodge in Liverpool and J.J. Thomson in Cambridge were all lecturing in physics to medical students during the last decade of the nineteenth century. These active links were to be essential to the rapid development of radiology in the early months of 1896 in Britain.

John Macintyre (1857–1928) was a Glasgow otolaryngologist and with his own department of medical electricity. Lord Kelvin, now over 70 and working from his sick-bed at the time, passed Röntgen's reprint, unopened, to his second-in-command and nephew, the physicist James Bottomley (1845–1926). He was exploring very high-vacuum tubes at the time[15] and, together with the local amateur scientist Baron Blythswood (1835–1908), helped to set up the apparatus that enabled Macintyre to carry out his pioneering x-ray studies. By contrast, in other centres that lacked an enthusiastic and knowledgeable medical electrician, patients were sent to the local physics laboratory. J.J. Thomson arranged for E. Everett and W. H. Hayles, assistants in his Cavendish laboratory in Cambridge, to make x-ray images of patients referred from Addenbrooke's Hospital.[16] Arthur Schuster in Manchester was "inundated by medical men bringing patients," to the point that his assistant, Arthur Stanton, had a nervous breakdown, and his own work on the magnetic deflection of cathode rays was seriously delayed. Other examples that built rapidly on pre-existing lecturing links between

FIGURE 9:
RADIOGRAPH OF AN EGYPTIAN CAT MUMMY.
(ARCHIVE GERMAN ROENTGEN-MUSEUM)

physics professors and medical schools were those of Oliver Lodge (1851–1940) in Liverpool, John Poynting (1852–1914) in Birmingham and William Hicks (1850–1934) in Sheffield. In London, the academic physicists remained largely separate from these early developments and medical men looked for scientific support elsewhere. Where there were well-established electrical departments, x-rays were quikkly introduced, for example by H. Lewis Jones at St. Bartholomew's Hospital, and in the London Hospital where Ernest Harneck became assistant to W.L. Hedley. Stanley Kent is notable as a non-medical scientist who first demonstrated and then established the x-ray service at

St. Thomas's Hospital. A rare example where the incumbent physics lecturer later helped to establish a radiological service was at the Royal Free Hospital, where Edith Stoney assisted her younger sister Florence. Sylvanus P. Thompson, later the first president of the Roentgen Society, was initially as interested in its physics as its medical applications.

Unsurprisingly, similarly rapid medical exploitation occurred in Germany, although Röntgen himself was not actively involved. The neurologist and psychiatrist Moritz Jastrowitz (1839–1912) first reported the use of x-rays for medical diagnostics at the Berlin Society for internal medicine.[17] One of the first x-ray laboratories "for preferential use by physicians," was established at the Physical Society to Frankfurt by the physicist Walter Koenig (1859–1936). In March 1896, Koenig published a special book with 14 radiographs, among them a picture of an Egyptian mummy (Fig. 9).[18] The Berlin physicist Paul Spiess of the Berlin Urania examined one of his employees, whose hand had been injured in the explosion of a glass vessel (Fig. 10). Since the scarred body still ached, he suspected a piece of broken glass was left in his hand and was able to locate it with the help of x-ray technology. In cooperation with the physician Paul Christian Franze, the soon-to-be professor for medical physics in Frankfurt, Friedrich Dessauer (1881–1963) wrote one of the first special textbooks of physical methods in hospitals taking particular account of the newly discovered x-rays (Fig. 11).[19]

The well-established structure of medical physics in France might have encouraged a similarly rapid growth in medical use, but at that time French medical physics was heavily focused on physiological and

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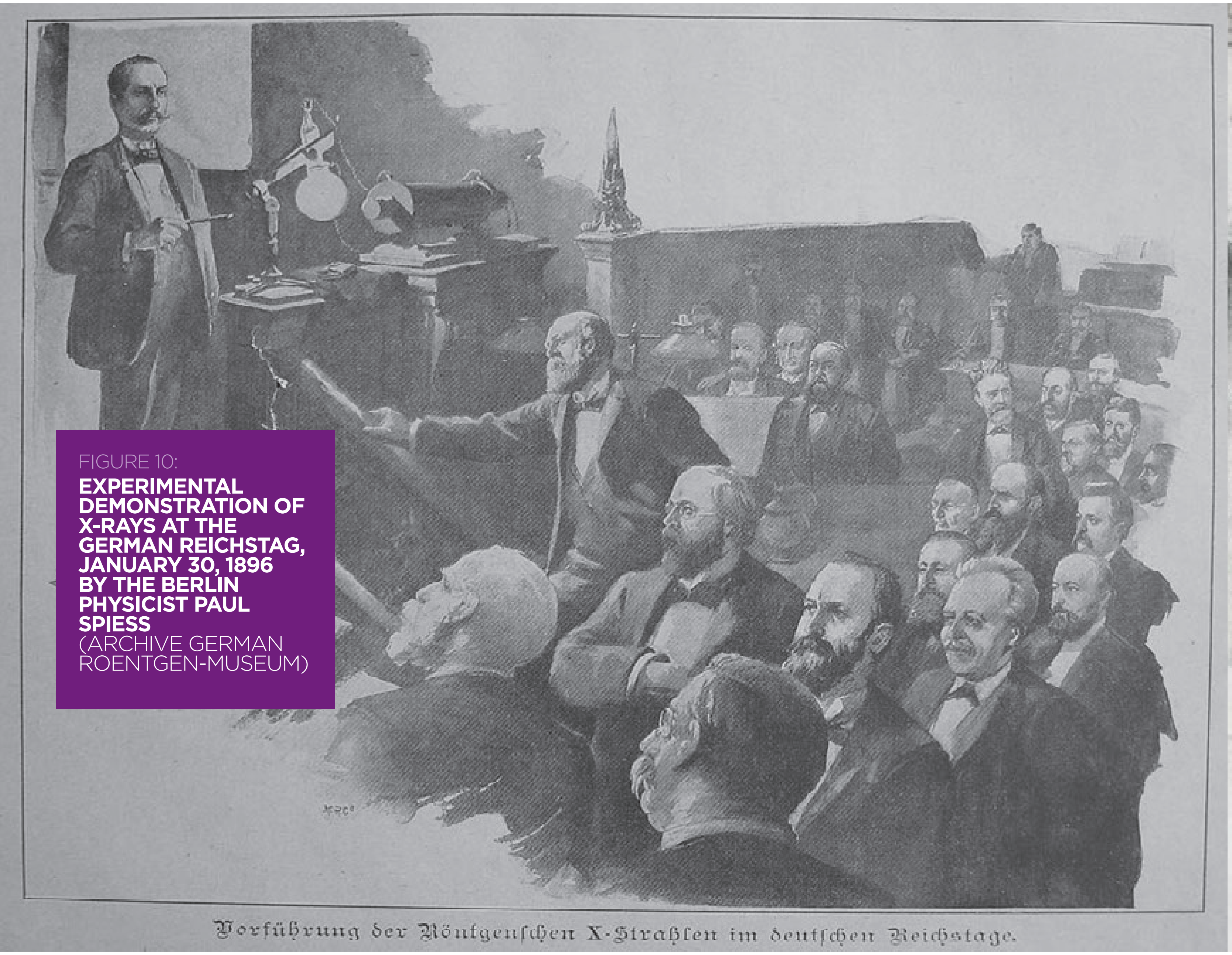

FIGURE 10:
EXPERIMENTAL DEMONSTRATION OF X-RAYS AT THE GERMAN REICHSTAG, JANUARY 30, 1896 BY THE BERLIN PHYSICIST PAUL SPIESS
(ARCHIVE GERMAN ROENTGEN-MUSEUM)

FIGURE 11:
MEETING OF MEDICAL PHYSICISTS AT THE UNIVERSITY WOMEN'S HOSPITAL FREIBURG IN 1920. LEFT TO RIGHT DESSAUER, SEEMANN, COOLIDGE, FRIEDRICH, GLASSER.

biological physics. Unlike Draper, Gariel's *Cours de physique médicale* (1892) included only the briefest of notes on Crookes and Geissler tubes, and Gariel himself, a professor of medical physics, was sceptical, pointing out that x-rays could not be focused, so limiting the images to projections only.[20] Early work was done by Lannelongue, Perrin, Mascart and Oudin. Professors of medical physics outside Paris were more involved, particularly Armand Imbert (1850–1922) in Montpellier, and later Henri Bordier (1863–1942) in Lyon, and Jean-Alban Bergonié (1857–1925) in Bordeaux. Paris was, of course, the location for Henri Becquerel's discovery of the radioactivity of uranium, work based on his own interest in fluorescence, spurred by the discovery of x-rays. And when the young physicist from Warsaw, Marie Skłodowska (1867–1934) (later Curie), was considering a suitable topic for her PhD in 1897, her "attention was drawn to the interesting experiments of Henri Becquerel on the salts of the rare metal uranium."[21]

SUMMARY

Medical physics has a longer heritage than medical radiology, starting from its emergence as a separate medical subject in Paris in the late 18th century. Over the decades it evolved through applications to medicine of mechanics, electricity, energetics, optics, acoustics, and their associated concepts and technologies. Nevertheless, it took Röntgen's discovery of x-rays in 1895 to finally bind medicine to physics, an engagement that has been of profound importance ever since.

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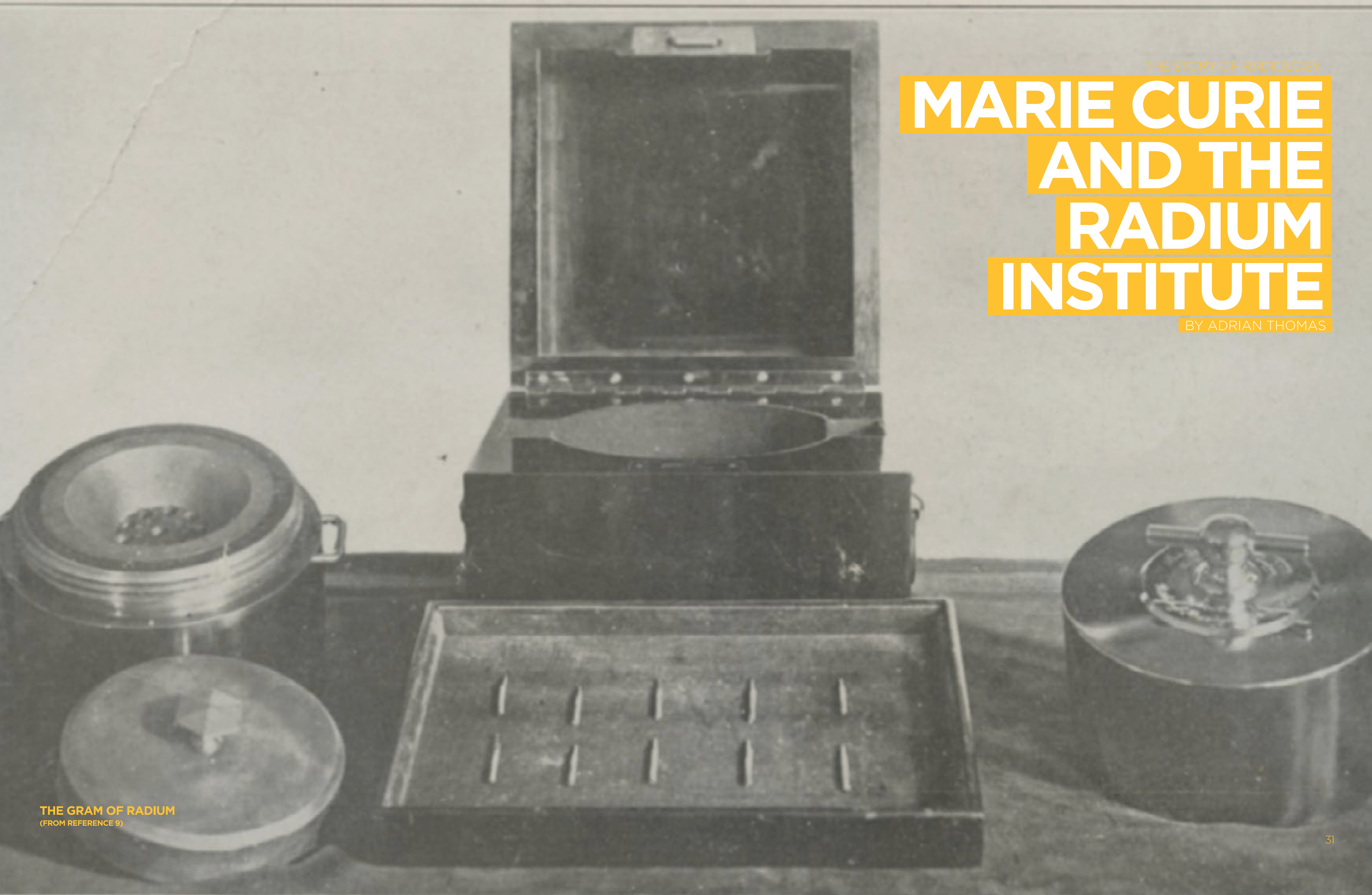
MARIE CURIE AND THE RADIUM INSTITUTE

BY ADRIAN THOMAS



THE GRAM OF RADIUM
(FROM REFERENCE 9)

FIGURE 1:
MARIE CURIE BY DR. JOSEF HILPERT (1893–1975)

The period 1919 to 1934 marks the final phase in the life of Marie Curie (1867–1934) (Fig. 1).[1-2] Her scientific partnership with her husband Pierre (1859–1906) had ceased many years before, following his tragic death in a road accident in Paris. During the First World War, she had put all her efforts into working for her adopted country of France; Curie having been born in Poland. During the war she had set up over 200 radiological rooms in field hospitals, and had developed cars equipped with radiological apparatus which could be used in medical units near the frontline. These cars were known as *Les Petites Curies* (Little Curies). Curie's daughter Irène accompanied her mother in Car E and her experience during the First World War gave Irène a lifelong commitment to work for peace, which she shared with her future husband and fellow physicist Frédéric Joliot.[3]

THE RADIUM INSTITUTE AND THE RESUMPTION OF SCIENTIFIC WORK

By 1919, it was possible for Curie to return to her scientific and laboratory work. Before the First World War plans had been made to fund the construction of the Radium Institute in Paris, in order to facilitate research into radioactivity.[4-6] The construction of the Institute had been very slow which caused Curie much frustration. The building was finally completed in July 1914, two years after the initial agreement had been signed (Fig. 2). The Sorbonne contributed 400,000 Francs towards the construction, and the Institute was located on Rue Pierre Curie. Curie had been involved in the design of the buildings, and especially the laboratories. The buildings consisted of double laboratories across

FIGURE 2:
THE PARIS RADIUM INSTITUTE
(FROM REFERENCE 5)

a central courtyard where there was a garden, and Curie had included a gardener in the Institute's budget. One of the laboratories was devoted to medical and biological research using radioactivity and radium, and the other laboratory was for research into the nature of radioactivity. However, all of this was to cease when, on June 28, 1914, Archduke Franz Ferdinand was assassinated and Europe was plunged into the horror of the First World War. For the duration of the hostilities, Curie deposited her precious stock of radium in Bordeaux.

The period after the First World War was not an easy one for Curie. She had to support both herself and her two daughters on her salary as a professor at the Sorbonne where she taught, and this was not very large. Her salary also included her work as the head of the Curie Pavilion. She was working on purifying and isolating polonium, which was a strong emitter of alpha particles. The main laboratories interested in investigating the atomic nucleus in Europe at that time were the Cavendish Laboratories in Cambridge, the Institute for Radium Research in Vienna, and the Curie Institute in Paris.

AN UNEXPECTED OFFER FROM AMERICA

Curie had never been particularly concerned with speaking to the press in spite of her worldwide fame. In 1920, an American editor of a well-known woman's magazine *The Delineator* paid Curie a visit. The editor in question was Marie Mattingly Meloney, who had achieved some considerable success in the male dominated publishing world. She was undertaking a European trip to meet various well-known figures,

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including the author H.G. Wells, the playwright J.M. Barrie and the philosopher Bertrand Russell. Meloney had been an admirer of Curie for many years. Her interview with Curie appeared in the April 1921 issue of *The Delineator*.[7] The article was entitled 'The Greatest Woman in the World' and was accompanied by the iconic image of Marie Curie dressed in black and alone in her laboratory (Fig. 3). Meloney and her readers were concerned with the changing role of women in society following the war, and the front cover of the magazine depicted a drawing of *A Beautiful American Working Girl* (Fig. 4). This is significant since Curie would have been for Meloney the epitome of the modern working woman; the successful woman scientist and double-Nobel laureate.

The interview that Meloney published in her journal helped to define the image that we now have of Marie Curie. It said that, in spite of all the work that Curie had done, she was too poor to purchase the precious radium for further and much-needed experiments. The article emphasised the number of men (not women) who had grown rich from Marie Curie's discovery of radium, and Marie is quoted as saying, "I gave the secret to the world. It was not to enrich anyone. It was all for all people." Meloney contrasted those in Pittsburgh in America who had made millions of dollars out of radium and who have "cars and servants and palatial homes" to the simplicity of the life of Curie. She visited Curie in the Institute Curie and specifically commented on the plain clocks and on the flower garden. She likened the reception room to a nun's cell and describes it as a "cold and a bare room, stripped of all human frivolity and pretense. It was like a blank canvas on which a great character would stand out in bold relief." She described Curie

FIGURE 3:
THE GREATEST WOMAN IN THE WORLD
(FROM REFERENCE 7)

FIGURE 4:
A BEAUTIFUL AMERICAN WORKING GIRL BY PAUL HELLEU
(FROM REFERENCE 7)

as being "tall and very thin. Her plain, black-serge dress was partly covered by a black cotton apron. She came towards me with a light, springy step of youthful energy. But there was no youth in her voice nor in her face. Her hands showed the toil of many years. The rounded shoulders and slightly bowed head evidenced a lifetime of desk work." Meloney repeated the spiritual symbolism and says that her face was like that of a medieval saint. There is a lovely portrait of Marie Curie that accompanied the article. It was in colour, with Curie looking like a saint with her eyes raised to heaven and a distant wistful look (Fig. 5). This theme of Marie Curie as a type of scientific saint was taken up by Françoise Balibar in her 2006 book *Marie Curie, Femme savant ou Sainte Vierge de la science?* (Marie Curie, Learned Woman or Holy Virgin of Science?).[8]

FIGURE 5:
MARIE CURIE BY FREDERICK REYNOLDS
(FROM REFERENCE 7)

Curie described her life as being simple and uneventful, consisting of years of study and work alongside her home and her children. She recounted the many years of work undertaken before radium was discovered. When the discovery was made with her husband Pierre, the secret was not kept and she said that they did not benefit financially. Meloney was again told that Curie did not now have enough radium to work with. They also talked about Curie's work during the war and how she trained assistants to "minister to the suffering soldiers."

When asked if she had ever been to America Curie said no, with real regret, and said that she had very much wanted to go. She said that as a mother she could not leave her children. When they returned to the visiting room after visiting the Institute, Meloney asked Curie what she would choose if the whole world were at her feet. Curie said that she would like a little radium with which to carry out further experiments, and she said this without any hesitancy.

In the editorial of *The Delineator,* Meloney described how she had brought Curie's request to a group of representative American women who pledged themselves to collect the required sum needed to obtain the radium, and that this sum was $130,000. The editorial was entitled 'That Millions Shall Not Die!', and this emphasised the very real sense of hope that the discovery of radium had given to those suffering from cancer. She also invited Curie to visit the United States to see the laboratories for refining radium in Colorado, and also to fulfil her desire to see the Grand Canyon in Colorado. Curie was to come to America to receive the gift of a gram of radium, and this was to be for her own and unrestricted personal use for experimental work. The Marie Curie Radium Fund Committee had been set up in the US and a number of scientists would meet with Curie.

THE GRAM OF RADIUM

The gram of radium that was given to Marie Curie was produced by the Standard Chemical Company of Pittsburgh, which at that time was the world's largest producer of radium.[9] The company was founded in 1911 by Joseph

FIGURE 6:
MARIE CURIE INSPECTING THE PLANT OF THE STANDARD CHEMICAL COMPANY
(FROM REFERENCE 9)

FIGURE 7:
THE RADIUM RESEARCH LABORATORY AND GENERAL OFFICES OF THE STANDARD CHEMICAL COMPANY IN PITTSBURGH
(FROM REFERENCE 9)

Flannery but was dissolved in 1933 because a rich source of radium had been discovered in the Congo, and it was no longer practical to produce radium in the United States. By 1921, approximately half of the world's stock of refined radium of approximately 140g had been produced in the United States by the Standard Chemical Company.

Curie sailed for America with her two daughters in May 1921 on board the Olympic (the sister ship to the ill-fated Titanic). While in the United States, Curie wished to visit Pittsburgh to see the radium works. Considerable effort was needed to produce a gram of radium each month and it involved 200 miners, mill men, and 150 additional men in the chemical works in Pittsburgh to process the 500 tons of ore.

The gram of radium was presented to Curie by President Warren Harding on behalf of the women of the United States of America at the White House during the afternoon of May 20, 1921 in the presence of over 500 representatives of women's organisations, the Cabinet, the Diplomatic Corps, Congress and distinguished leaders in medical, chemical, physical and other scientific fields.

On the afternoon of May 26, Curie visited Pittsburgh (Figs. 6 & 7) and saw the processes in the research laboratory of the Standard Chemical Company (Fig. 8). She also visited the

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FIGURE 8:
FINAL STAGE OF CRYSTALLISATION OF THE GRAM OF RADIUM
(FROM REFERENCE 9)

chemical reduction work in Cannonsburg, Pennsylvania. The gram of radium was placed in ten glass tubes within a mahogany case (Fig. 9, see page 30). Each glass tube contained one-tenth of a gram of radium in the form of pure radium bromide. The mahogany case had a gold key which was engraved on one side with the words: *The Women of America to Marie Curie,* and on the other side: *The White House May 20 1921.* An inscription on gold plate was placed on the top of the mahogany case (Fig. 10).

The trip to America was not without difficulty for Curie. Her health was not good and her vision was poor and she also suffered from cataracts in her eyes. During her send-off in Paris, the actress Sarah Bernhardt had read out an 'Ode to Madame Curie.' However, there was concern about the overinflated clinical claims for the use of radium. Whilst in America she visited many colleges, lecture halls and museums. She became very tired and it all became a little too much. She had to abandon her schedule because of what was described as 'too much hospitality.' She was treated well in America, and in addition to her gram of radium she was given a further $50,000 for her research.

RETURN TO HER LABORATORY

Following her return from America, Curie set about the work of equipping the Radium Institute and working on radioactivity. Although she was only in her 50s, she was becoming increasingly tired and ill. During the 1920s, the Radium Institute progressively developed, receiving various grants and awards, and attracted many visiting scientists.

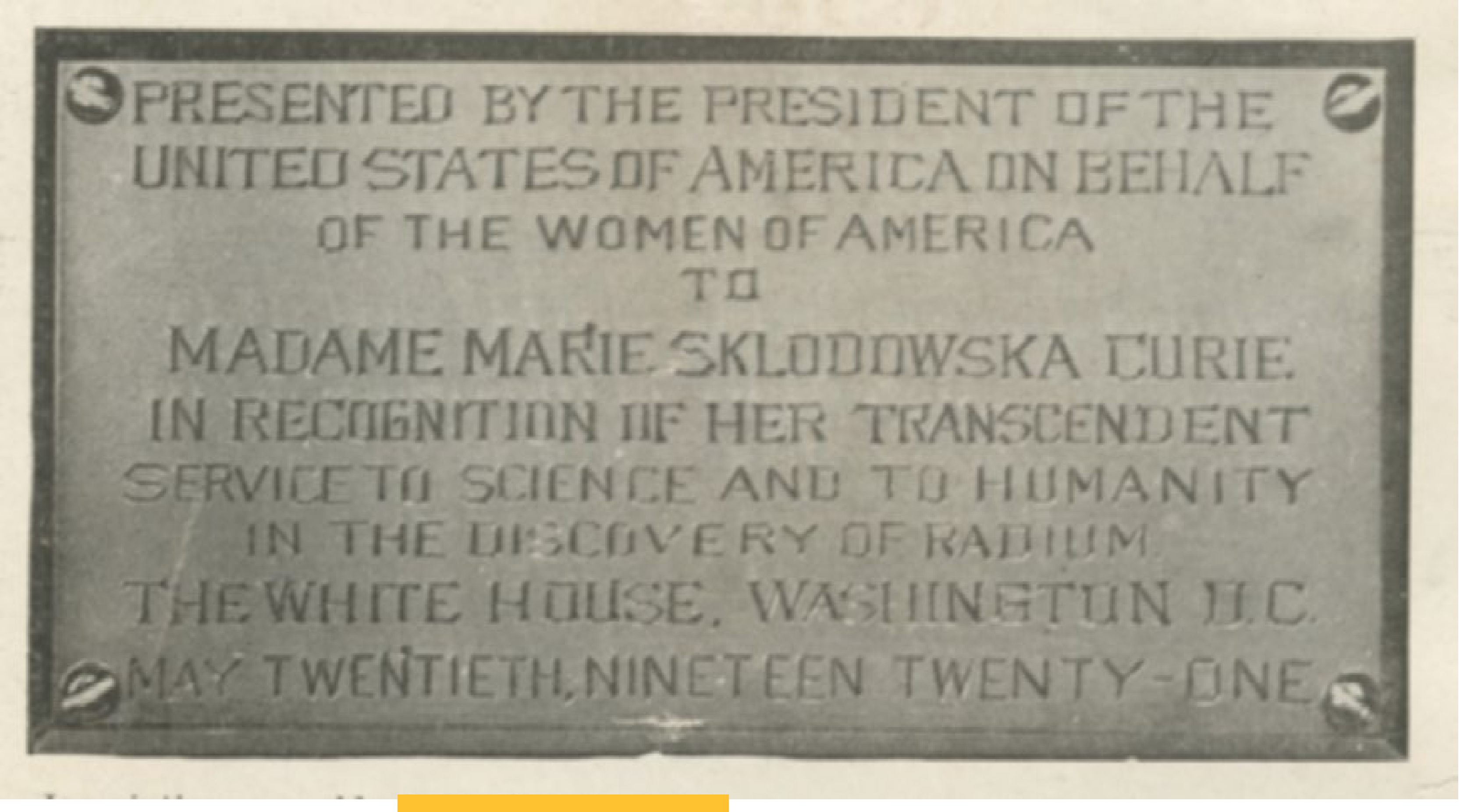

FIGURE 10:
THE PLAQUE ON THE CASE CONTAINING THE GRAM OF RADIUM
(FROM REFERENCE 9)

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The Institute grew to include 40 researchers. Many young scientists were recruited, including many female researchers, which was unusual at that time.

In the 1920s, the dangers of radiation and of radium were increasingly giving grounds for concern. In England, following the death of Dr. Ironside Bruce in 1921 from radiation exposure, and in particular following his work with radium, a committee of radiation protection was set up. Curie herself showed evidence of injury from radiation, including burns on her hands and fingers. Two of the workers at the Radium Institute died of the effects of radiation. Part of the problem was that at that time knowledge of radiobiology was poor and it was believed that rest and exercise would cure the effects of excess radiation exposure. However, she would not retire, but attended conferences and spent time in the countryside. She wrote a biography of her husband Pierre which appeared in 1923. The book had an introduction by Meloney and as a postscript had autobiographical notes written by Curie.[10]

Curie was joined in her work by her daughter Irène and then by her husband Frédéric Joliot. Irène and Joliot married in 1926.

THE CURIE INSTITUTE

In the 1920s, the Curie Institute had a clinical division which was headed by Claude Regaud, and a physics division which was headed by Marie Curie. Octave Monod and Henri Coutard both led sections on clinical radium and x-ray therapy.

FIGURE 11:
COLLECTING RADIUM EMANATION AT THE PARIS RADIUM INSTITUTE
(FROM REFERENCE 5)

The Institute made many improvements to radiation treatment, including the surface application of radium and radiotherapy (Figs. 11 & 12). Scientific radiotherapy was still in its early days and there were many variables that needed to be coordinated, including distance, treatment time, the area to be treated, the distribution of any external sources and any fractionation. The quality of work was very high and Brian Windeyer, subsequently professor of radiotherapy at the Middlesex Hospital in London, who was attached to the Institute in the 1920s, described

the particular attention to detail and excellent results that were being achieved. He described the Curie Foundation as being a cornerstone of his career, as would many of the foreign scientists who were attached to the Institute for training. M. Lenz from America gave tribute to the spirit of honesty, integrity and dedication which dominated all the work at the Curie Institute during his stay in the 1920s.

Curie opened the Warsaw Radium Institute in 1925, where her sister Bronya was the director. In 1929, the women of America donated another gram of radium to the Warsaw Institute and Curie made her second visit to the United States. On this occasion she received her gram of radium from President Herbert Hoover.

1934 AND THE END

The year 1934 was a memorable one for the Curie family. On January 15, Irène and Frédéric Joliot-Curie announced their discovery of artificial radioactivity. They received the Nobel Prize for Chemistry for this in 1935. Marie and Irène are the only mother and daughter to win the Nobel Prize.

While working in her laboratory one day, Curie complained of a fever and went home. She took to her bed and was sick and very weak. It was recommended by her doctors that she attend a sanatorium. Curie and her daughter Eve went to Sancellemoz, a sanatorium in the town of Passy, in Haute-Savoie in eastern France. She had been diagnosed as having anaemia in 1933, which was probably the result of her radiation exposure. The doctor who looked after her said that she died from "an aplastic pernicious anaemia of rapid, feverish development. The bone

FIGURE 12:
RADIOTHERAPY AT THE PARIS RADIUM INSTITUTE
(FROM REFERENCE 5)

marrow did not react, probably because it had been injured by a long accumulation of radiations".[11] She died on the morning of July 4, 1934 at the age of 67, and was buried in the family plot in Sceaux Cemetery next to her beloved husband Pierre.

THE BODY OF MARIE CURIE

And what of the body of Marie Curie? It is been said that her body was radioactive and that she had to be buried in a lead lined coffin. Was this the case? When it was decided to transfer the bodies of the Curies to the Panthéon there was some concern about the state of the bodies and whether there was any residual radioactivity.[12] When Marie Curie's coffin was opened the body was found to be well preserved and the face was quite recognisable. The coffin was indeed lined with lead. Radiological measurement showed a slight increase in alpha particle contamination. There was little evidence of contamination of the body with radium, which may be related to biological elimination during her life. In her later years there was less exposure to radium; however, during the war years there was a significant exposure to x-rays and it was this, combined with her work on polonium, that contributed to her radiation exposure.

The condition of the body of Pierre was a little different. The gamma dose rate was significantly higher than the surrounding background and there was contamination of the bones with radium. The coffin was not lined with lead because at that time there was less awareness of the risks of radiation. During his work, Pierre Curie had suffered serious contamination with radium, and it was well known that he often had to delay his experimental work for several hours because his clothes were so radioactive that he could not go near his instruments. The Curies' laboratory was impregnated with radium and because of this they had to move to another location for experimental work.

THE PANTHÉON

On April 20, 1995, Marie and Pierre Curie's bodies were interred in the Panthéon in Paris with a formal ceremony. The Panthéon is the national mausoleum of France. Curie was the first woman to be buried in this national monument and the French President, François Mitterand, said, "By transferring these ashes of Pierre and Marie Curie into the sanctuary of our collective memory, France not only performs an act of recognition, it also affirms a faith in science, in research, and its respect for those who dedicate themselves to science, just as Pierre and Marie Curie dedicated their energies and lives to science."

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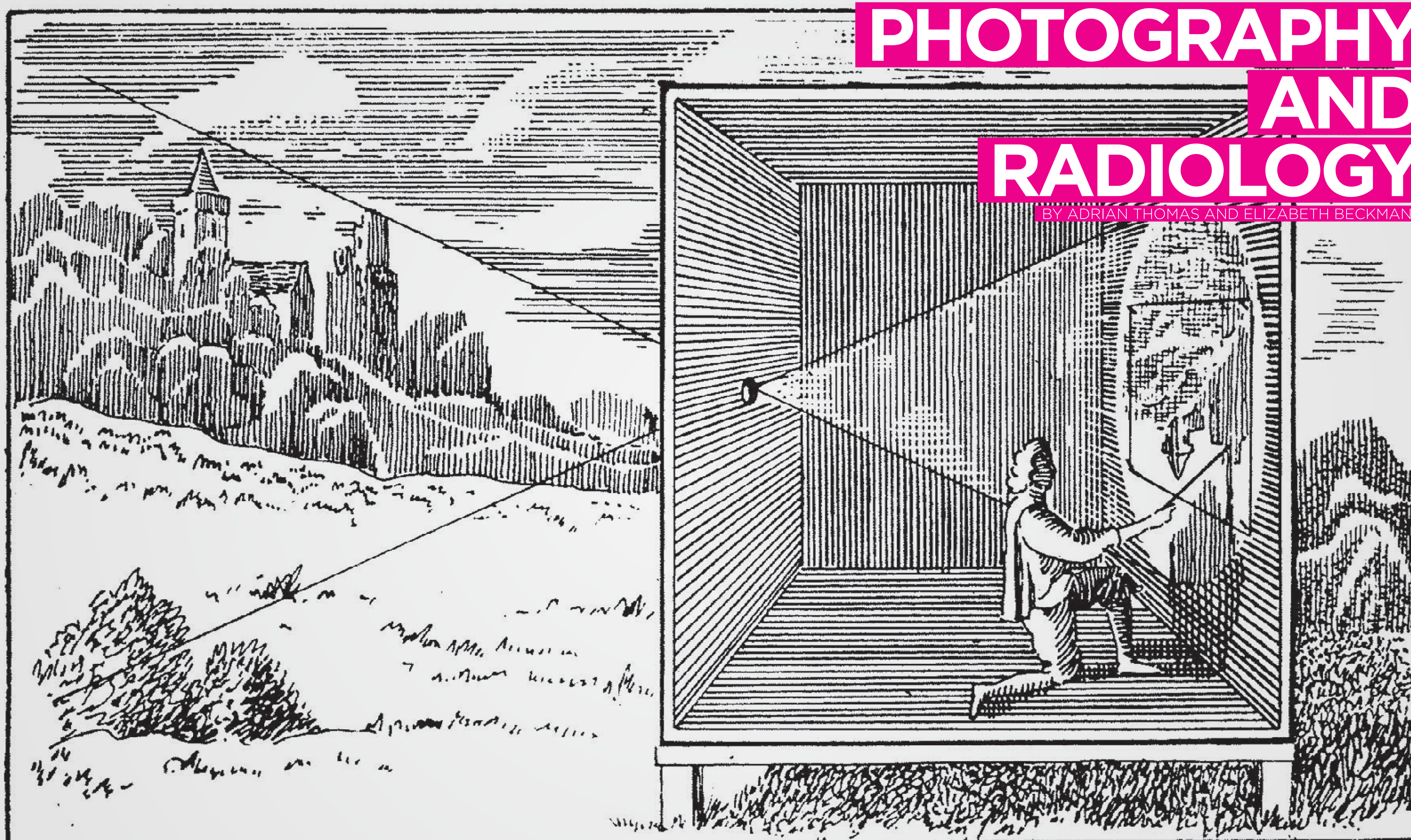
PHOTOGRAPHY AND RADIOLOGY

BY ADRIAN THOMAS AND ELIZABETH BECKMANN



THE CAMERA OBSCURA.
(CAMERA OBSCURA, PORTSMOUTH NATURAL HISTORY MUSEUM, CUMBERLAND HOUSE)

"Of especial interest in many ways is the fact that photographic dry plates show themselves susceptible to x-rays. We are thus in a position to corroborate many phenomena in which mistakes are easy, and I have, whenever possible, controlled each ocular observation on fluorescence by means of photography."

William Conrad Röntgen, First Communication, 1895

FIGURE 1:
PHOTOGRAPH BY WILHELM CONRAD RÖNTGEN AT ENGADIN. ENGADIN IS A VALLEY IN THE SWISS ALPS, LOCATED IN THE CANTON OF GRAUBÜNDEN. (COURTESY OF THE GERMAN RÖNTGEN MUSEUM)

INTRODUCTION

Wilhelm Conrad Röntgen's first paper, 'On a New Kind of Rays' (Über eine neue Art von Strahlen) in which he announced the discovery of Röntgen rays, or x-rays, was published on December 28, 1895.[1] It is perhaps worth remembering that Röntgen was a keen amateur photographer (Fig. 1) and that the discovery was made using a photographic method. In his original paper Röntgen indicated that either glass plates or film could be used.

The new discovery was seen as a development of photography and was therefore termed 'the new photography.' In the United Kingdom the discovery was announced in a photographic magazine, *The Amateur Photographer,* on January 13, 1896 and the technique used was illustrated on February 7, 1896 (Fig. 2).[2]

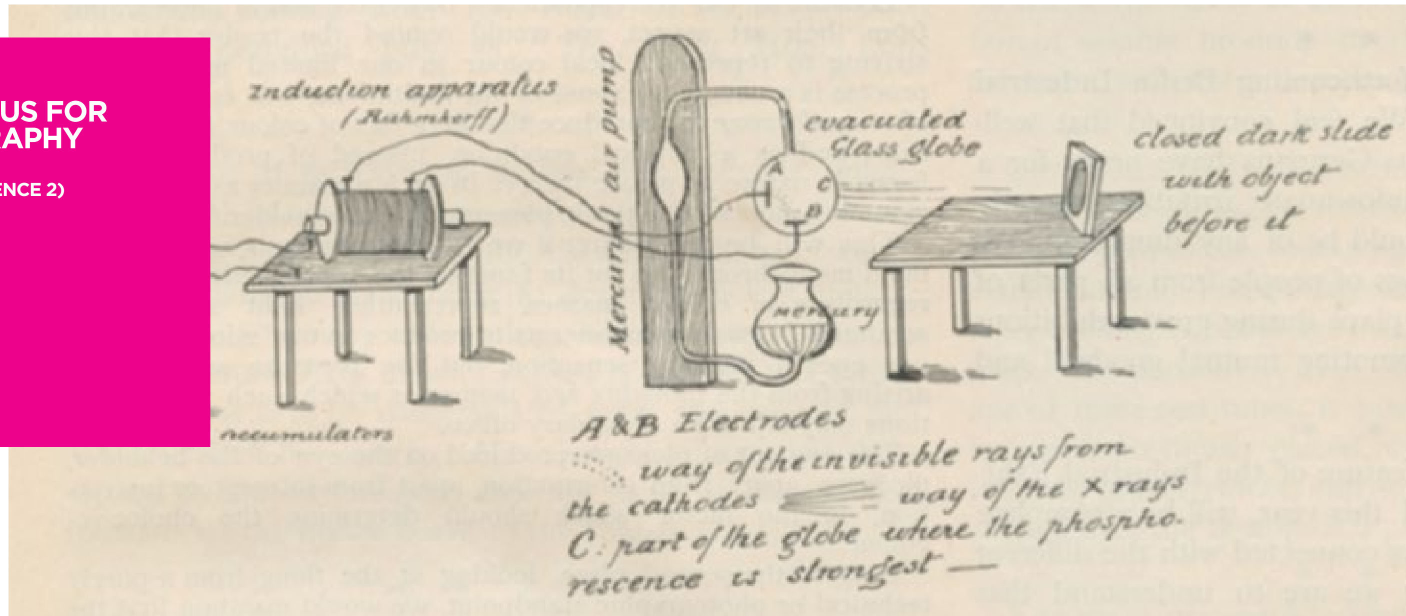


FIGURE 2:
APPARATUS FOR RADIOGRAPHY IN 1896
(FROM REFERENCE 2)

EARLY PHOTOGRAPHY

Photography has a long history.[3] As far back as ancient times camera obscura (Fig. 3, see page 72) were being used to create images on walls in darkened rooms. These early devices consisted of a hole in the wall at one end of a room, which created an upside-down image on the wall at the other end of the second room. These images were formed using the pinhole camera technique. In the 16th century, the brightness and clarity of camera obscura images were improved by enlarging the hole and by inserting a telescope. During the 17th century, the camera obscura was frequently used by artists and was made portable by being placed in a box. These portable camera obscura were often pointed at a scene to project the inverted image onto a ground-glass screen. The artist would then trace the scene from the ground-glass screen onto a piece of paper and then make the finished picture.

In 1727, the German chemist Johann Heinrich Schulze mixed chalk, nitric acid and silver in a flask and noticed the darkening that took place on the side of the flask exposed to sunlight. This resulted in the accidental creation of the first photosensitive compound, and is another example of scientific serendipity.

The early 1800s saw the first photographic portraits of people. Thomas Wedgwood and Sir Humphry Davy made sun pictures by placing opaque objects on leather treated with silver nitrate. However, the resulting images deteriorated rapidly. Creating an image was relatively straightforward. The problem was fixing the image so it did not deteriorate.

In 1816, Nicéphore Niépce, who was born and lived in Chalon-sur-Saône in France (Fig. 4), combined the camera obscura with photosensitive paper and in 1826 he created a permanent image of the view from the window in Le Gras. This first photograph (light drawing) or heliograph (sun drawing) was created using a pewter plate, bitumen of Judea and oil of Lavender and an exposure time of about eight hours. This image was a unique image and not reproducible, and it was of low quality. The house of Nicéphore Niépce can be visited today in that lovely part of France. Niépce was quite a character. In 1792, he enlisted in the French Revolutionary Army and took part in campaigns in the south of France and Sardinia. In 1807, with his brother Claude he developed the first internal combustion engine in the world named the Pyreolophore. It was placed in a model boat about two metres long and travelled upstream on the Saône River.

FIGURE 4:
STATUE OF NICÉPHORE NIÉPCE IN CHALON-SUR-SAÔNE. MOLYBDENUM COMPANY, NEW YORK

The Englishman William Henry Fox Talbot worked with a camera obscura. In 1834, he found that a sheet of paper coated with salt and a solution of silver nitrate darkened in the sunlight. A second coating of salt slowed further darkening or fading. Talbot initially used this technique to record images of plants. In 1835, he placed sheets of impregnated paper into small cameras and recorded his famous images of Lacock Abbey. In 1839, he created the first negative and reproducible imaging process, the Calo-type (beautiful impression), using silver chloride, paper and silver iodide/gallo nitrate, creating a silver negative image which could be reproduced with an exposure of only five seconds. This process was patented as Calotype in 1841. Talbot also created positive images by contact printing onto another sheet of paper.

In 1837, Louis Daguerre in France created images on silver-plated copper, coated with silver iodide and developed with heated mercury. This was an entirely different method to that of Fox Talbot, and the beautiful images were known as a Daguerreotype.

PHOTOGRAPHY DEVELOPS

It was 22 years later, in 1851, that Frederick Scott Archer, a sculptor in London, used a collodion wet-plate process involving a glass plate, collodion (Nitro cellulose/ether/alcohol), silver chloride, silver iodide, silver nitrate to create a glass-based sharp, clear image with a five-second exposure. This process gave improved photographic resolution, and was much cheaper than the Daguerreotype process.

Collodion was invented in 1848, was used as a wound dressing, as well as an emulsion for photographic plates, and it dried to a celluloid-like film. This nitrocellulose-based plastic slightly predated the development of celluloid.

Stereoscopic imaging began in 1855 at the same time that direct positive images on glass (ambrotypes) and metal (tintypes or ferrotypes) became increasingly popular, particularly in the United States.

In 1865, Alexander Gardner took a picture of Abraham Lincoln, just two months before he was assassinated. The glass plate image has a crack, which runs across the plate through the top of Lincoln's head. This crack shows the fragility of the glass plates.

In 1861, The Scottish physicist James Clerk-Maxwell demonstrated a colour photography system involving three black and white photographs, each taken through a red, green, or blue filter. The photos were turned into lanternslides and projected in registration with the same colour filters. This became known as the colour separation method.

Between 1861 and 1865, Mathew Brady and his staff covered the American Civil War, exposing around 7,000 negatives, to create some of the first military photographs on a large scale.

In England in 1871, Richard L. Maddox developed a dry-plate process using a glass plate, gelatin emulsion (giving an increased sensitivity of silver compounds) and silver salts to achieve a photograph with an exposure of less than one second.

FIGURES 5A & 5B
LATE 19TH CENTURY CABINET PHOTOGRAPHS.

In 1877, Eadweard Muybridge, born in England as Edward Muggridge, used a time-sequenced photograph of Leland Stanford's horse to settle the question of "do a horse's four hooves ever leave the ground at once."

In 1880, George Eastman set up the Eastman Dry Plate Company, and in 1888 Kodak launched their first camera with a 20-foot roll of paper, enough for 100 2.5-inch diameter circulate pictures. The end of the 1800s saw the first action photos of a horse and rider. The first half-tone photograph appeared in a daily newspaper, the *New York Graphic,* and 1888 was also the year that the first issue of the *National Geographic* magazine appeared.

THE NEW PHOTOGRAPHY

Photography was already well developed by the time Röntgen discovered x-rays (Figs. 5a & 5b). Röntgen was a keen amateur photographer, which was one of the reasons that he had photographic plates in his laboratory, which helped with his early experimentation and discovery of x-rays. Early x-ray imaging was a photographic process and this perhaps explains why many of the pioneers, such as John Hall-Edwards from Birmingham, were keen amateur photographers. The production of good quality radiographs in the early years was directly related to the photographic knowledge of the radiographer. In the early years the plate was not interpreted directly because of the wide latitude and poor contrast of the plates. The best results were obtained by viewing paper prints. The process of producing an image for interpretation was seen to be complex and time consuming (Fig. 6).

FIGURE 6:
THE HAND OF DR. SEBASTIAN GILBERT SCOTT (1898). NOTE THE RETAINED BULLET.

The original photographic plates used in radiography were those designed for ordinary photography and were not entirely satisfactory. The images could appear to be rather thin. One way to overcome this was to have the emulsion on both sides of the glass plate. The concept of using a fluorescent screen was announced in March 1896 by Professor Mihajlo Pupin. Pupin had the brilliant idea of painting the back of the plate shutter with luminous paint, or to dip the sensitised plate in a fluorescent substance. Pupin found that a beautiful exposure could be obtained with an exposure of only a few seconds. In March 1896, Thomas Edison found that crystallised calcium tungstate gave better results than barium platino-cyanide and that simple photographs were unnecessary (Fig. 7). The use of fluorescent screens developed to a considerable degree of sophistication, leading to the use of rare earth screens. However, the use of fluorescent screens resulted in some unsharpness, and for detailed peripheral radiography the use of non-screen film persisted.

FIGURE 7:
TRADITIONAL X-RAY FILM CASSETTE WITH INTENSIFYING SCREENS.

Francis H. Williams, who was born in Uxbridge, UK, spent most of his working life in Boston, USA, and it was here that he used fluoroscopy for the early detection of tuberculosis and other life-threatening chest disorders. By the summer of 1896, he had accumulated more than 100 volumes containing tracings of clinical chest fluoroscopy. In April 1896, Williams described the air bronchogram in a radiograph of a patient with pneumonia. Williams was committed to fluoroscopy because of the poor penetration of early radiographic apparatus and its poor visualisation of the chest and abdomen. Sadly, fluoroscopy was associated with considerable risks to the operator, a property not associated with plain radiography.

But in many other centres, early radiographs were largely of the periphery of the body, and it was not until around 1905 that fluoroscopy began to be used, and even then as it was when Francis Williams used orthodiagraphy, it was a similar technique to the very early camera obscura images, where the image on the glass screen was drawn around. This resulted in the operator being in the line of the x-rays and the scatter and suffering a significant amount of radiation exposure. There were two typical techniques, one where the operator would look at the fluoroscopic screen and then draw the image and for the other they would use a device directly on top of the fluoroscopic screen.

DEVELOPMENTS IN RADIOGRAPHY AND PHOTOGRAPHY

In many areas the progress of photography and radiography paralleled each other, although not always at the same time. In some cases, through the 20th century, differences were driven by technological challenges. This was the case for portable imaging. By the time of the discovery of x-rays in 1895, photographic cameras were already transportable, and with the introduction in 1889 of the improved Kodak camera with a roll of film instead of paper, and then in 1900 the introduction of the Kodak Brownie box roll-film camera, the photographic camera became truly portable. But it was a much greater challenge for the x-ray machine to become 'portable' and even to this day, while there are mobile x-ray units which can be wheeled around hospitals and small basic portable x-ray units which can be taken to remote sites for imaging, these still pose a challenge as they need a source of electricity. The

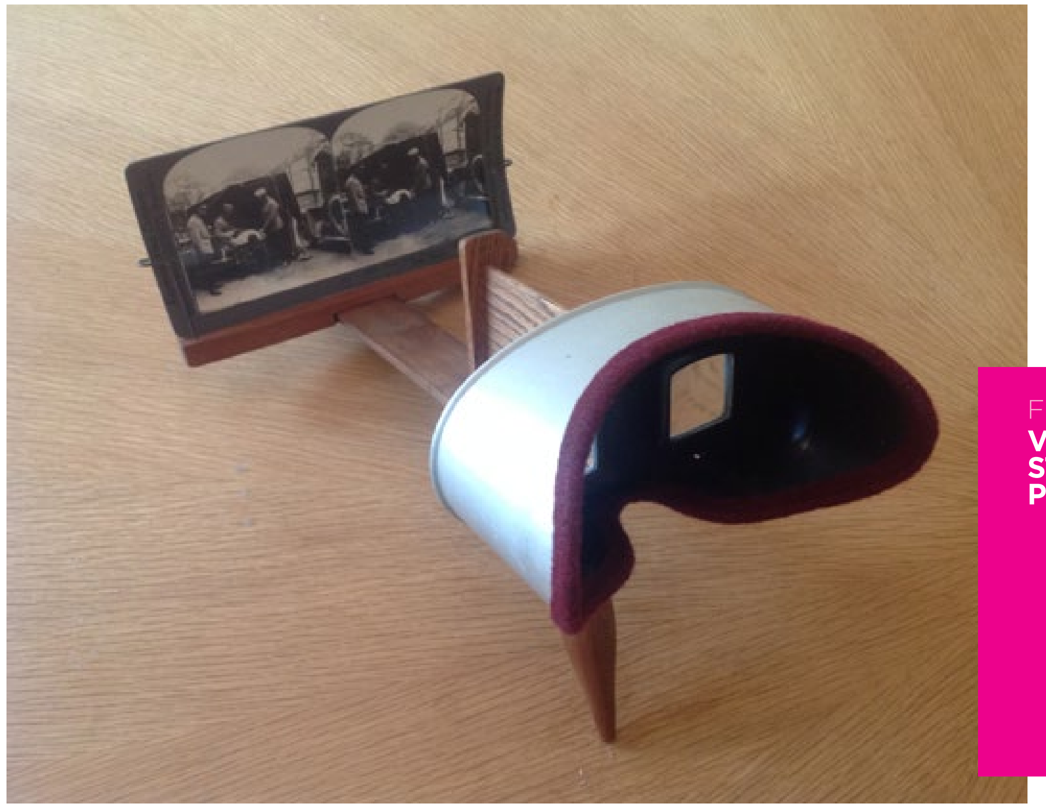


FIGURE 8:
VIEWER FOR STEREOSCOPIC PHOTOGRAPHY

electrical power can be generated from a large battery unit, but these have limited capacity between recharging.

Another area which moved swiftly into x-ray imaging was the production and viewing of pairs of stereoscopic images (Fig. 8), which had developed from its first use in photography in the mid-1850s to be adopted very quickly in radiography. Elihu Thomson published as early as 1897 on these 'stereoscopic Röntgen pictures'.

Prior to the introduction of computer-based and digital imaging, both photographic images taken on exposed film or plates, and x-ray film required processing to produce an image that could be viewed and retained for permanent or semi-permanent viewing. It was this pro-

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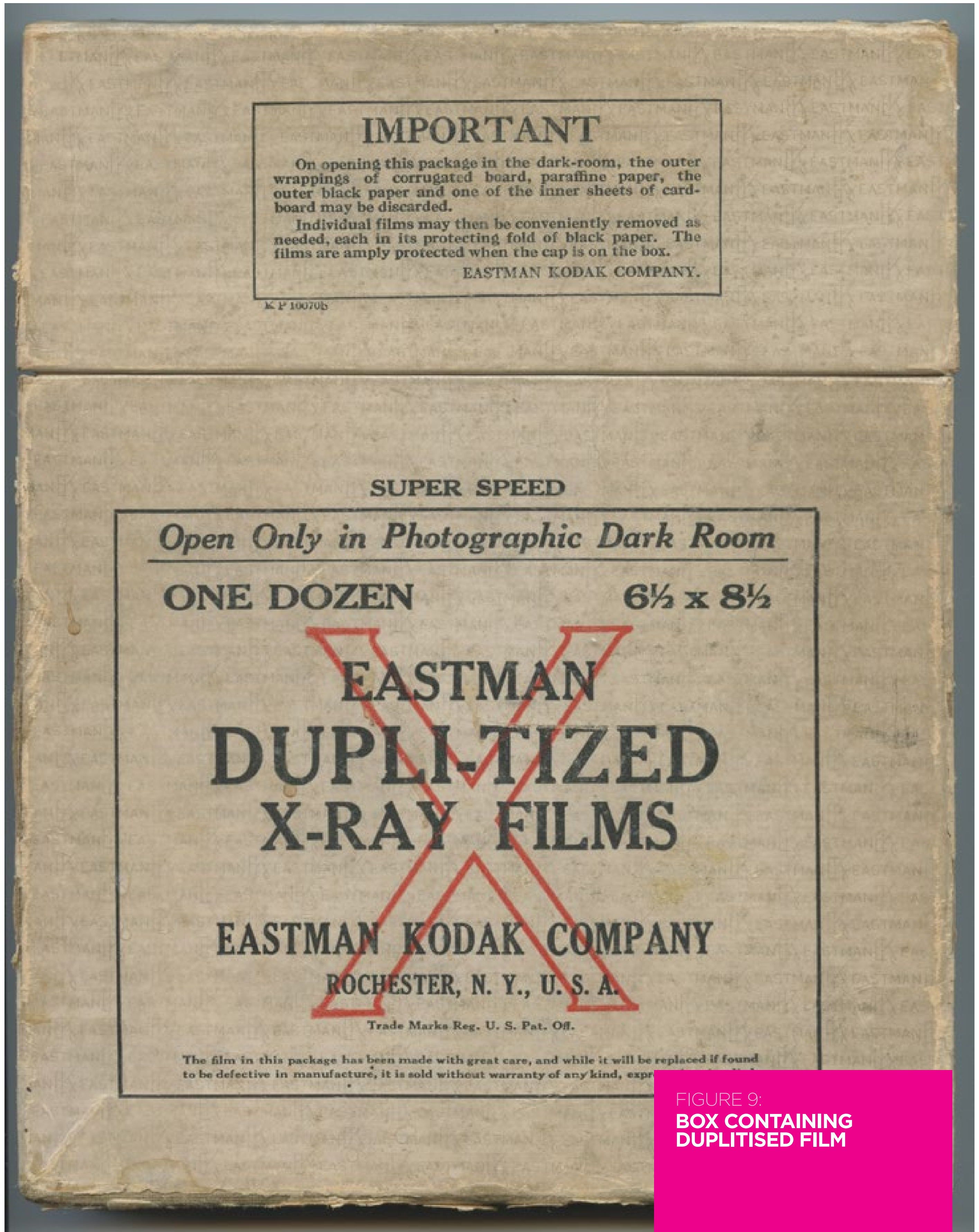

FIGURE 9:
BOX CONTAINING DUPLITISED FILM

cessing of the images to create a permanent record that was the greatest challenge in x-ray imaging as it had been in photography. Whilst film had some advantages over glass plates in that it would not break, the disadvantage of film lay in its tendency to bend and wrinkle and this resulted in image distortion. Prior to the First World War the glass used for photographic plates came from Belgium. During the war, there was a dramatic increase in the need for plates and it was almost impossible to meet this demand. In 1914, the Kodak Company adapted the cellulose nitrate base that had been used in photographic film, and introduced a film coated on a single side with emulsion. This film had a greater sensitivity than any plate made up to that time. The problem with this film was that it tended to curl and was difficult to develop in trays. The film was therefore held in a special frame and was developed in a tank. In 1918, a film was introduced that was coated on both sides, the duplitised film (Fig. 9). Even though radiologists were very accustomed to plates, this new film proved to be so successful that by 1930 no radiologist would dream of returning to the use of plates.

The whole process of film processing was the same for x-ray image processing and photography, originally a manual process before the introduction of automatic processors and eventually the introduction of daylight processing and the transition for both x-ray imaging and photography to digital imaging.

Photography and x-ray imaging shared many similarities, they both used film and screens, they both generated an image, and for both the

FIGURE 10:
POSITIVE IMAGE ON PAPER SHOWING URETERIC BOOGIED (1913).

image needed to be focused. Like early photography, x-ray imaging went through the stages of glass plates, paper (Fig. 10) and film, albeit at later dates than photography. In fact in many countries, the training of radiographers and radiographic technicians includes a significant photography syllabus.

X-ray film developed and used a number of different material bases, initially celluloid nitrate was common, but this was flammable, as demonstrated by the infamous fire of 1929 at the Cleveland Clinic in Ohio that was caused by films in the x-ray film store being too close to an incandescent lamp, resulting in 123 people losing their lives. In 1925, because of the fire risk of cellulose nitrate, celluloid acetate was introduced as a base. This was called safety film, because it was 'safe' and non-flammable. The main problem with cellulose acetate was in the difficulty of producing it in large quantities. The initial bases were clear. Before the Second World War the images were commonly viewed as positive prints; however, post-war the images were more commonly viewed as negatives. Both photography and x-ray imaging films were generated in different sizes, although photographic film tended to be smaller in size than x-ray imaging film.

Photography saw some developments which were not followed by x-ray imaging, including the development and significant growth in colour films and the inception, in 1932, of Technicolor for movies, where three black and white negatives were made in the same camera under different filters, and the development of Kodachrome, the first multi-layered colour film in 1936. Polaroid started selling instant black and white film in 1948, and their first colour instant film was developed in 1963. The black and white Polaroid film was used for imaging early CT scans.

Film processing, both for radiography and photography, became progressively more automated following the Second World War. Initially, the glass films were manually processed in dishes. When film was introduced it was processed in tanks and held in hangers, fastened at the edges by clips. The edges were square and cutters were developed to make the edges rounded. The patient data was written on the films, initially in pencil and then after refining and drying in white ink. The undried images could be sent to the clinician in the hanger as a wet film. It is interesting that even in the 1980s it was common for clinicians to ask for WPP (wet plates please). The films were initially dried in cabinets. The early automatic processors replicated the manual process, where the film in a hanger was moved between developing and fixing (Fig. 11). This was then later replaced by a continuous system where the film was moved by rollers between the various stages of processing. This however required the film in its cassette to be opened in the darkroom and manually introduced into the automatic processor. With these automatic processors a typical processing time of 90 seconds could be achieved. The final development was the removal of the darkroom and the introduction of daylight systems, where the whole process could take place in normal light. Daylight systems enabled the film to be automatically removed from the cassette and processed. Traditional radiography reached a high degree of sophistication. Angiocardiography could be performed on a roll of film measuring 30cm

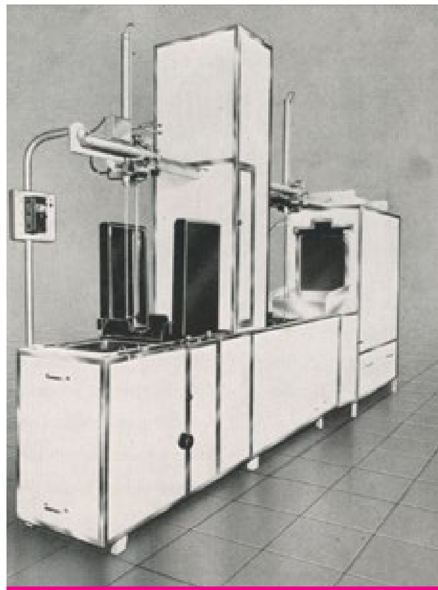

FIGURE 11:
AUTOMATIC FILM PROCESSING IN 1952 (J RUSSELL ELECTRONICS). THE PROCESS RESEMBLED MANUAL PROCESSING.

PHOTOGRAPHY AND RADIOLOGY
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FIGURE 12:
ANGIOCARDIOGRAM ON ROLL FILM (30CM X 10M).

FIGURE 13:
XERORADIOGRAPHY OF THE SOFT TISSUES OF THE NECK (1976).

by 10m (Fig. 12). Xerography was developed to enhance soft tissue detail (Fig. 13). There were significant storage problems and the x-ray film store required a large space (Fig. 14).

THE DIGITAL AGE

The development of computers and computer techniques, together with the increasing cost of silver (a key element in silver nitrate film) during the late 1970s, started the research and investment by the film companies into the development of digital imaging and storage. The initial films used had a high silver content and a wide latitude. This silver could be reclaimed from both the film and the processor. As time progressed, and

FIGURE 14:
X-RAY FILM STORE.

the cost of silver increased, the amount of silver on the film was reduced resulting in a loss of image quality. The first working CCD-based digital still camera was shown as a prototype for photography in 1975 at Kodak, where it recorded a black-and-white image on a digital cassette tape.

Since then, both photography and x-ray imaging, together with most other imaging in radiology, have developed into computer-based digital imaging techniques, and photography and radiological imaging continue to develop in parallel and share many innovations. The initial digital images were printed as hard copies for reporting and storage using laser printers to print onto film that resembled x-ray film. As technology progressed the images were stored electronically on PACS and were viewed as soft copies on digital displays. Images are no longer printed as hard copies and are either transferred between locations electronically or stored on a CD.

The introduction of digital imaging has transformed clinical practice (Fig. 15). In the 1980s, the practice of interventional radiology was difficult because there were delays in processing angiographic series and image subtraction was manual. The photographic aspect of radiography has been transformed since the 1980s. We now live in a virtual world and one can only speculate as to how image generation and storage will develop in the future.

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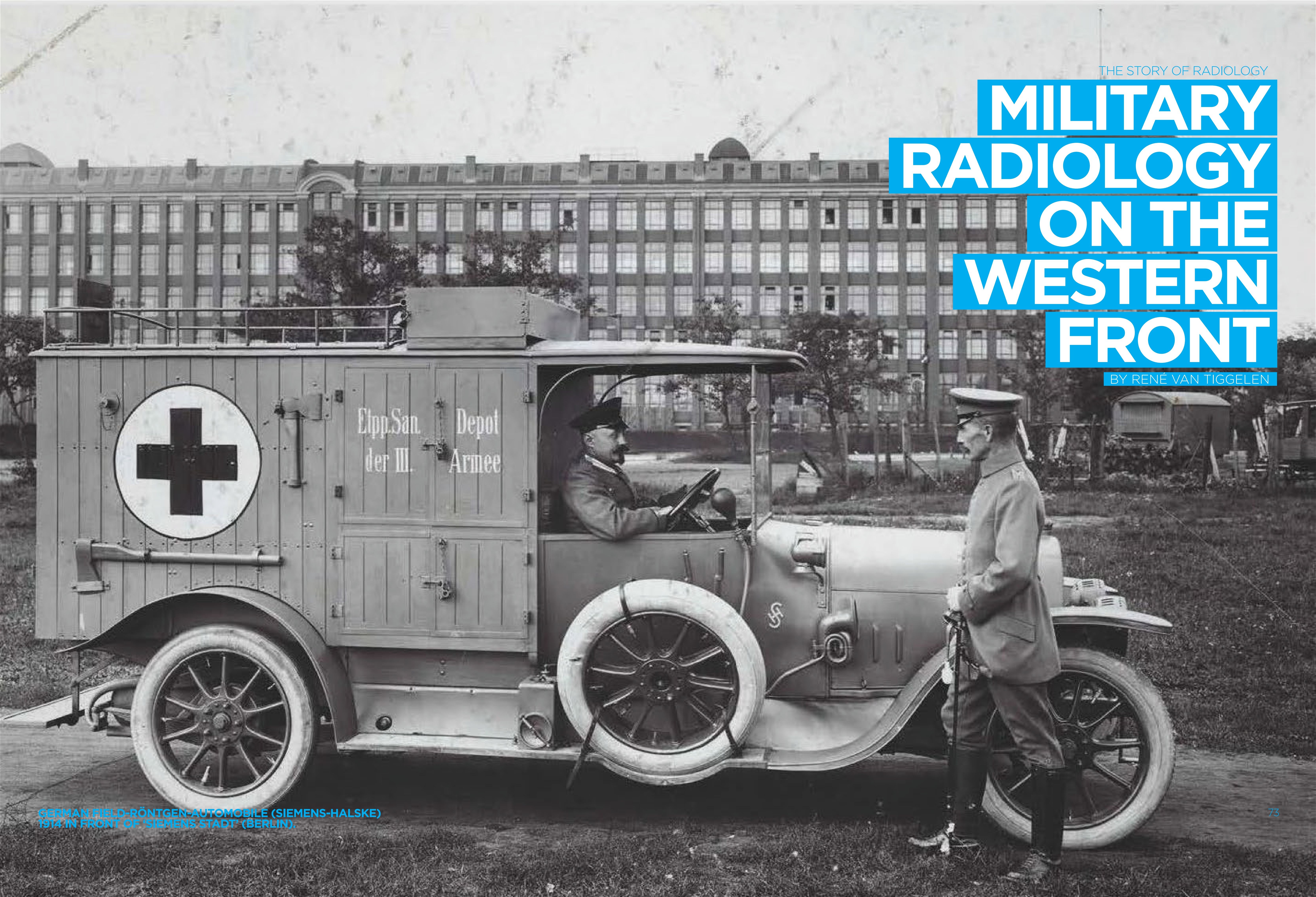
FIGURE 15:
DIGITAL RADIOGRAPH 2005.

MILITARY RADIOLOGY ON THE WESTERN FRONT

BY RENÉ VAN TIGGELEN



GERMAN FIELD-RÖNTGEN-AUTOMOBILE (SIEMENS-HALSKE) 1914 IN FRONT OF 'SIEMENS STADT' (BERLIN).

MILITARY RADIOLOGY
ON THE WESTERN FRONT

THE STORY OF RADIOLOGY
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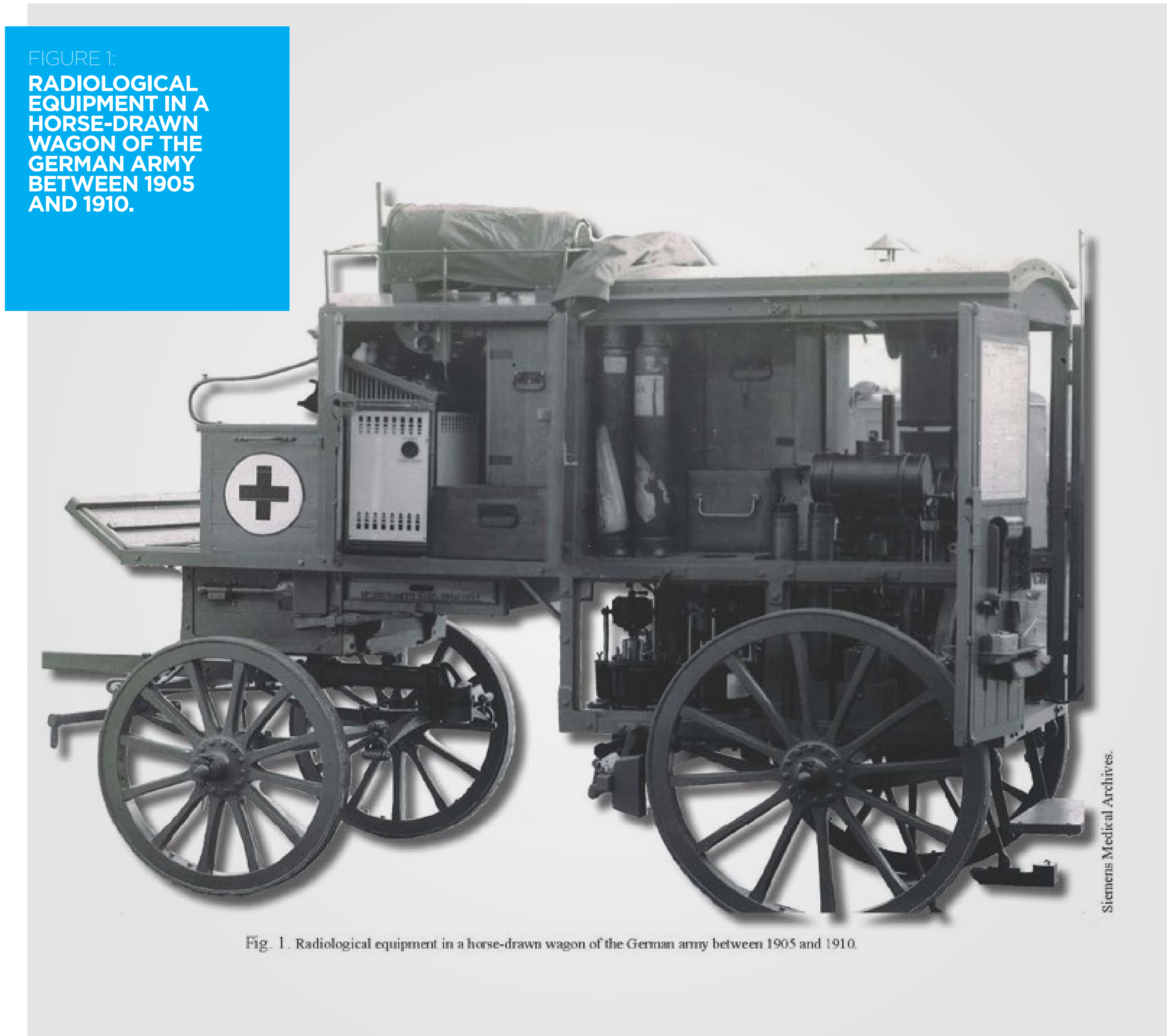
FIGURE 1:
RADIOLOGICAL EQUIPMENT IN A HORSE-DRAWN WAGON OF THE GERMAN ARMY BETWEEN 1905 AND 1910.



INTRODUCTION

At the beginning of the First World War, the discipline of radiology was only 19 years old and its equipment was still rudimentary and ill-suited for use near the front lines. Yet both sides made use of the technology during the war.

IMPERIAL GERMAN ARMY

W.C. Röntgen's discovery in November 1895 spread rapidly, at a time when Germany was considered a 'locomotive' of science and industry. The German medical service introduced this new application immediately as a medical procedure in surgery.

In 1905, the German Army began transporting radiological equipment by horse-drawn carriage (Fig. 1) which included a folding table, a dismountable x-ray tube holder, and a power generator, allowing for the rapid deployment of radiology in the field. In 1903, W. Stechow (Fig. 2), a German physician general, published an illustrated treatise on the subject. In 1907, field x-ray wagons became the standard in the Army Medical Service and were assigned to the field army with the following equipment: x-ray (coil and gas tube), darkroom, four boxes of chemicals, glass plates, and spare x-ray tubes. Twelve of this these were available in 1914, and an additional 20 were acquired later.

Later, the field Röntgen automobile emerged (Fig. 3, see page 94). Its motor powered the generator and the supplying firms provided the necessary technologists. In total, the German military deployed 275

FIGURE 2:
W. STECHOW (PAINTING FROM WILHELM AUBERTEN).

FIGURE 4:
RADIOLOGICAL CAR WITH KRUCK CHASSIS OF THE 'VEIFA' COMPANY OF FRANKFURT-AM-MAIN. THE GENERATOR IS POWERED BY THE ENGINE OF THE VEHICLE AND THE BODY OF THE TRUCK IS USED AS DARK-ROOM.

x-ray units. Standardisation was encouraged, for instance, the 18cm x 24cm x-ray plate was considered the most practical one. Necessary accessories became part of the equipment: stereoscopes, localisation devices, x-ray atlases and even silver recovery units.

For remote areas, portable equipment was designed (packed in 16 boxes). The boxes were used as bases and accessory tables (Fig. 4). The x-ray equipment was operated from field wagons, each with a company of one technologist (usually a uniformed civil servant), one medical sergeant, one medical corporal, and two drivers. A medical officer supervised the operation of the equipment and the examinations. The technologists, usually engineers, were also drafted physics professors or other physicists.

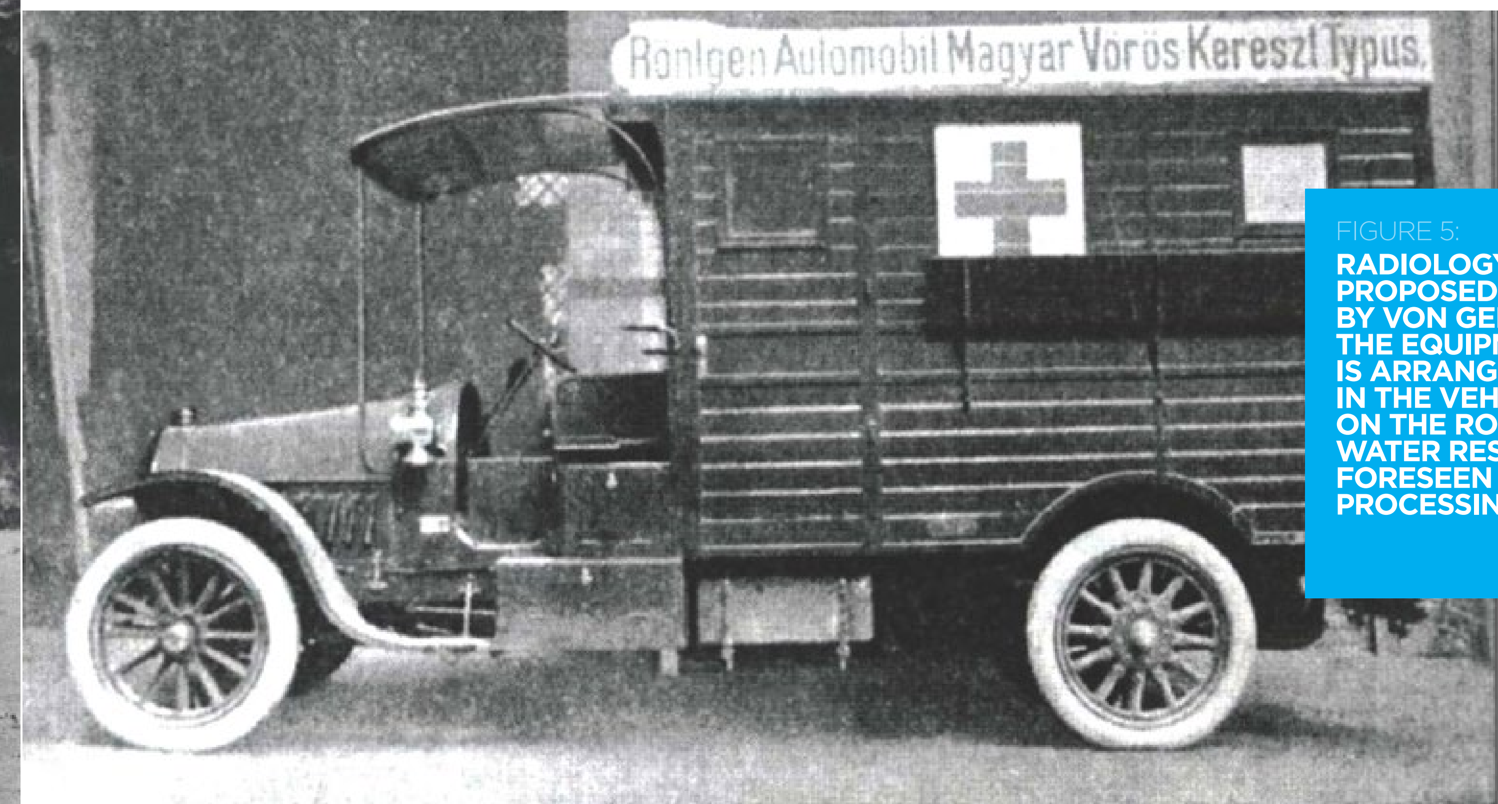


FIGURE 5:
RADIOLOGY VEHICLE PROPOSED IN 1914 BY VON GERZÖ. THE EQUIPMENT IS ARRANGED IN THE VEHICLE. ON THE ROOF, A WATER RESERVE IS FORESEEN FOR FILM PROCESSING.

Fully trained roentgenologists were rare, usually assigned to the field army, and travelled as advisors. GI-specialists and surgeons had radiological training in their fields and together with the technologists they did well. The personnel performed the radiographic examinations. The fluoroscopy and radiographic examination of the wounded was performed by physicians. In hospitals and large clinics, nurses and photographers were available.

The Austro-Hungarian Empire was no exception. There were private initiatives and actions taken by Dr. E. von Gerzö, assistant surgeon at the Royal Hungarian University of Budapest. He described in detail an automobile with radiological equipment. He used an Opel (Fig. 5) chassis and x-ray equipment installed by Reiniger, Gebert and Schall.

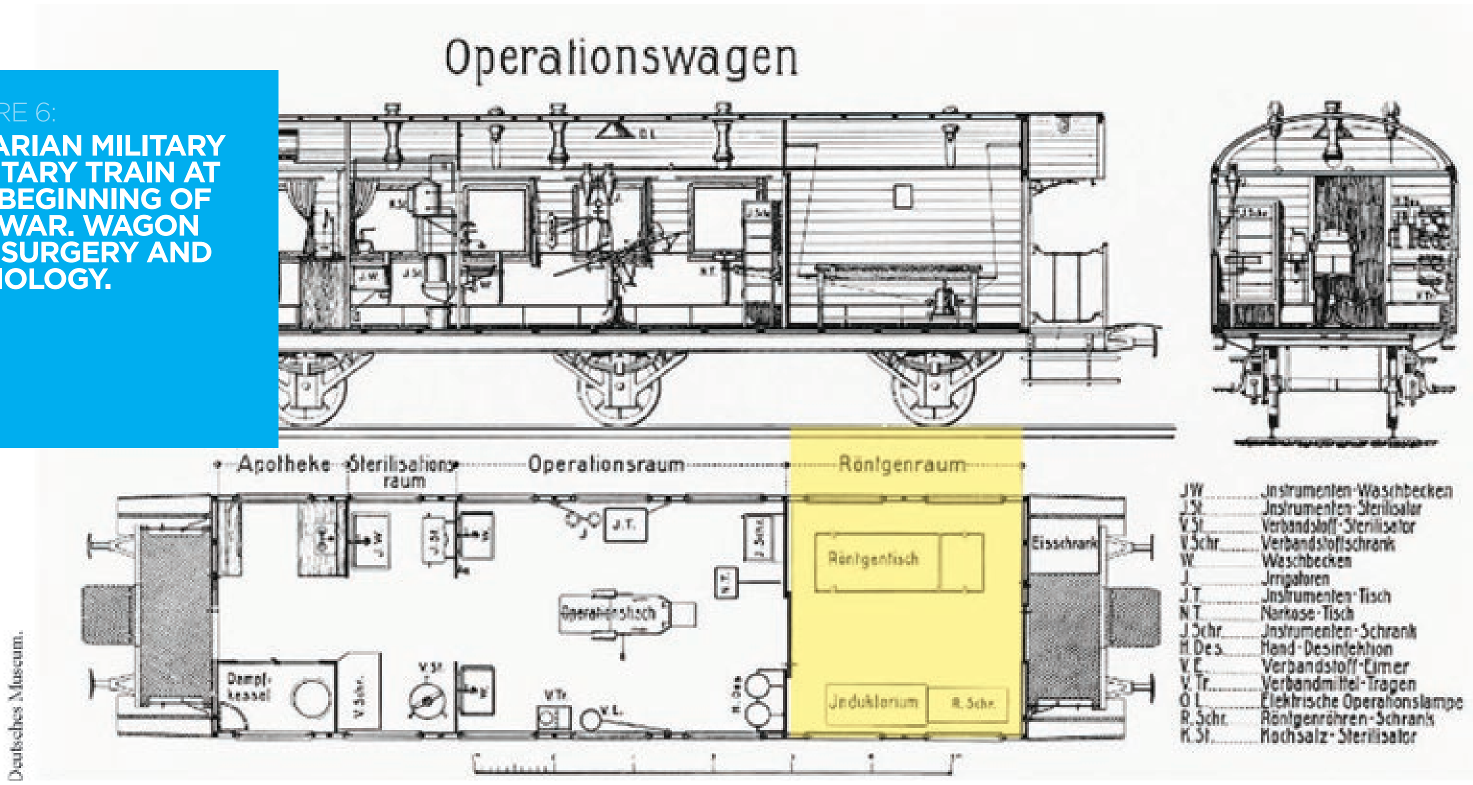


FIGURE 6:
BAVARIAN MILITARY SANITARY TRAIN AT THE BEGINNING OF THE WAR. WAGON FOR SURGERY AND RADIOLOGY.

Many other initiatives emerged. Professor L. Brauer and Dr. F. Haenisch of Hamburg used *Adler* and *Fiat* vehicles in 1915, fitted with radiological equipment from the firm Seifert & Co of Hamburg. The imperial army also had sanitary trains, some of which were equipped with radiological apparatus (Fig. 6).

Before the war, Germany had colonies and a large navy. Along with a dozen auxiliary vessels, the Imperial Navy requisitioned passenger liners to turn them into hospital ships (Scharnhorst, Chemnitz, Kassel, Frankfurt, Sierra Ventona, and Schleswig) with surgical theatres, pharmacies, laboratories and radiological equipment.

FRENCH ARMY

The French already had eleven mobile x-ray units from their colonial campaigns in North Africa.

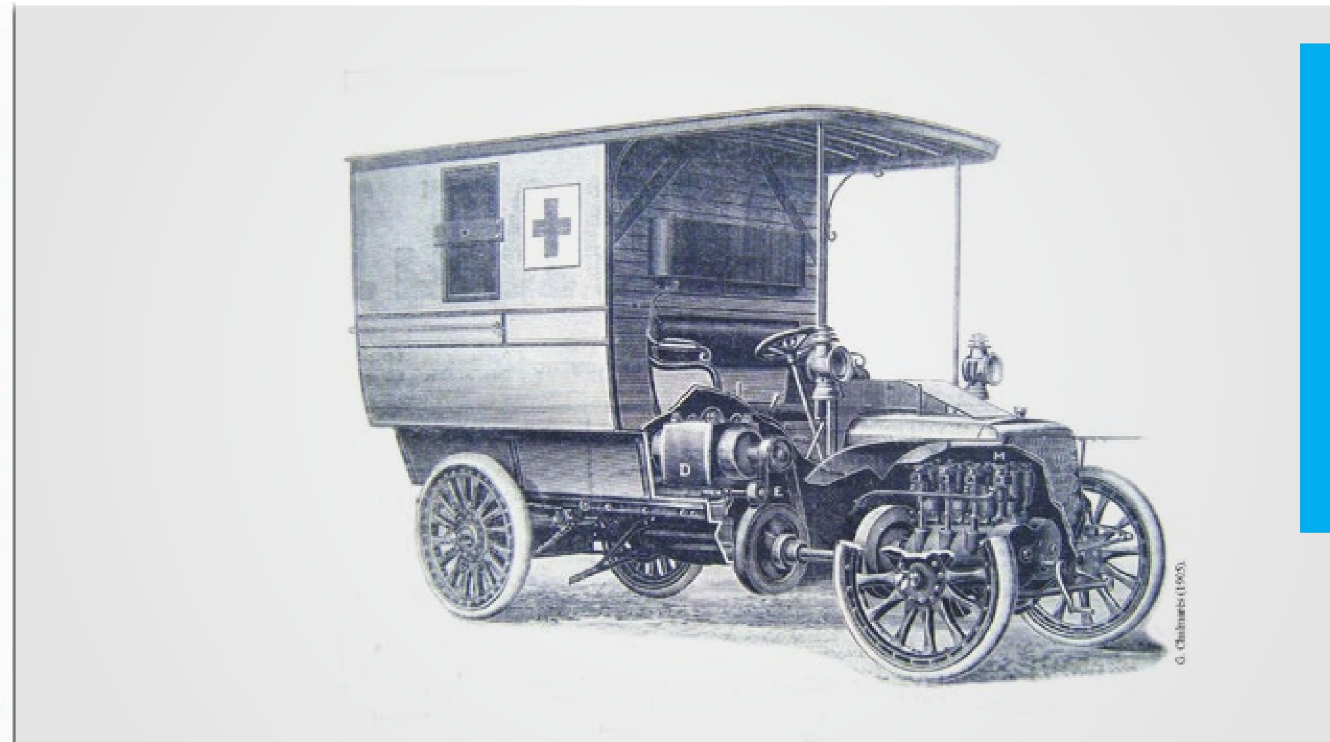


FIGURE 7:
MOTOR VEHICLE FOR RADIOLOGY EQUIPMENT. THE DRIVING IS DONE WITH CHAINS! THE CUT-OUT IN THE WHEEL SHOWS THE DRIVE (E) OF THE BIPOLAR ALTERNATOR (110V 24 A) BY THE ENGINE OF THE VEHICLE, IF THE PROPULSION MECHANISM IS DISENGAGED.

A radiological vehicle by the firm Gaiffe was acquired by the Greek government and was used during the Balkan War (1913). The French military medical service showed interest and sought to compare it with their *Massiot* radiology car in 1914. After mobilisation, the radiology automobile Massiot no. 1 (Fig. 7) was added to the First Army with its designer, G. Massiot, mobilised as a technologist. Surgeon General A. Troussaint ordered the medical majors A. Béclère, P. Aubourg and G. Haret to organise radiology crews equipped with dismountable equipment. When they joined the army there were two equipped cars (Fig. 9). By January 1915, twenty vehicles were in service.

These mobile units fell into several categories. Motorised surgical field clinics (ACA) had three trucks of equipment, a van, and six cars for transporting personnel and the wounded. The whole support unit was made up of truck A, for the steam sterilisation and the storage of the linen; truck B for the operating theatre, fluoroscopic and photographic

FIGURE 9:
SAURER 50 HP. TRUCK BUILT BY G. GALLOT INSPIRED BY AN IDEA OF MASSIOT. DEMONSTRATION OF EQUIPMENT BEFORE LEAVING IN AUGUST 1914. ONE RECOGNISES TO THE LEFT THE MEDICAL OFFICER G. HARET, FORMER STUDENT OF PROFESSOR A. BÉCLÈRE.

FIGURE 10:
BAVARIAN MILITARY SANITARY TRAIN AT THE BEGINNING OF THE WAR. WAGON FOR SURGERY AND RADIOLOGY.

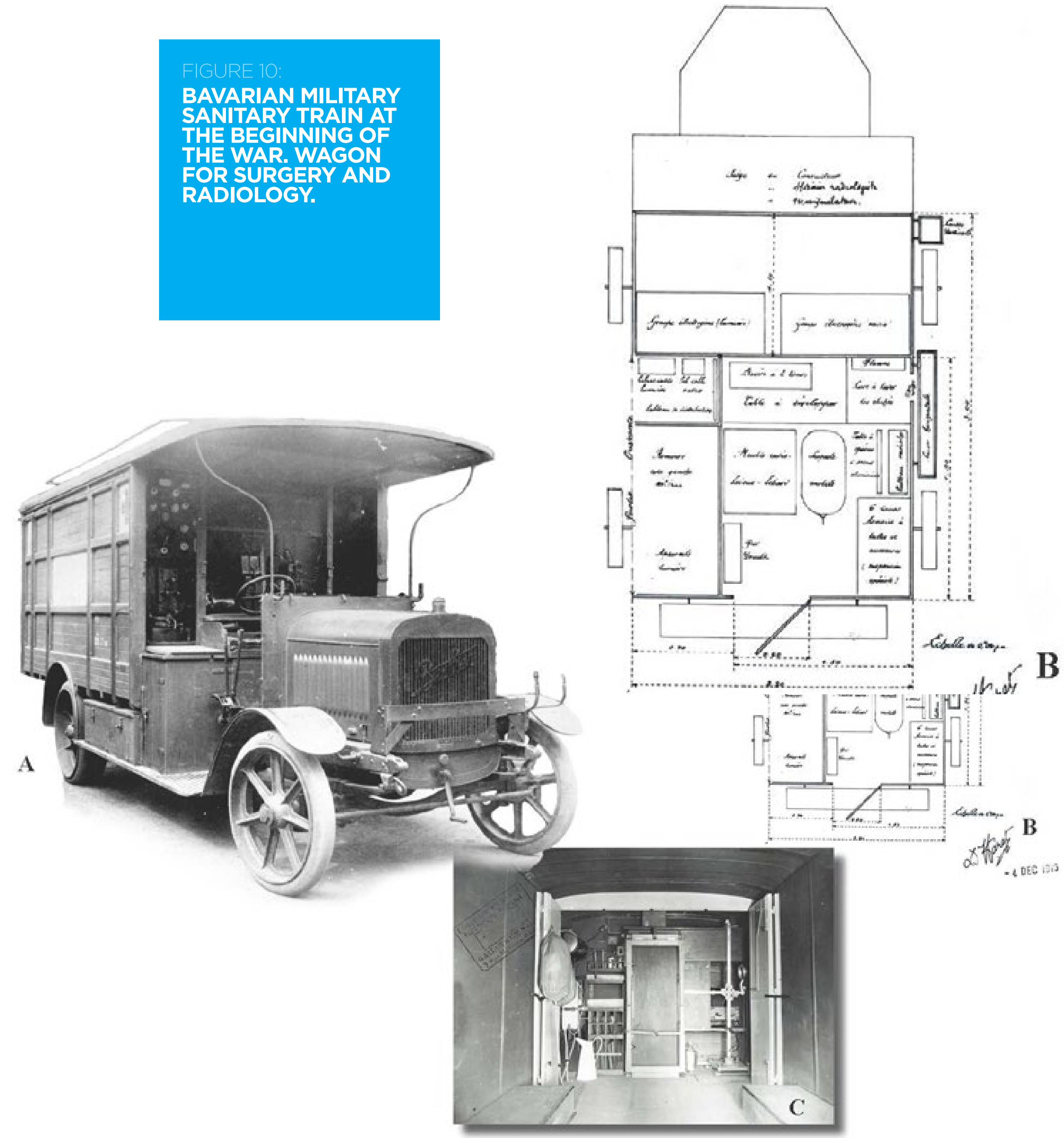


FIGURE 11:
MARIE CURIE DRIVES, SOMETIMES HERSELF, THE AUTOMOBILE OF RADIOLOGY. OF THE TWENTY CARS THE PHYSICIST STARTS UP, SHE RESERVES ONE FOR HER OWN USE: AN OLD RENAULT 'CROCODILE HOOD' BODIED AS A DELIVERY TRUCK (OCTOBER 1917).

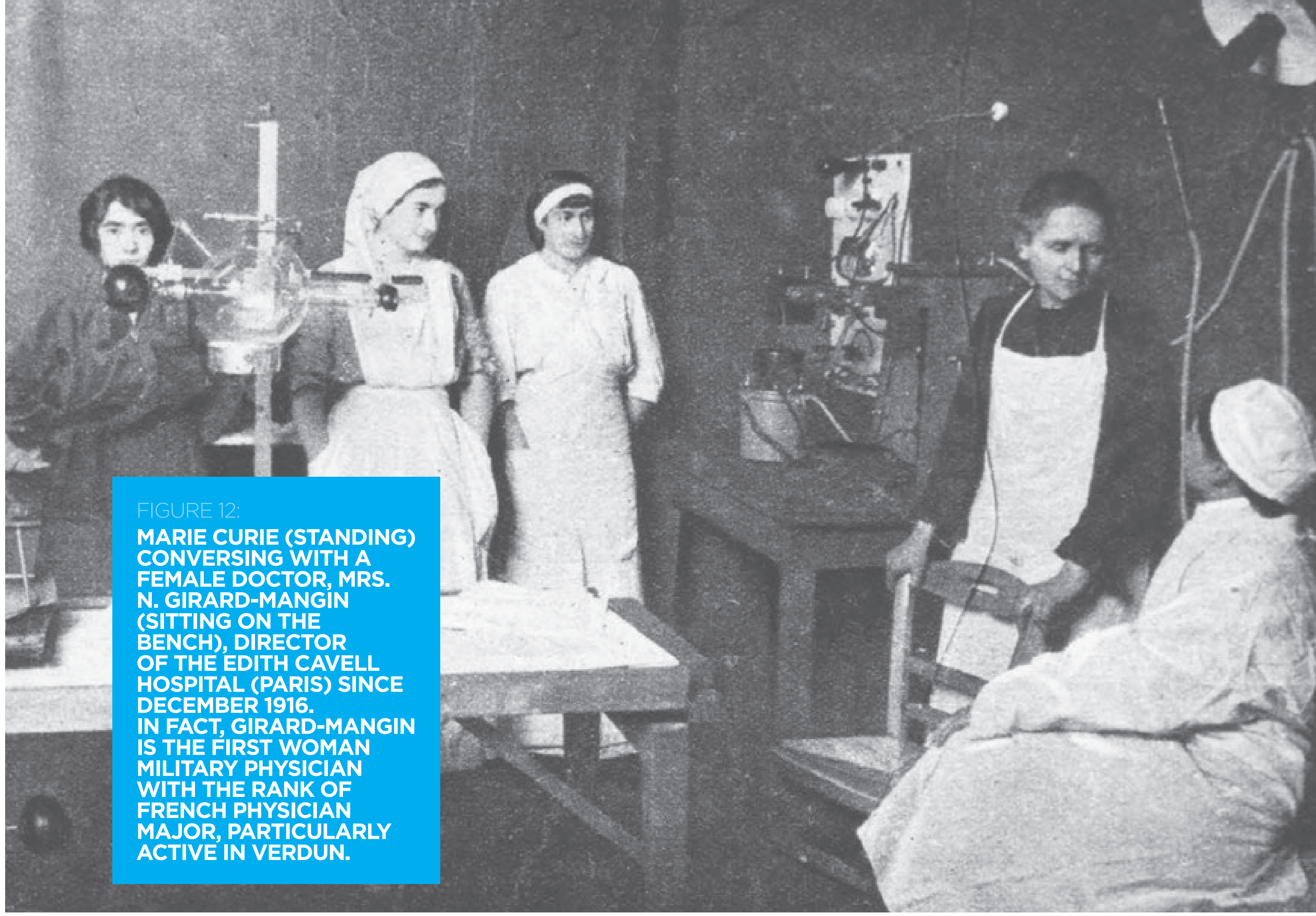


FIGURE 12:
MARIE CURIE (STANDING) CONVERSING WITH A FEMALE DOCTOR, MRS. N. GIRARD-MANGIN (SITTING ON THE BENCH), DIRECTOR OF THE EDITH CAVELL HOSPITAL (PARIS) SINCE DECEMBER 1916. IN FACT, GIRARD-MANGIN IS THE FIRST WOMAN MILITARY PHYSICIAN WITH THE RANK OF FRENCH PHYSICIAN MAJOR, PARTICULARLY ACTIVE IN VERDUN.

equipment; and truck C (Fig. 10) carried the generator, x-ray equipment, and surgical instruments. The cumbersome size and weight of these ACA trucks meant their mobility was limited; however, there were also more mobile surgical units with lighter portable equipment. Only fluoroscopic equipment was placed in a car with sterilisation equipment, lighting, and a generator, as well as a small dismountable operation shack on a trailer. These were still only semi-fixed stations (182 in 1918) to supply electricity to radiology equipment and evacuation hospitals (HOE) with radio-surgical equipment.

Marie Curie played a very important role. She was responsible for the technical implementation of radiology operations for the National Patronage of the Wounded, and she created an auxiliary radiology department within the French Military Medical Service. She significantly increased the number of vehicles, nicknamed 'Little Curies', and her organisation distributed approximately 200 units to hospitals. She equipped eighteen passenger cars and vans with radiological equipment, powered by either a generator or dynamo. Curie designed the interior of the radiology vehicles and committed herself (Fig. 11), with her daughter Irène, to delivering them by car or train. They were frequently spotted at the front explaining the use of radiological equipment to doctors, who were still largely unfamiliar with this new technology. They also came to Belgium on several occasions. Furthermore, Curie taught the concepts of radiology at the Hospital School Edith Cavell (Fig. 12) in Paris, to both civilian and military paramedics. From September 1916 to November 1918, 120 female technologists benefited from this training.

Technologist training was also set up by the medical service for its 1,010 recruits (Fig. 13). They aimed to train a large number of professionals to handle the fixed and mobile radiological units, operating at times

FIGURE 13:
TUTORIALS IN PRACTICE GIVEN AT THE GENERAL WORKSHOPS OF THE MEDICAL SERVICE TO THE CANDIDATES TECHNOLOGISTS.

without the presence of a radiologist. The technologists assembled, disassembled, and calibrated the radiology equipment, and they also learned to use the locator compasses. They were selected from engineers, electricians, chemists and from the professors of the faculties of science. The courses, in groups of ten, dealt with mechanics, electricity, physics, photographic processing and anatomy. The courses were based on the contents of the *Radiology Technologist's Handbook* by L. Mathé and V. Baudot.

Upon mobilisation, none of the 175 radiologists in France were assigned to a position in radiology. The only radiologist from the Army was assigned as commander of a clinic without a radiology facility. The medical officer G. Haret not only created and standardised the radiological equipment but also assigned competent radiologists. Since there was only a relatively

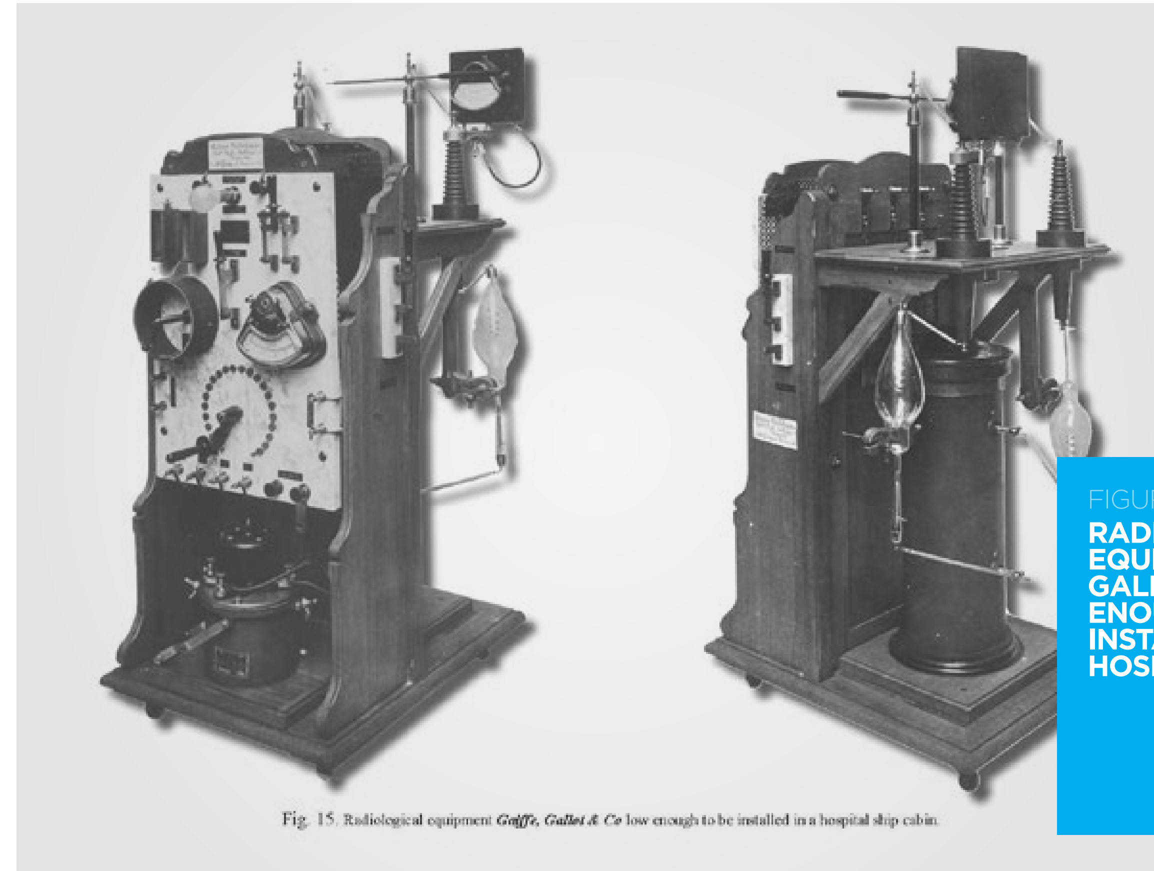
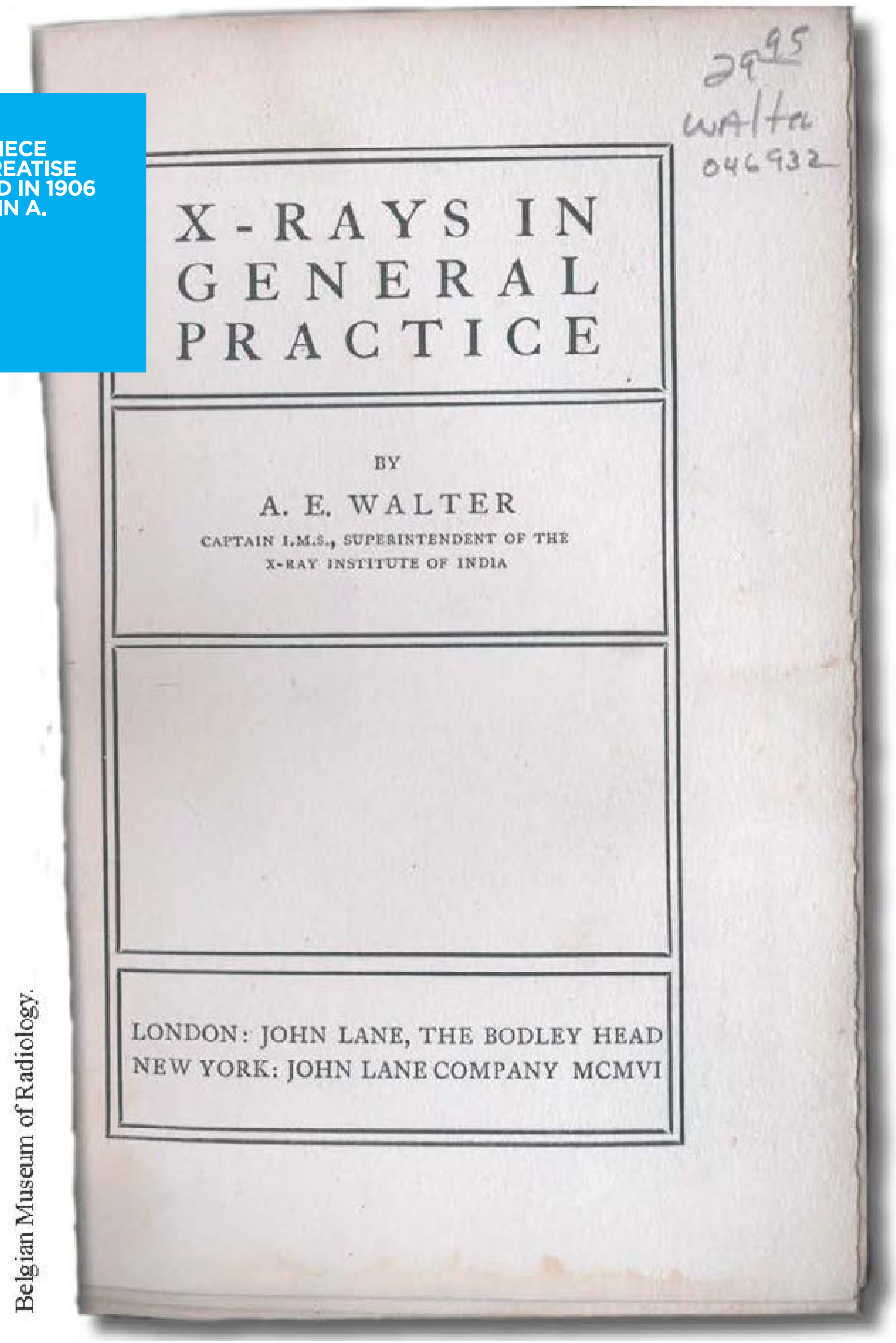


FIGURE 15:
RADIOLOGICAL EQUIPMENT GAIFFE, GALLOT & CO LOW ENOUGH TO BE INSTALLED IN A HOSPITAL SHIP CABIN.

small number of radiologists, radiographers and technologists, responsibility for training was given to the medical officers J. Hirtz and A. Béclère. Both doctors organised training courses at Val-de-Grâce.

G. Haret reported that by the armistice, there were 850 radiological stations, with 840 radiologists. Of these, 700 were trained during the conflict.

France converted many vessels into hospital ships. The first one of these was the troopship Duguay-Trouin (formerly Tonkin) in August 1914. It was equipped with x-ray equipment, specially designed given the limited size of the ship (Fig. 15). After 1915, most of these and other requisitioned ships were sent to the eastern Mediterranean front. In 1916, there were eight hospital ships and sixteen by the end of the war.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X-RAYS IN GENERAL PRACTICE

BY

A. E. WALTER

CAPTAIN I.M.S., SUPERINTENDENT OF THE X-RAY INSTITUTE OF INDIA

LONDON: JOHN LANE, THE BODLEY HEAD
NEW YORK: JOHN LANE COMPANY MCMVI

FIGURE 16:
FRONTISPIECE OF THE TREATISE AUTHORED IN 1906 BY CAPTAIN A. WALTER

Belgian Museum of Radiology.

BRITISH EXPEDITIONARY FORCE

In 1910, A.J. Walton succeeded H. Henry as army x-ray instructor. In 1909, the Indian Medical Service established an x-ray institute at Debra Dun, its director was an army officer, Captain A. E. Walter, the author of an early textbook called *X-rays in General Practice* (1906) (Fig. 16). One of his most promising pupils was a 24-year-old Scottish surgeon, D.B. McGrigor (Fig. 17), who became the first radiologist in the British Army, going on to later become a general and president of the British Institute of Radiology (1939–1942). By 1897, the Royal Army Medical Corps (RAMC) had deployed mobile radiology equipment to India, Egypt and South Africa. The electric power was supplied by a little dynamo driven by a bicycle.

Apart from the First Aid Nursing Yeomanry, most women volunteers joined the newly formed Voluntary Aid Detachments under the auspices of the War Office and the Red Cross. In 1914, Florence Stoney, radiologist at the Royal Free Hospital, offered her services to the War Office, but was rejected. She became head of a surgical hospital in Antwerp run entirely by British women, like in Cherbourg, and in 1915 was appointed as the first female head of a radiology department in England run by the War Office. The British Red Cross also supplied several x-ray units for use in France and Belgium. The British Field Hospital was initially located in Antwerp (Fig. 18), later in Veurne, then Hoogstade before being taken over by the Belgians.

When the British Expeditionary Force was sent to the Western Front in 1914, there were few full-time radiologists outside large cities. Although several radiologists were called up for war service, mainly to

FIGURE 17:
MAJOR GENERAL D.B. MCGRIGOR

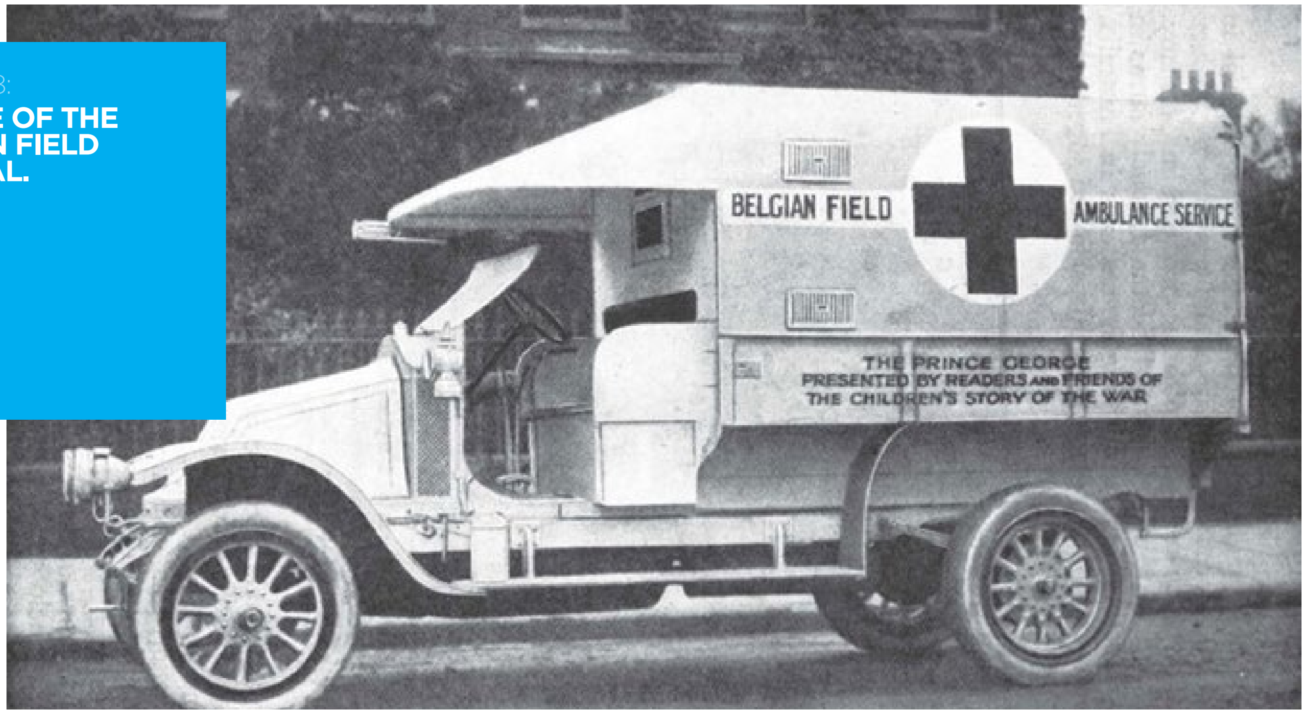

FIGURE 18:
VEHICLE OF THE BELGIAN FIELD HOSPITAL.

perform unskilled tasks, radiological procedures were carried out by untrained doctors, scientists, and even orderlies.

Early on, power supplies were poor; a small one horsepower engine was the only source of power. This independent unit was better than the units sent out with the original medical units of the Expeditionary Force. The constant search for independent power supplies suitable for x-rays continued. The absence of suitable sources was due to the fact that alternating current had not yet been developed by military engineers.

In 1914, British ambulances were horse-drawn and the RAMC had no x-ray facilities on the continent. There were only two mobile x-ray cars in 1915, devised before the war to overcome the electrical generation problem. Later, an ad hoc assembly of vehicles with dynamo, dark room

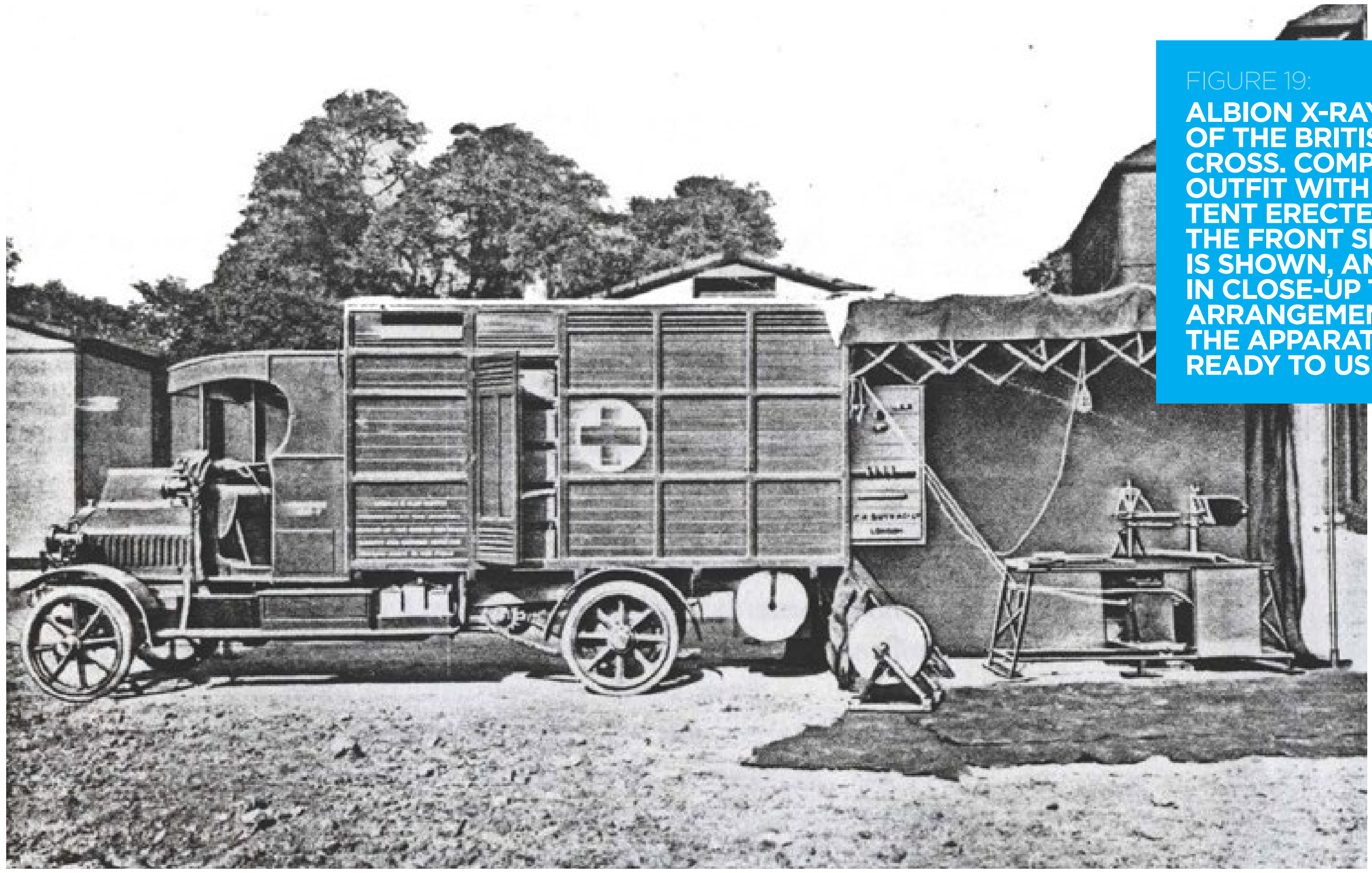

FIGURE 19:
ALBION X-RAY VAN OF THE BRITISH RED CROSS. COMPLETE OUTFIT WITH THE TENT ERECTED. THE FRONT SIDE IS SHOWN, AND IN CLOSE-UP THE ARRANGEMENT OF THE APPARATUS READY TO USE.

and radiographic apparatus were introduced. Motorised ambulances gradually replaced horse-drawn carriages. No single standard ambulance or other regular chassis was available in England at the time. The Albion, made in Scotland, is one of the makes adapted by the British Red Cross during the war (Fig. 19). With thirty-two horse power and a three ton chassis it was relatively powerful. The dynamo was driven by the engine which powered a set of accumulators. Despite its size, with a 3.25m wheelbase, it did not house the examination room within the body of the vehicle. Instead a canopy could be pulled out on a frame behind it to provide an x-ray room with some shelter in windy weather.

FIGURE 20:
SIR ARCHIBALD REID. HIS LATER YEARS ARE DARKENED BY SEVERE RADIODERMITIS WHICH CONTRIBUTE TO HIS PREMATURE DEATH AT THE AGE OF 53.

Sir Archibald Reid (Fig. 20) was a very important radiologist during the First World War. He was commissioned as a major and assigned to the Queen Alexandra Military Hospital, Millbank, and to the Second London General Hospital, Chelsea. From 1914 to 1919, he served as president of the War Office X-ray Committee. To resolve the shortage of trained x-ray staff, he set up a course of training lectures at Millbank in 1915, assisted by Dr. R. Reynolds and the physicist C.E.S. Phillips. Reid's unique military experience convinced him that national training facilities for radiologists were urgently required, and he was a cofounder of the British Association of Radiology. He helped to create the Society of Radiographers in 1920, and served as its first president. Reid and his army committee dealt with several technical matters, including the design of mobile x-ray vehicles.

The British Army sent ten mobile x-ray units to France. Some were manufactured by the Army's department of radiology research centre at Woolwich. One of them (an Austin wagon) was described in detail by H. Head (1918) (Fig. 21). This made more compact, powerful and efficient apparatus available. General and base hospitals received radiographic sets early on. Casualty clearing stations were originally considered to be suitable for the type of surgery requiring radiological services, but with the onset of static trench warfare the role of surgery and radiology in these forward units increased in significance. Radiography went on to become routine in hospitals specialising in the treatment of fractures.

Wounded soldiers and sailors returned to Britain by ship. At the time, the British Empire had the largest fleet in the world. Ocean liners were

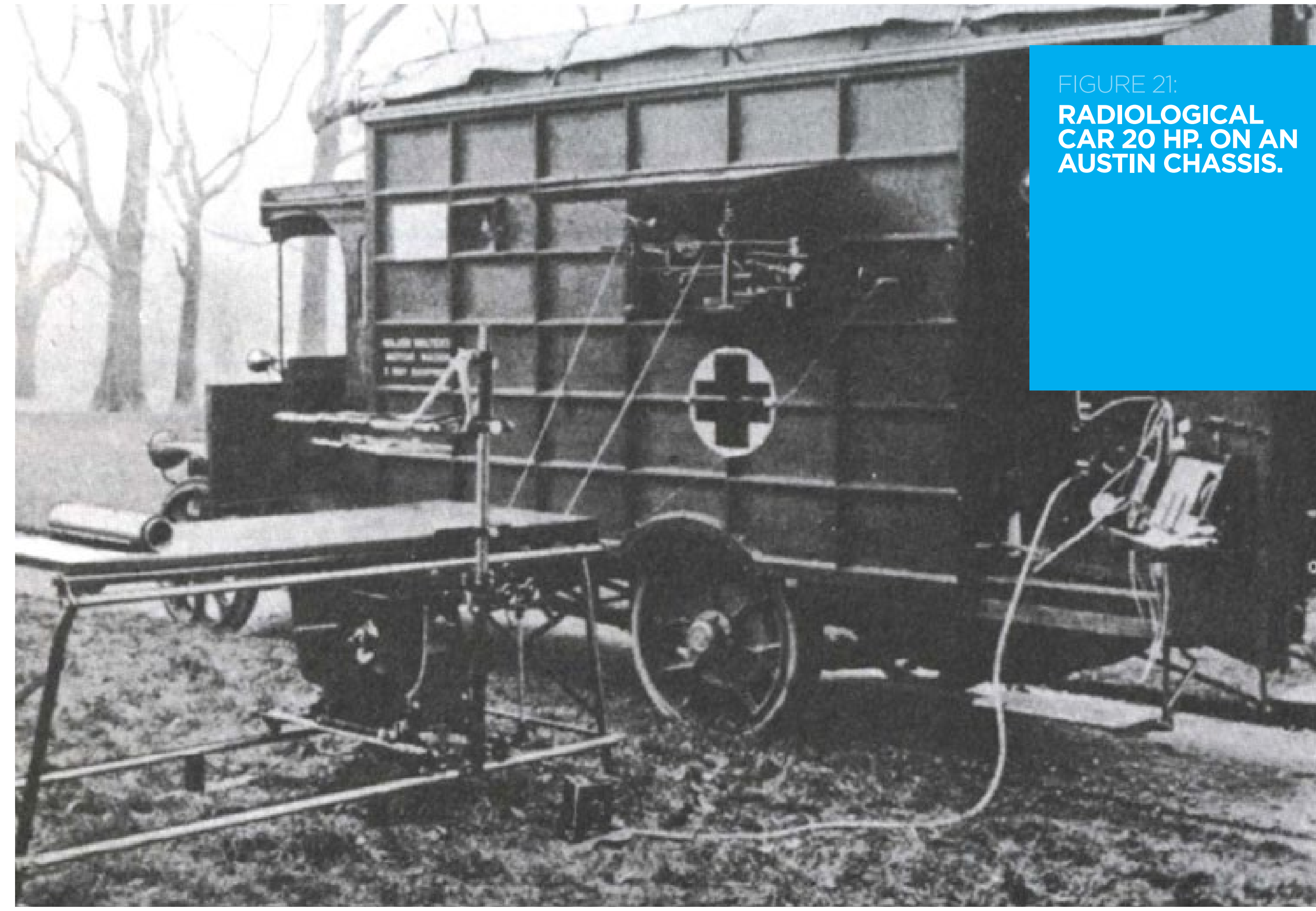

FIGURE 21:
RADIOLOGICAL CAR 20 HP. ON AN AUSTIN CHASSIS.

requisitioned as hospital ships and extensively adapted for caring for the sick and wounded. They were true floating hospitals and were medically and surgically equipped to deal with all kinds of injuries and diseases. Many were fitted with radiographic apparatus. Altogether, 77 military hospital ships and transports were commissioned during the war: 22 in 1914, 42 in 1915, seven in 1916, and six in 1917. Four Belgian Government Mail Steamers were also included: the Jan Breydel, Pieter de Coninck, Stad Antwerpen and Ville de Liège.

FIGURE 22:
GROUP OF AMERICAN RADIOLOGISTS IN TRAINING AT THE TRAINING CENTER OF THE HOSPITAL DESCARTES IN TOURS (FRANCE). IN THE MIDDLE OF THE PHOTO PROF. R. LEDOUX-LEBARD.

AMERICAN EXPEDITIONARY FORCE

Before the war, the US Army's only x-ray equipment was made up of the machines installed at military hospitals. Although some portable x-ray machines were used in some hospitals, there was no specific military field x-ray equipment.

Surgeon General W. Gorgas recognised the immediate need for x-ray-trained physicians and sought help in mobilising radiologists from the executive council and officers of the American Roentgen Ray Society (ARRS). L.G. Cole, together with A.C. Christie, both ARRS members, enlisted in the medical corps and developed training for non-radiologists. More than 700 physicians graduated from these mini-courses.

American units were complemented with French combat units, including those from Tours (Fig. 22) and Paris, where Marie Curie (Fig. 23) assisted J. Case who was in charge of radiology. The physicians were trained in positioning and film processing, and most

FIGURE 23:
MARIE CURIE WITH HER DAUGHTER IRÈNE, INSTRUCTING AMERICAN OFFICERS (MD) IN A PARIS LABORATORY.

importantly, the localisation of foreign bodies (Fig. 24). Another common problem was the lack of trained technologists. The US Army established several schools to train corpsmen and published a very well-written manual.

Cooperating with manufacturers, A.C. Christie quickly developed a suitable field apparatus; a mobile fluoroscopic unit with x-ray equipment for use in vehicles. Another portable unit, developed by the Picker X-ray Company, became the basic standard in equipment. A remarkably efficient and silent portable apparatus was developed by W. Coolidge and C.N. More, equipped with an air-cooled, fine-focus hot cathode and a small bulb tube.

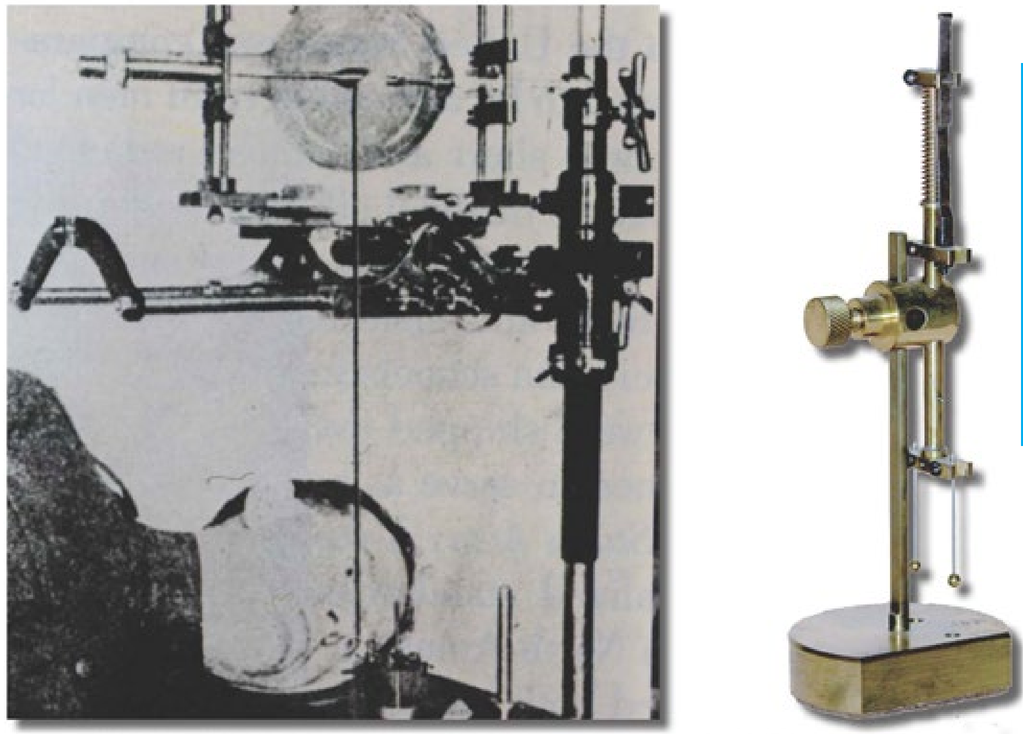

FIGURE 24:
THE TECHNIQUE FOR THE LOCALISATION OF PROJECTILES IN THE EYE. A TUBE SHIFT METHOD IS USED WITH TWO RADIOGRAPHS AND THE W. SWEET DEVICE (SEE DETAIL VIEW).

The advantage of the English and French vehicles over the Americans is that they could accommodate a dark room. Experience from the War shows that the greater part of the work was fluoroscopic. An elaborate dark room was therefore unnecessary. The engine of the American vehicle did not generate power for x-rays, but it did have some advantages: it was much lighter, had demountable apparatus and came with spare parts (Fig. 26). The sturdy standard US Army x-ray table could be assembled quickly (Fig. 27). In addition, it could be used as a table in the x-ray room, as a stretcher for carrying patients, or as a surgical operating table (with its Bakelite covering impervious to antiseptic solutions). The fluoroscopic screen had wires for foreign body localisation. The apparatus was packed in 19 boxes with accessories, books, films and darkroom supplies. It weighed about 2.25kg. By the end of the war, 719 US x-ray units had been shipped overseas: 150 complete sets for

FIGURE 26:
FROM LEFT TO RIGHT: BRITISH, FRENCH AND AMERICAN RADIOLOGICAL WAGONS (PARIS).

base hospitals, 250 bedside machines, 55 x-ray trucks, 264 portable machines, and hundreds of accessories.

Since the war took place on another continent, logistics was a significant consideration, though it was less important for the Europeans as they did not have to cross an ocean. The first hospital ship in the world to be purpose-built and equipped with all medical equipment and modern radiology was the USS Relief (AH-1) (Fig. 28).

The heavy and fragile glass plates were replaced by film from the Eastman Chemical Company in 1913. By this time, the Coolidge tube replaced the less reliable gas tube, and in 1916 the introduction of the Potter-Bucky diaphragm, as well as E. Caldwell's diaphragm, freed x-ray images of their fogginess and indistinctness. Because of the War,

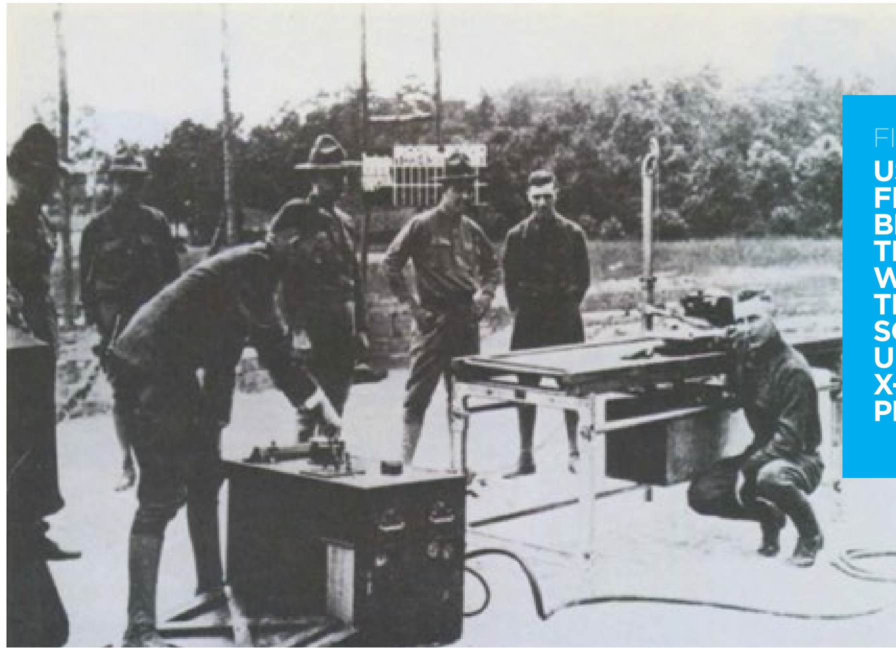

FIGURE 27:
US ARMY X-RAY FIELD UNIT THAT CAN BE DEMOUNTED FOR TRANSPORTATION WITHIN 3 MINUTES! THE FLUOROSCOPIC SCREEN IS ENCLOSED UNDERNEATH THE X-RAY TUBE IN A PROTECTIVE BOX.

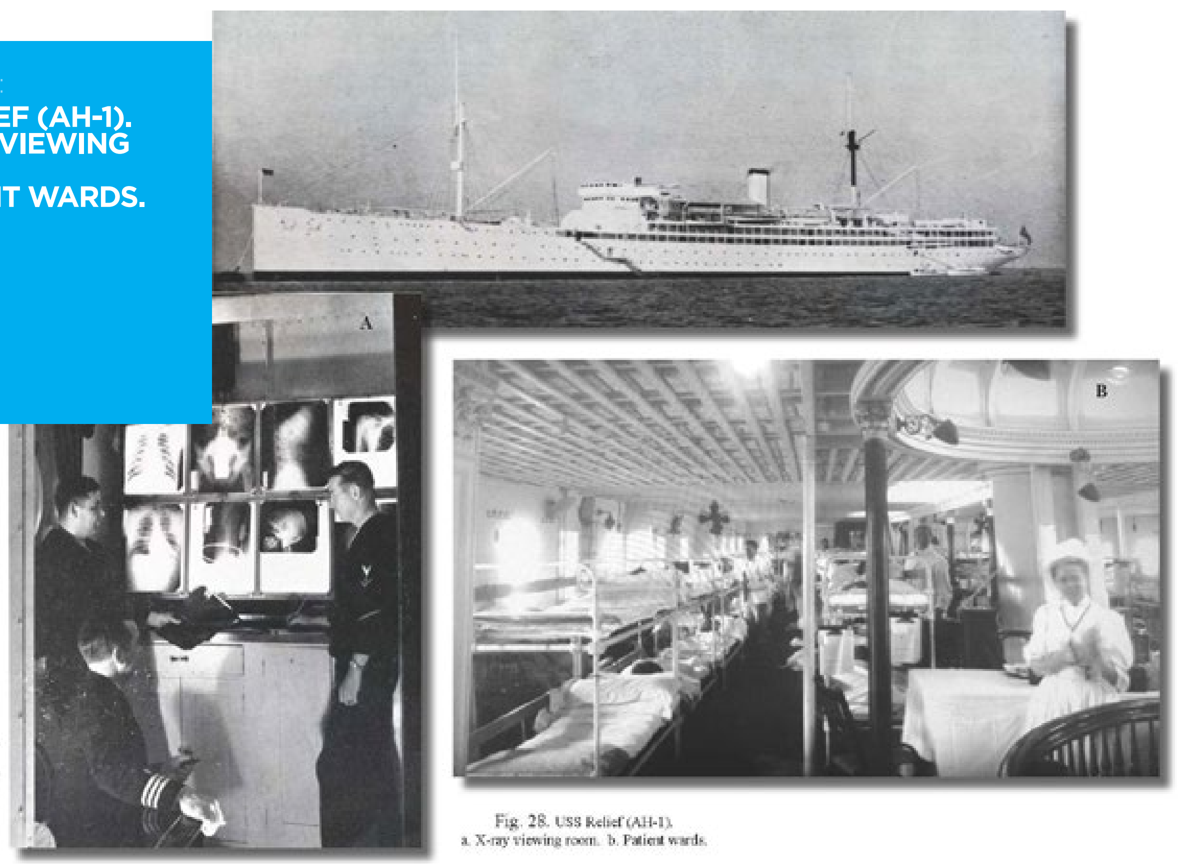

FIGURE 28:
USS RELIEF (AH-1).
A. X-RAY VIEWING ROOM.
B. PATIENT WARDS.

Potter was not aware of Bucky's invention until Caldwell told him about their similar approaches. Soon, most x-ray manufacturers offered a grid. As a result of these three great discoveries, the American Expeditionary Force was supplied with the finest x-ray equipment in the world. From then on, the standardisation and portability of equipment shaped the civilian practice of radiology.

CONCLUSION

During the war many innovations were introduced: the invention of the radiological film, the Coolidge tube and the Potter-Bucky diaphragm. The discovery in 1916 by the mobilised French physician A. Bocage of conventional tomography remains undiscussed here. Finally, we mention the most important positive fact; after the First World War, there was not a single hospital, clinic, or sanatorium without an x-ray room. Radiology had become an accepted part of medicine.

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ABOUT THE AUTHORS

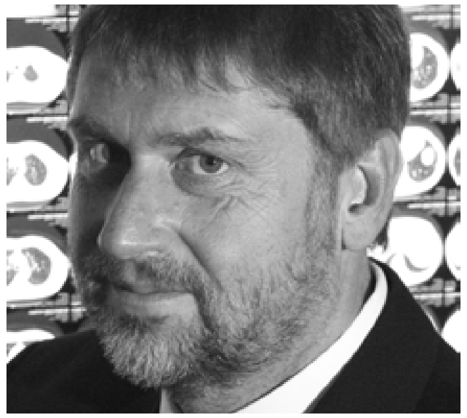
ELIZABETH BECKMANN

Elizabeth Beckmann from Orpington, UK, is a committee member of the International Society for the History of Radiology.

She is a fellow and former president of the British Institute of Radiology (BIR) and a co-author of the book 'Godfrey Hounsfield: intuitive genius of CT'. Beckmann is a trustee of the British Society for the History of Radiology and honorary secretary of the British Society for the History of Medicine.

Beckmann has worked in the field of Medical Imaging since 1977, working initially for EMI Medical Ltd, inventors of the CT scanner. She launched her own company, Lanmark, in 1989.

UWE BUSCH



Dr. Uwe Busch from Remscheid, Germany, is honorary secretary and a founding member of the International Society for the History of Radiology.

Dr. Busch is deputy director of the Röntgen Museum in Remscheid, Germany. He is well-known within the field of radiology as a historian of all things x-ray related. He studied nuclear physics at the University of Bochum where he received a diploma and later went on to earn a PhD in medical physics at the University of Erlangen in Bavaria.

Dr. Busch has written three books, over 40 published papers and has delivered over 25 international invited lectures. His other interests include the history of medical physics and physics in the 19th century.

FRANCIS DUCK

Francis Duck is from Bath, UK. He was a medical physicist and is now visiting professor at the University of Bath, having retired from his post at the Royal United Hospital Bath where he spent most of his career.

His work focused on the medical uses of ultrasound, and he remains a member of an ultrasound working group of the International Commission for Non-Ionising Radiation (ICNIRP). He has published on the precursors of medical ultrasound, including the discovery of piezoelectricity by the Curies and the development of ultrasonic echo-location during the First World War.

Recently, he published a book, *Physicists and Physicians: A History of Medical Physics from the Renaissance to Röntgen*, (Institute of Physics and Engineering in Medicine, 2013), which traces three centuries of the contributions made by physicists to medicine. He learned how to carry out book restoration some years ago and now cares for his own collection.

ADRIAN THOMAS

Prof.Dr. Adrian Thomas from Bromley, UK, is chairman and a founding member of the International Society for the History of Radiology.

Prof. Thomas is currently President of the British Society for the History of Medicine (BSHM) and past-Chairman of the British Society for the History of Radiology (BSHR). He is also honorary librarian at the British Radiology Institute and has worked as a consultant radiologist for the Sloane Hospital, Kent and Bromley NHS University Hospitals, London, since 1987.

Prof. Thomas is a member of the British Medical Association and a former president of the Royal Society of Medicine's radiology section. He has recently written a book with Arpan K. Banerjee chronicling the development of radiology, and entitled: 'The History of Radiology' (Oxford University Press, 2013).

RENÉ VAN TIGGELEN

René Van Tiggelen graduated in medicine at the University of Louvain (UCL, 1967). He then specialised in radiology under the leadership of Professors P. Bodart (UCL) and G. Cornélis (UCL/KUL) and also earned a degree in social medicine and hospital management. He spent his entire career working as a radiologist in the Belgian Armed Forces.

As a colonel in the Belgian Armed Forces, he became the deputy chief of staff of the medical component. As a senior hospital lecturer he taught musculoskeletal radiology at the VUB (Brussels Free University, Flemish section) from 1982 to 1996, and he has been a guest teacher at the EHSAL University Brussels since 1998. With a group of volunteers he created the Belgian Museum of Radiology in 1990 and has been its managing director since.

ABOUT THE AUTHORS

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Phone: (+ 43 1) 533 40 64-0
E-mail: communications@myESR.org
www.myESR.org

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