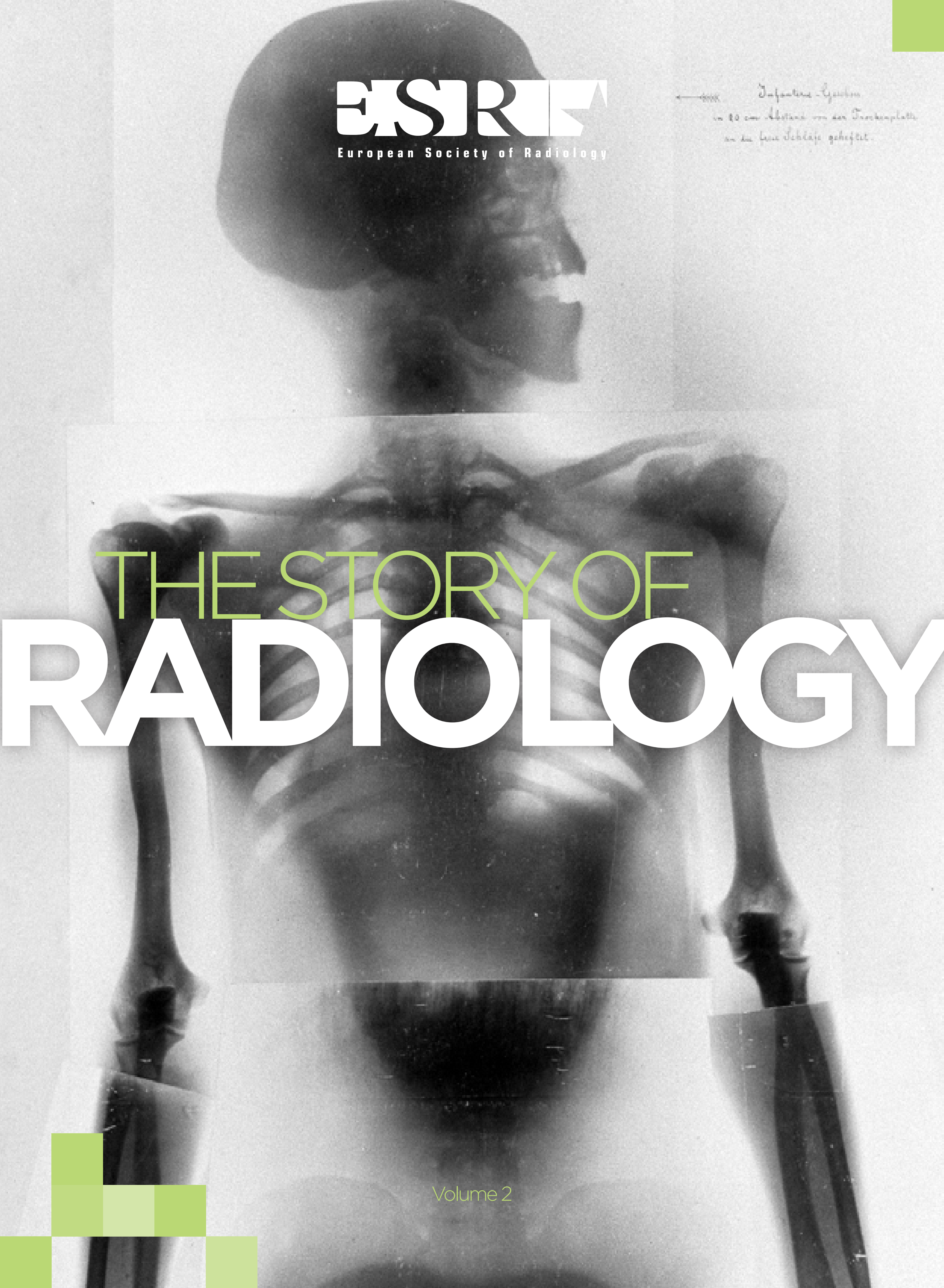

European Society of Radiology

THE STORY OF RADIOLOGY

Volume 2

INTERNATIONAL DAY OF RADIOLOGY

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THE STORY OF RADIOLOGY

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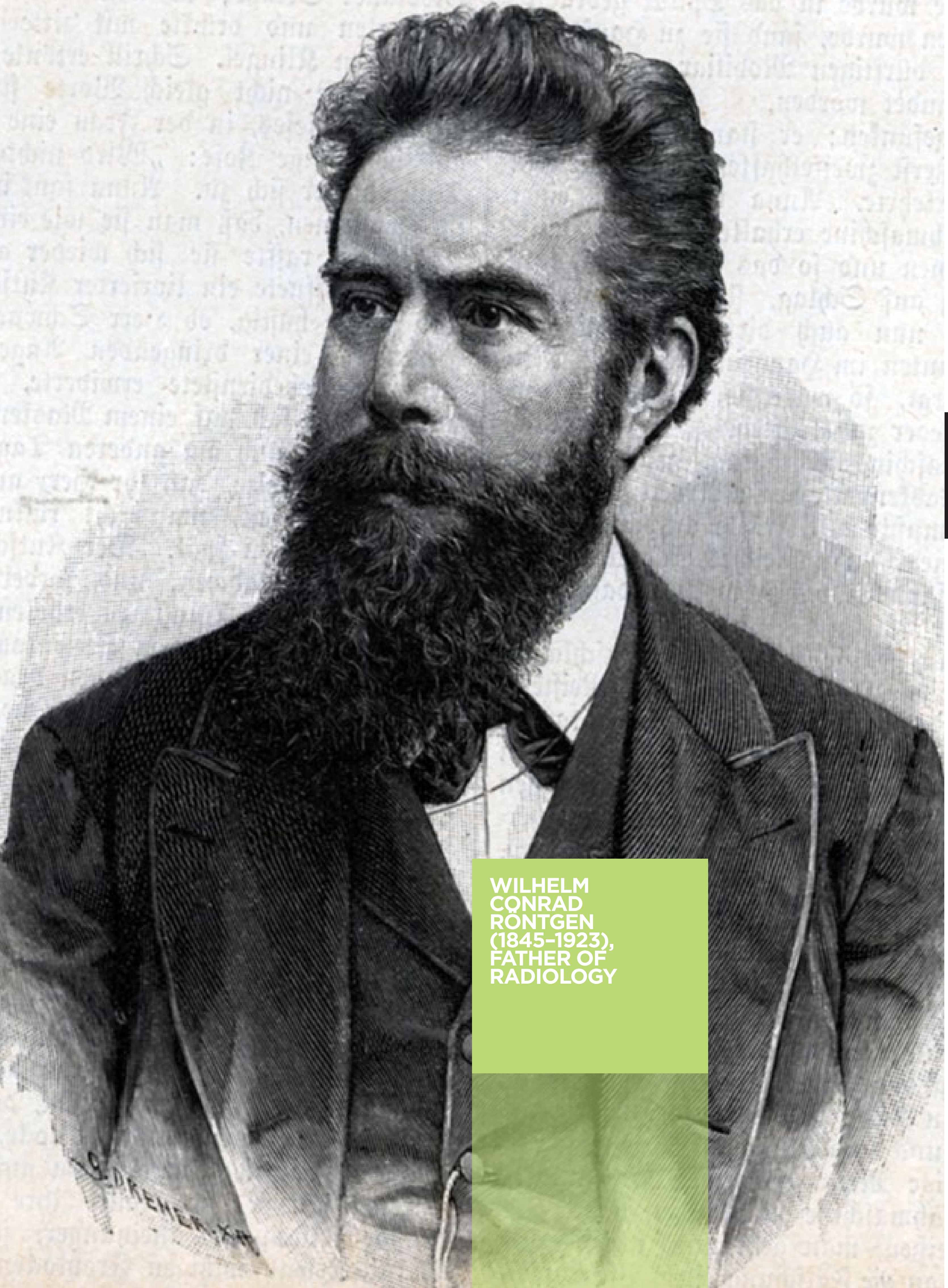


WILHELM CONRAD RÖNTGEN (1845–1923), FATHER OF RADIOLOGY

THE STORY OF RADIOLOGY
AN INTRODUCTION

The world of radiology is celebrating again. This time it's the second International Day of Radiology, and this book marks the second instalment in the *Story of Radiology*; covering more than a century of scientific discovery and innovation which has revolutionised medicine.

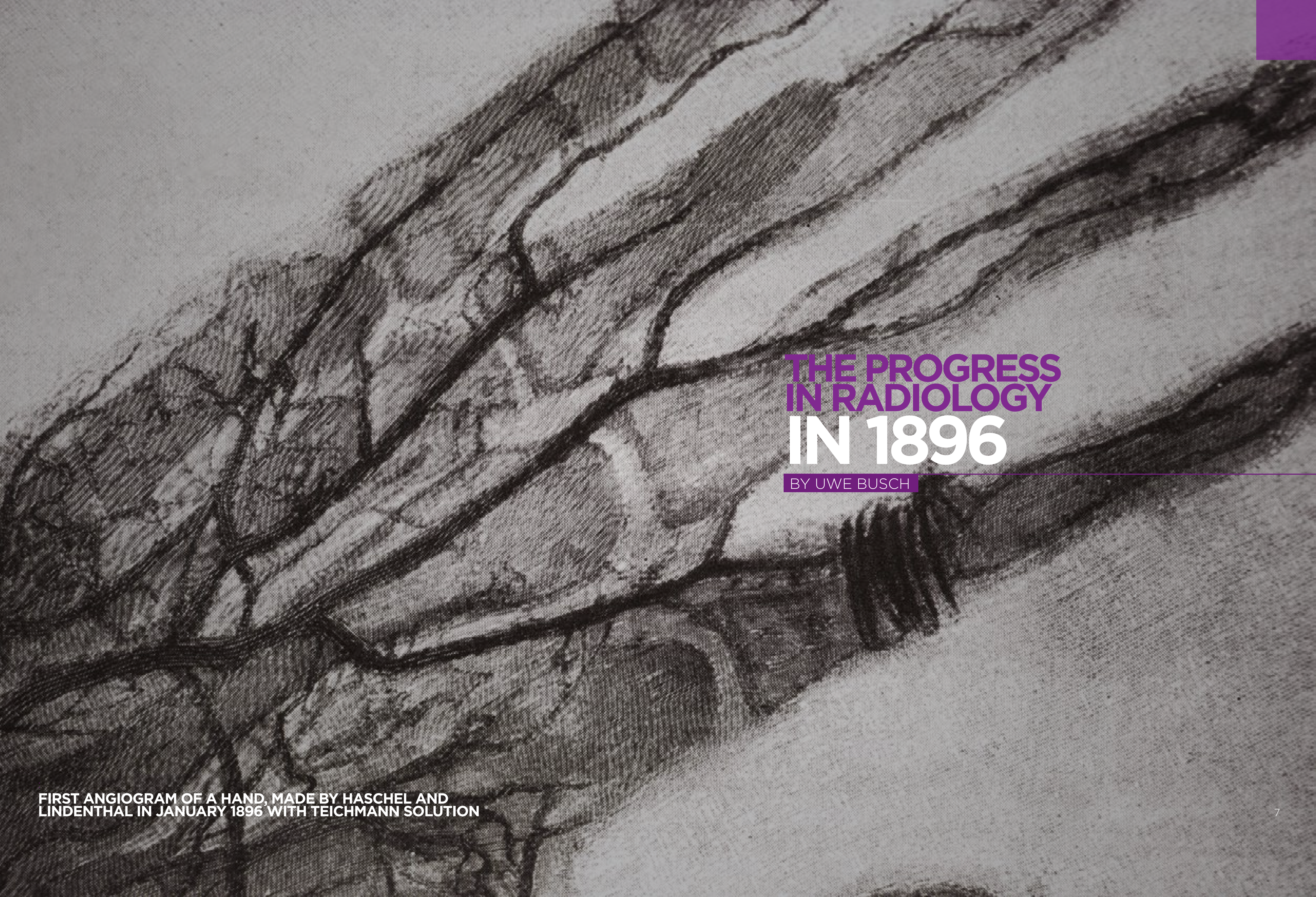
The first International Day of Radiology was organised by the European Society of Radiology (ESR), the Radiological Society of North America (RSNA) and the American College of Radiology (ACR) as a joint initiative. Though the main aim of the campaign is to promote the benefits of radiology to the wider public, we haven't forgotten about the radiological community and that is why we have put together this second volume on the history of radiology.

However, as was the case last year, we could not have produced this book without help from the experts at the International Society for the History of Radiology (ISHRAD) and the German Röntgen Museum, who were kind enough to provide the content of this book. Given the rapid technological progress and development taking place in radiology, it is more important than ever that we understand the history of the discipline in order to foresee what future developments might bring.

This book is only a snippet of the vast history of radiology, and so it is best to view it as merely another chapter in the *Story of Radiology*. We are a confident that this second volume will prove as popular as the last, and we look forward to adding many more chapters to the story.

THE PROGRESS IN RADIOLOGY IN 1896

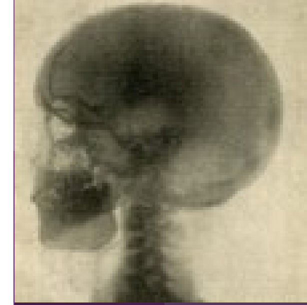
BY UWE BUSCH



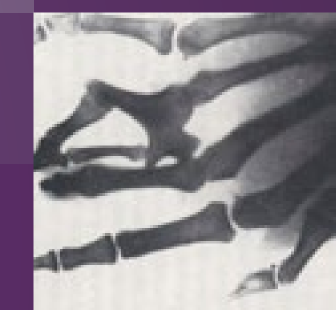
FIRST ANGIOGRAM OF A HAND, MADE BY HASCHEL AND LINDENTHAL IN JANUARY 1896 WITH TEICHMANN SOLUTION

The year 1896 was a momentous one, with major discoveries and inventions in the field of radiodiagnostics and the emergence of radiotherapy. In the first year after the discovery of x-rays, a total of 49 books and brochures, and 1,044 scientific essays were written on the scientific aspects and possible applications of the newly discovered rays[1]. A multitude of these publications dealt specifically with possible applications in medicine.

On November 8, 1895, while doing research work on the electric discharge process in diluted gas, Wilhelm Conrad Röntgen (1845–1923) discovered a 'new kind of ray' which was previously unknown to physicists. It took Röntgen only six weeks to finish his first scientific research on this phenomenon. On Saturday, December 28, he submitted his manuscript to the secretary of the Würzburg Physical Medical Society. On Tuesday, December 31, he received the copies of his paper, which he sent together with nine x-rays to his colleagues.[2] One of the first recipients was his friend, Professor Franz Exner (1849–1926), director of the Second Physicochemical Institute of the University of Vienna, with whom Röntgen had been acquainted since their academic days in Zurich. On Saturday, January 4, 1986, Exner showed Röntgen's x-rays to a group including Ernst Lechner, professor of physics at the German University in Prague, who informed his father, the editor of Vienna's daily newspaper *Die Presse*. That same night the first news article on x-rays was written and then published in *Die Presse* on Sunday, January 5, under the headline 'A Sensational Discovery'. In addition to the scientific facts, the possible development of these new rays was described in a prophetic manner.



The news spread like wildfire. Shortly afterwards, articles were published in the *Frankfurter Zeitung* (7.1.), the *Electrical Engineer, New York* (8.1), the *Würzburger Anzeiger* (9.1), *The Electrician,* London (10.1), *The Lancet* (11.1), the *British Medical Journal* (11.1), *Le Matin,* Paris (13.1), *Nature,* London, *The New York Times,* (16.1), *Science,* New York (24.1.), and *La Settimana,* Florence (25.1.). Due to the global circulation of the sensational news, Röntgen received an inquiry from the American physician Robert Watkins in New York, as early as January 8, requesting him to send some radiographs.



In addition to Watkins, physicians in Germany heard about Röntgen's discovery from the newspapers. Surprise, laughter and disbelief frequently led many to exclaim, "we must have such an apparatus".

The fascination with medical diagnostics in this new era was described by the orthopaedic surgeon Hermann Gocht (1869–1938). In order to get more information about the new rays, Gocht and his friend Gustav Opitz contacted the glass blower, Carl Heinrich Florenz Müller in Hamburg (1845–1912).

"When I think of this first evening! ... The factory rooms of Müller were on the raised ground floor of the front building; the mercury air pump for the evacuation of the tubes stood in the front room and was operated by Müller's factotum, Mr. Schmidt, a kind, very capable but simple man, who became a victim of the x-rays too.
Furthermore there were some smaller inductors and a big 25–30cm inductor with a platinum interrupter; more than a dozen x-ray tubes were

available. Müller had already produced some plates with bowls, spirals, drawing instruments, fingers and parts of hands. At first he showed us his installation and explained the construction and evacuation of the tubes. In a back room sat a glass blower, Mr. Becker, who created new tubes and parts of tubes in front of our very eyes. These first tubes were still constructed in a way that the cathode rays started from an aluminium plane mirror and fell on the opposite convex glass wall. This spot of the glass wall fluoresced especially intensively and became so very hot that one had to be very careful with the current supply; sometimes after a long exposure time, the tube suddenly burst with a big bang.

A small apparatus was also part of this very simply range of instruments. This small apparatus had been built by Müller himself who gave it the name 'Searcher': A black cardboard cylinder which was closed at one end; some bariumtetracyanoplatinate crystals had been fixed on the inner bottom of the cylinder.

In my thoughts I can still see and hear the joy with which Müller demonstrated everything to us, and I remember the tension and impatience in anticipation of the first experiments. Finally, the inductor was connected and the pear-shaped blown tubes lit up for the first time. Opposite the cathode, the glass wall fluoresced especially intensively; when the current had been switched off he made us feel the hot tube wall and finally we put the searcher before our eyes in order to catch a glimpse of the cathode rays and to observe the glowing of the bariumtetracyanoplatinate crystals. At first we saw nothing until suddenly a weak light appeared. This evening, the small searcher wandered from one eye to another with us three, the light was very slight but to us it meant an almost supernatural radiance and a glance into a new world"[3].

FIRST MEDICAL SUCCESSES

The early understanding of the possible applications of the new rays in medicine developed from the amicable relationship between Röntgen and Exner. As early as January 10, Exner's brother, the physiologist Sigmund Exner, reported on Röntgen's discovery to the Royal Imperial Society of Physicians of Vienna. After his speech, Sigmund Exner addressed Professor von Neusser, the director of the Second Vienna School of Medicine, and asked him to send patients for the purpose of testing the diagnostic application of x-rays at his brother's institute. It was Neusser's assistant, Gustav Kaiser (1871–1947) who was entrusted with this task. The first medically indicated radiograph was taken together with Eduard Haschek (1875–1947) who at that time was Franz Exner's assistant at the physics institute. The patient's hand showed trauma to the middle phalanx.

Sigmund Exner presented a second x-ray image on January 17, which was important to the development of radiology. The anatomist Tandler placed the hand of a corpse at the disposal of Haschek and Otto Lindenthal (1872–1947) at the physics institute. The arterial vessels were filled with Teichmann's solution (iodine solution), a mixture of chalk, cinnabar and paraffin. After 57 minutes of exposure, the first angiogram was created.

On January 23, Röntgen received an invitation to give a lecture at the Würzburg Physical Medical Society. After being welcomed by rapturous applause Röntgen held his lecture on 'A new kind of rays'. Towards the end of his speech, the silhouette of the skeleton of a human hand was taken by radiograph. It was the right hand of the honorary

president of the society, Prof. Albrecht von Kölliker, who suggested naming the new rays 'Röntgen rays'. During the ensuing discussion, Röntgen talked about the possibility of using the new rays for medical purposes.

APPARATUS AND TECHNICAL PROCEEDINGS

Due to the rapid spread of the news of these sensational rays and the fascination about the first x-rays of hands, research work was carried out around the world and the technical apparatus for the production of x-rays began to improve. In particular, the ionic tubes had to be improved. In his second communication, Röntgen explains the construction of special Röntgen tubes.

"... According to my experience gained to date, platinum is best suited for the production of most intensive x-rays. For some weeks now I have been using a discharging device with good success, in which a concave mirror of aluminium serves as a cathode, and a platinum sheet is placed against the mirror axis at an angle of 45 degrees and installed in the bending radius to function as an anode ..."[4]

A 'Röntgen industry' developed rather quickly. Companies like that of C.H.F. Müller in Hamburg or Emil Gundelach in Gehlberg were producing special x-ray tubes by the spring of 1896. Werner Siemens (1816–1892) and Johann Georg Halske (1814–1890) founded a telegraph construction company in 1847 and they immediately started producing their own x-ray devices. In March, the company Siemens & Halske applied for their first patent for a special x-ray tube, which already included an appliance for the regulation of a vacuum.[5]

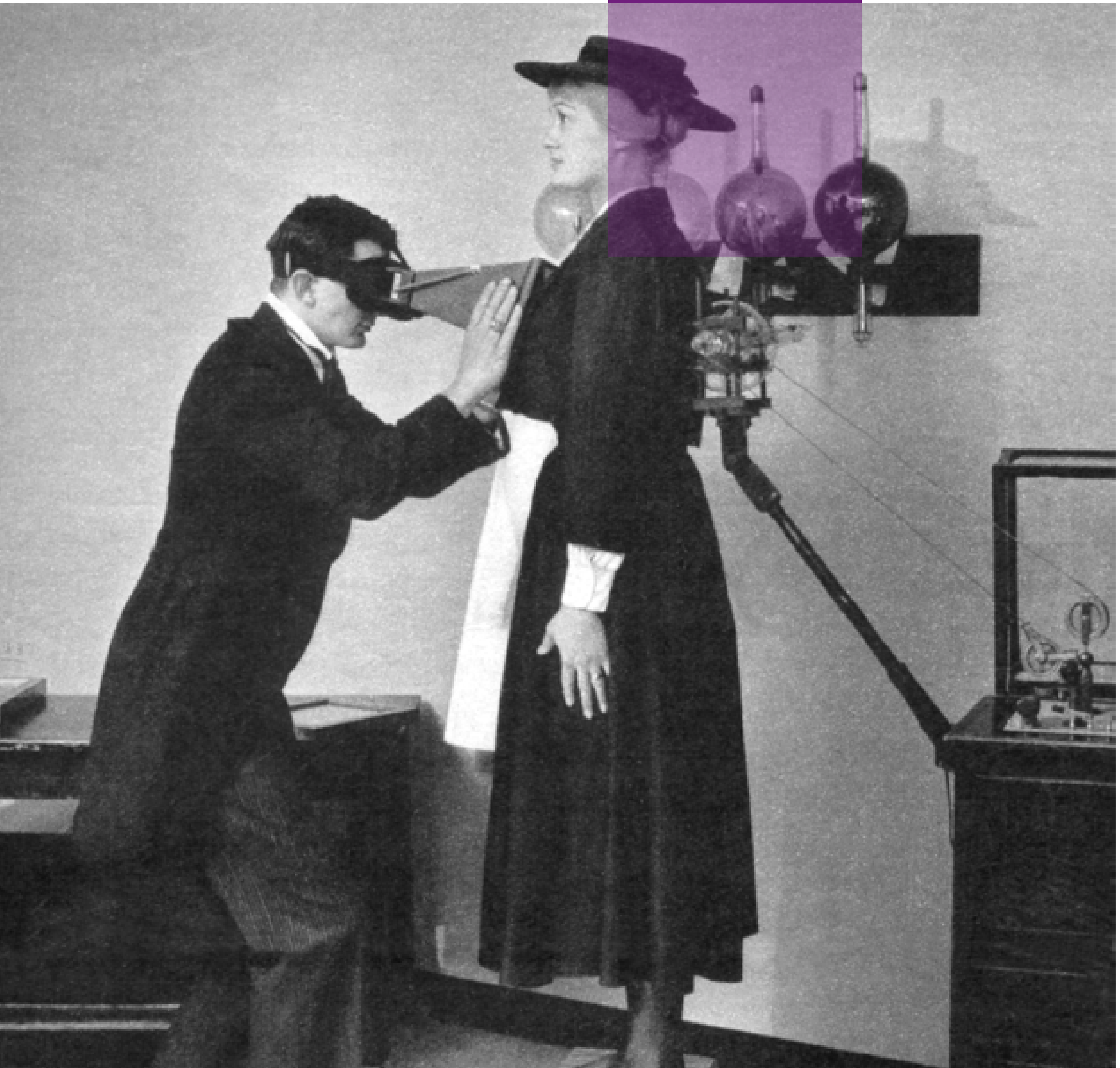
Several papers were published on the development of the photographic radiographic technique. C. Henry from Paris suggested the application of phosphorescent white vitriol for the magnification of the effect of the x-rays.[6] The American x-ray pioneer, Michael Pupin (1858–1935), achieved considerably better results with fluorescent screens made from calcium tungstate in early February. His x-ray of a hand with a shot gun wound is very impressive.[7]

Shortening the long exposure time was a technical challenge. In May, with preparatory work by John Macintyre (1857–1928)[8], Hermann Gocht succeeded for the first time in reducing the exposure time from 45 seconds to 5 seconds[9]. Gocht's idea of snapshots was used in the development of the apparatus for x-ray cinematography by the British physician John Macintyre in December. The movements of a frog's legs could be seen in a first x-ray film shown to the Philosophical Society in Glasgow.[10]

The method of producing stereo pictures in photography was in use before the discovery of x-rays. Röntgen himself, as an enthusiastic photographer, had made many stereo pictures. On March 11, 1896, Elihu Thomson (1853–1937), a British-American electronic engineer, reported on the production of stereoscopic x-rays.[11] That same month, Armand Imbert (1850–1922) and Henry Bertin-Sans (1862–1952) presented some impressive stereograms of two mice at the Academy of Science in Paris.[12]

It was the special radiographic photo plates produced for Röntgen by Carl Moritz Schleussner (1868–1952) which contributed to a noticeable improvement in photography. The radiographic plate, which was

RADIOGRAPHIC EXAMINATION IN 1896, PUBLISHED IN THE GERMAN JOURNAL *GARTENLAUBE*



THE STORY OF RADIOLOGY
THE PROGRESS IN RADIOLOGY IN 1896

coated with a special silver bromide emulsion drastically reduced the exposure time from several minutes to just a few seconds.

These technical improvements paved the way for the successful application of x-rays in different clinical fields during 1896.

SKELETAL RADIOGRAPHY

Due to technical limitations at the beginning of 1896, the application of x-rays could only be used to examine bone structure in the extremities, where it was possible to achieve great success in the search for foreign bodies. On January 19, the physician L. Pfaundler, from Graz, Austria, located a needle in the hand of a twelve-year-old girl[13] using x-rays, which the surgeon had failed to locate in the wound. Further successes in locating foreign bodies were published and in August, after several technical improvements, Albert Eulenburg (1840–1917), from Berlin, was able to take good x-rays of bullets in the brain.[14]

The application of x-rays moved on to look at fractures, and at the end of January, Fessler succeeded in producing the first x-ray of a forearm, with an exposure time of twelve minutes, at the University of Munich's faculty of physics.[15]

In addition to locating foreign matter and diagnosing fractures, the analysis of bone diseases was of great importance for surgical purposes. Initial attempts to show a sarcoma on a shinbone were made by the surgeon Franz König (1832–1910) in Berlin. Part of the joint of the tibia of a 46-year-old woman was distinctly swollen. The diagnosis confirmed beyond any doubt the presence of a neoplasm. Taking x-rays in vivo failed. It was only after amputating the limb that they succeeded in taking the first x-rays of a tibia sarcoma.[16]

On February 17, Huber presented various x-rays taken at the Technische Reichsanstalt, including some examples of acute joint damage.[17]

The rapid technological developments broadened the range of diagnostic capabilities. By June, Charles Thurston Holland (1863–1941) had already presented x-rays of congenital deformations of hands[18], followed by Julius Wolff (1869–1933), who succeeded in the radiological diagnosis of congenital hip joint luxation and managed to demonstrate the subsequent surgical treatment using radiographs.[19]

In April, Ludwig Zehnder (1854–1949), professor of physics at the University of Freiburg and a student of Röntgen in Giessen, succeeded in depicting the entire human skeleton using radiology for the first time. His whole-body x-ray of a dead soldier measures 1.84m and was taken in nine sections, with an exposure time of five minutes per section.

During 1896, numerous anatomic changes as well as diseases of the skeleton were diagnosed using radiodiagnostics and with the increasing level of knowledge it was possible to treat these more successfully.

THORAX

In March, the British pioneer John Macintyre succeeded in taking an x-ray of a thorax organ in situ for the first time. The radiograph enabled

him to examine the form and size of the heart.[20] One month later, the American Francis Henry Williams (1852–1936) published the first chest x-rays taken at the Massachusetts Institute of Technology in Boston.[21]

However, for these x-rays the exposure time was 60 minutes due to the poor performance of the x-ray unit, resulting in rather blurry radiographs. The subsequent diagnosis was very limited and based on details such as form and size of the heart, position of the diaphragm, large shadows caused by pleural fluid, translucence by pneumothorax, broadening of the mediastinum and the description of the thoracic skeleton.[22]

APPLICATION OF CONTRAST MEDIA

In his first publication Röntgen described the different levels of absorption: “Similar to metals, even salts in liquid or solid form can be distinguished according to their permeability.”[23]

In March, Wolf Becher (1862–1910), a physician from Berlin, used these results to work on the depiction of internal organs through the application of contrast media. To identify suitable contrast media, different substances were examined for their suitability. Becher used lead acetate in his examinations.[24] Haschek and Lindenthal used mercuric sulphide for the depiction of the blood vessels of an amputated hand. Dutto used calcium sulphate[25] to visualise the blood vessels, and Ernst Sehrwald (1861–1945) performed in vitro examinations on absorption properties of halogens in July, thus paving the way for the use of nonmetallic elements like iodine compounds as contrast media.[26]

GASTROINTESTINAL, UROLOGICAL AND GYNAECOLOGICAL RADIOLOGY

After Becher had described the initial steps towards depicting the stomach of a guinea pig, the German-American John C. Hemmeter (1864–1931) made his patient swallow a balloon with a tube attached, which was then filled with lead acetate. After the radiograph was taken the lead acetate was aspirated and both the bag and tube removed from the stomach.[27] In April 1896, Carl Wegele suggested a practical solution for examining the stomach of a living person using x-rays. To depict the greater curvature, a soft stomach tube would be introduced orally like a gastric tube and then a metallic spiral would be added.[28] Half a year later, E. Lindemann returned to this idea and succeeded in producing the first in vivo x-ray of the greater curvature. In his experiments, Lindemann used a rubber tube containing a fine copper mesh as a stomach tube.[29]

Urologists were very interested in the application of x-rays. In July 1896 John Macintyre imaged a kidney stone using x-rays. He was able to make a diagnosis of a kidney stone in his patient because the structure and the silhouette of the organ with the kidney stone were clearly visible on the x-ray. The subsequent operation confirmed this diagnosis.[30]

In March, the American obstetrician Edward Parker Davis (1856–1973) performed the first gynaecological experiment using x-rays when he placed the head of a newborn child into the pelvis of a female body. After an exposure time of one and a half hours he produced the first gynaecological radiograph.

Following this success, Davis took an x-ray of a pregnant female patient, which took one-and-a-half hours before he was able to recognise the body of the foetus. He was able to define the head, but little more: "While the experiment failed to distinctly outline the skeleton of the foetus, it offers information which may be of value in further attempts …"[31]

DENTAL MEDICINE

After Röntgen's discovery, dentists quickly recognised the diagnostic potential for their own medical field. Particularly in dental surgery, significant progress was made thanks to the new option of radiological examination. In mid-January, the German dentist Otto Walkhoff (1860–1934) asked the physicist Friedrich Giesel (1852–1927), from Braunschweig, to take an x-ray of his back teeth. The resulting image, which was the first intraoral x-ray, was produced after an exposure time of around 25 minutes. In March, the German physicist Walter König (1859–1936) from Frankfurt published a radiograph of the front teeth of the upper and lower jaw.[32]

VETERINARY MEDICINE

Animals were often used for the first radiographic experiments. In the photographic portfolio gathered by Joseph Maria Eder (1855–1945) and Eduard Valenta (1857–1937), from Vienna, one can find numerous radiographs of animals.[33]

Despite the great interest of veterinarians in the new diagnostic possibilities of x-rays, their application only developed gradually. The scientific interest, however, was evident at a very early stage. In 1896, five treatises were published by veterinarians Eberlein and Tröster in Germany; Hobday and Johnson in England; and Lemeoine in France. Richard Eberlein (1869–1921), director of the Royal Veterinarian University in Berlin, demonstrated the advantages of the radiodiagnostic procedure on animals[34], but it was Hobday and Johnson who succeeded in taking x-rays of a living horse in September.[35]

RADIOBIOLOGY, RADIOTHERAPY AND RADIATION INJURIES

Despite intensive research, Scottish x-ray pioneer Campbell Swinton (1863–1930) was unable to demonstrate any negative biological effects of x-rays. Three weeks after Swinton's investigations, on April 23, John Daniel, a physicist at the Vanderbilt University in Nashville, reported a new phenomenon which had not been mentioned before. Daniel was asked by a physician to locate a bullet in the head of a child by means of x-rays. However, even after an exposure time of one hour there were no results. Three weeks later, the child lost his hair.[36] In April, the physician Wilhelm Marcus, from Berlin, reported an early case of dermatological changes in a 17-year-old male who had taken part in various radioscopic experiments.[37] As a result of this report, several physicians used x-rays for the therapeutic treatment of hypertrochoses, eczema and mycoses. The Viennese dermatologist Leopold Freud (1868–1943) performed the first basic scientific research towards analysing the biological efficacy of x-rays in the treatment of diseases.

RADIOGRAPH OF A CHAMELEON 1896

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ROENTGEN EXPERT ‘ENCASED FROM THE ***SCHNURRBART*** TO THE FOOT IN A VERITABLE SUIT OF ARMOUR’.

A SHORT HISTORY OF EARLY RADIATION PROTECTION

BY UWE BUSCH AND ARPAN K. BANERJEE

In 1895, while experimenting with cathode rays, Röntgen accidentally saw the puzzling luminescence of a piece of paper coated with a light-sensitive, fluorescent substance (barium platino-cyanide). It was lying at some distance from a gas-discharge tube he was working with at the time. The fluorescence did not fade even after Röntgen shielded the tube with cardboard. He recognised at once that he had stumbled upon something entirely new.

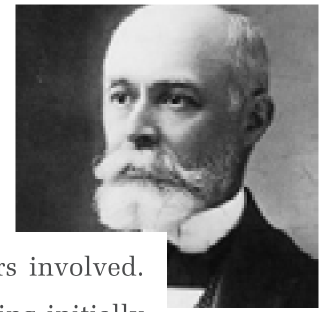
Röntgen recognised the importance of his discovery and described his research results in a paper titled *On a new kind of rays. Preliminary communication,* published on December 28, 1895. Within a few days the news of Röntgen's findings travelled round the world and he became a superstar of science. In 1901 the discovery earned Röntgen the first Nobel Prize in Physics.

The public was intrigued by the invisible ray, with its ability to pass through solid matter and produce images of the interior of the body. Scientists were captivated by an extraordinary new radiation, of shorter wavelength than light, which now opened up new avenues of research and enquiry.

Within weeks of Röntgen's announcement, hospitals throughout the world quickly started to open up x-ray rooms and so the early radiology departments were born. Within a month, several medical radiographs had been made which were used by surgeons to guide them in their work. Experimenters and physicians, electrical engineers and physicists alike set up x-ray generating apparatus and went about their work

THE STORY OF RADIOLOGY
A SHORT HISTORY OF EARLY RADIATION PROTECTION

ANTOINE HENRI BECQUEREL (1852–1908)



with a complete lack of concern for the potential dangers involved. This attitude is quite understandable, for there was nothing initially to suggest that x-rays would be in any way hazardous. In fact it was initially thought that x-rays would be beneficial in the therapy of some diseases, as well as for diagnosis.

Two months after the discovery of x-rays, Antoine Henri Becquerel, a French physicist, published his discovery of similar rays emitted from salts of uranium. His discovery, unlike that of the x-rays, went virtually unnoticed. It was not until the discovery of radium by the Curies in 1898 that interest in radioactivity became more wide spread.

Only about a dozen papers on radioactivity were published in the first year following Becquerel's discovery. It was not until 1902, when Marie Curie was able to separate enough radium from tons of pitchblende, that radium, like x-rays a few years earlier, quickly captured the public imagination. Its potential in medicine was soon realised, and in 1904 radium became well established as a part of the treatment of various conditions. Antoine Henri Becquerel, Pierre Curie, and Marie Curie won the Nobel Prize in Physics in 1903 for the discovery of spontaneous radioactivity.

The first two reports of self-exposure experiments with radium causing skin burns were made by two Germans: Otto Walkhoff and Friedrich Giesel. In a chemistry journal in October 1900, Giesel described the strapping of 270mg of radium salt to his inner forearm for a duration of two hours; he also wrote to inform Pierre Curie about the experiment.

MALIGNANT TRANSFORMATION IN X-RAY DERMATITIS IN AN X-RAY ENGINEER

Walkhoff's report in 1900 consisted of just three lines in a three-page general review presented to a photographic club in Munich.

Giesel was the first person in Germany to prepare sources of radium for sale, through the Buchler company of Braunschweig. 'French radium' was prepared and sold by Armet de Lisle in Paris. Interestingly, both companies were involved in quinine production and some of the manufacturing processes for quinine and radium were similar. Henri Becquerel's radium burn was accidental. He received it after he had placed a radium source inside his jacket pocket. However, he gave credit for the first observations of radium burns to Walkhoff and Giesel.

Henri Danlos of the Hôpital St-Louis, Paris, was the first physician to whom Pierre Curie loaned a source of radium. The first patient to receive treatment received it for lupus rather than for skin cancer, and a local surface application was reported in 1901 by Henri Danlos and Paul Bloch.

Radioactivity and specifically radium were thought to be beneficial in quantities too small to produce acute tissue damage, although the fact that it could be used to treat malignant areas must have meant people were aware of its potential harmful effects. This was the start of a great public infatuation with radium that was to last for decades – resulting in the development of medicines containing radium, devices used to generate radium solutions for daily consumption and radium-based beauty creams, to name but a few applications.

X-RAY BURN TO THE HAND OF AN X-RAY ENGINEER

None of the early experimenters with x-ray photography had taken measures to protect themselves or their patients from radiation exposure. Often injuries were not attributed to x-ray exposure, in part because of the latent period before the onset of systems, and more so because there was simply no reason to suspect x-rays as the cause. The extent of radiation-induced injury to human tissues was not immediately obvious and took some years to be universally realised.

The first biological effect of x-rays to be noticed by pioneer radiographers was irritation of the mucus membranes and the skin. Thomas Edison, the great American inventor reported in Nature in March 1896 that his eyes were sore and red after prolonged experiments. Radiation burns to hands were reported vividly by G. M. Frey, from Boston, in *the Electrical Engineer* in July 1896. He wrote:

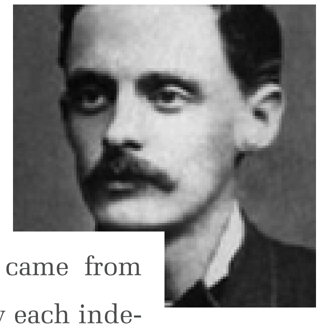
“I am inclined to think that a continuous application of from one to two hours will start the effect. In my case it was an application of about ten or fifteen minutes a day for about a week before I could notice the effect. At first the skin becomes brown the same as sunburn, then the hand begins to swell and in color turns blue. In my case, water blisters were raised, one of 3/8-inch diameter. At times there is a burning, itching feeling for a few minutes, then the pains disappear again. The swelling increased for several days until I decided to stop experimenting on my own hands ... Three or four days after I stopped it began to improve. The skin peeled off; I should say I took off three layers. At that stage I was obliged to test three tubes and thoughtlessly I exposed the same hand for about a minute or a minute and a half. This completely stopped all improvement for a number of days. At present my hand is nearly in good condition again ..."

Cases were also described in the *British Medical Journal* in April 1896, the *Fortschritte auf dem Gebiete der Röntgenstrahlen* and other national radiological journals. Thus, by the time of the discoveries of polonium and radium in 1898 by Pierre and Marie Curie, the effects of x-rays on the skin were well known.

During the ensuing years, x-rays started to be used for treatment. The rationale for this treatment was the biological action of the x-rays on human skin, which enabled Leopold Freund of Vienna to successfully depilate a pigmented hairy naevus in November 1896. His patient, a 5-year-old girl with a hairy naevus, 36cm in length, started treatment on November 24, 1896. After successful epilation, an x-ray ulcer persisted for about 6 years, but it was considered to be cured in 1902 when only a scar remained. This epilatory effect of x-rays established them as a direct agent for producing biological change. Freund's case is considered the first authenticated successful application of radiotherapy, and his treatment heralded the birth of a new branch of medicine. He published his results on March 6, 1897, in the *Wiener Medizinische Wochenschrift*.

This patient was followed up when she was 75 years of age; apart from back pain, she was found to be in good health at the time. The ulcer in the lumbar area had fully scarred over the years. The findings of the inner organs were normal. She was in good health just like her son and grandson.

ELIHU THOMSON (1853–1937)



The first warning of possible adverse effects of x-rays came from Thomas Edison, William J. Morton, and Nikola Tesla. They each independently reported eye irritations from experimentation with x-rays but did not really appreciate the reasons for this, believing that eye strain may have been a cause.

Other reports began to appear and in late 1896, less than a year after Röntgen's announcement, Elihu Thomson, an American physicist, deliberately experimented by exposing the little finger of his left hand to an x-ray tube for several days, half an hour per day. The resultant effects – pain, swelling, stiffness, redness and blistering – were convincing for Thomson and others, but not for all. Many prominent physicians still denied that x-rays were in any way harmful. Often the denial was tempered by a qualification that the effects noted were attributable to misuse of the x-ray.

In further experiments Thomson showed, that "the burns are produced chiefly by those rays of the x-ray order which are most readily absorbed by the flesh. Such rays are sent out in large amount when the vacuum in the tube is too low or when the tube is 'soft'. A 'hard' tube, or one with a high vacuum and requiring a high potential too, will give rays that pass freely through the flesh, and not being absorbed by the skin, can not of course do injury." He recommended: "To avoid the risk of x-ray burns even with prolonged exposures we must work the tube at such a high vacuum as to give rise almost entirely to rays of great penetrating power, or nonabsorbability ..."

The German born electrical engineer Wolfram Conrad Fuchs opened an x-ray laboratory in Chicago and by the end of 1896 Fuchs had performed more than 1,400 x-ray examinations. In December of 1896, he made the following recommendations in the *Western Electrician:*

» Make the exposure as short as possible.

» Do not place the x-ray tube closer to the body than 12 inches (30cm).

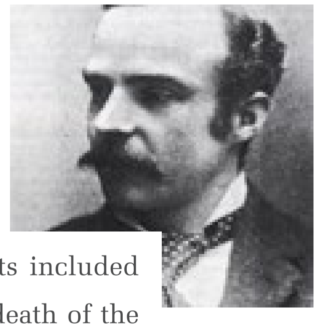
» Rub the skin carefully with Vaseline and leave a layer on the part that shall be exposed.

His extensive experimentation resulted in severe roentgen-dermatitis, and as time went on the fingers and thumbs of his hands were amputated in an effort to stop the devastating effects of the x-rays. His affliction soon made it necessary for him to retire from his laboratory in 1905. Between 1905 and the time of his death in 1907, he made an effort to write a book based upon his knowledge of x-ray work, but it was never completed due to the terrific pain from his hands and his later inability to write. After several operations he finally succumbed to multiple metastasis on April 21, 1907.

William Herbert Rollins, a Boston dentist, made numerous original contributions to the emerging science of radiology during the decade following the discovery of x-rays. An x-ray-induced injury to his hand led to a lifelong effort to convince others to proceed with care. He was a pioneer of radiation protection and introduced leaded tube housings, collimators, and high voltage techniques to limit patient dose.

Rollins performed a series of experiments that showed x-rays could kill guinea pigs. Being exposed for two hours a day the guinea pigs died

JOHN HALL EDWARDS (1858–1926)



between the 8th and 11th day of exposure. His experiments included exposure of a pregnant guinea pig which resulted in the death of the foetus and which led to Rollins expressing concern about the use of x-rays in pelvic exams of pregnant women. Rollins was a true pioneer of x-ray protection and could be described as one of the fathers of medical physics and radiation protection.

He advised three safety precautions:

» The physician when using the fluoroscope should wear glasses of the most non-radiable material that is transparent.

» The x-light tube should be in a non-radiable box from which no x-light can escape except the smallest cone of rays which will cover the area to be examined, treated or photographed.

» The patient should be covered with non-radiable material, exposing only the necessary area.

The delayed impact of x-ray radiation was emphatically described by the Birmingham pioneer radiologist Dr. John Hall-Edwards. In an article he published in *Archives of the Roentgen Ray* in 1904, he wrote:

“The dermatitis commenced nine years back, and followed the usual course until three years ago, when I first noticed some loss of power in the middle, ring and little fingers of the left hand. This gradually increased until they became totally useless and immovable. The arm was carried in a sling. Amputation was ultimately rendered necessary by the extreme pain caused by a large epitheliomatous ulcer on the back of the hand. The condition of the bones was only ascertained after the decision to amputate. Beneath the ulcer they appeared to be normal but the terminal phalange of each finger appeared to be breaking down. Small pieces of degenerated bone had separated from the shafts, and were lying in the surrounding soft-tissue. The phalanx of the middle finger had a clear-cut hole which might have been cut out with a sharp-edged tool. The right hand, taken after amputation, showed only absorption of the spongy tissue of the terminal phalanges."

Hall-Edward's paper, which aimed to draw attention to skeletal changes induced by x-rays, is a landmark in English-language radiological literature. The author's plight prompted the movement towards adequate protection.

By the end of 1896 numerous reports of x-ray dermatitis and even more serious injury had been published. Inevitably, the widespread and unrestrained use of x-rays for medical diagnosis led to serious injury. The example (see page 28) shows the development of an injury of an x-ray engineer from 1904–1924 who worked in diagnostics and took about 400 examinations a month using fluoroscopic apparatus without any protection devices.

By 1900 it was apparent to most of the medical and scientific community that x-ray exposure, if too frequent or intensive, could produce skin burns for the patients, too. Reduction of exposure time and frequency were the most obvious ways to limit dose to patients, and experimenters sometimes used enclosed tubes or distance to protect themselves. Filtration of the x-ray beam was advocated prior to 1900, as was limitation of beam size. Other techniques, including the use of intensifying screens to reduce exposure time and higher x-ray generating voltages, were also

A 'VERITABLE SUIT OF ARMOUR' USED TO PROTECT AGAINST X-RAYS used to minimise patient doses of x-rays. The impetus to provide patient protection was spurred by malpractice law suits which ruled in favour of patients who had been injured as a result of diagnostic x-ray exposure.

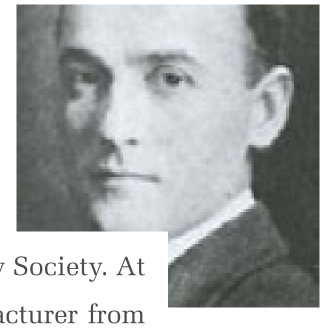
The response to these incidents and other evidence of radiation injury further prompted the use of protective coverings for the operator. German and French radiologists were especially affected by the discovery by Professor Heinrich Albers-Schoenberg from Hamburg in 1903 that the biological action of x-rays on the reproductive organs of animals may induce sterility. Soon, the German Roentgen expert was "clad from head to toe in a veritable suit of armour".

In Britain, protection against the rays took the form of enclosing the vacuum tube in a similar manner, in addition to the routine use of gloves and aprons after 1905. Although the basic techniques of x-ray protection were then well known, implementation was spotty. Thus, during the 1920's and 1930's, and even the 1940's, it was not uncommon to find medical x-ray units with virtually no safety precautions.

The hazards of radioactivity were better controlled, partially because the radium sources in use in medicine were very expensive and therefore stored with great care. The storage of radium in locked, shielded safes was common.

In the early days, the primary concern was with exploring applications of x-rays, but great gains were made in technical and biological knowledge which later contributed to improved protection. One little known event that is of historical significance in medical physics was reported

SIDNEY RUSS
(1879–1963)



at the October 1907 meeting of the American Roentgen Ray Society. At that meeting, Rome Vernon Wagner, an x-ray tube manufacturer from Chicago, reported that in order to control his personal exposure, he started to carry a photographic plate in his pocket and to develop the plate each evening to check whether he had been exposed.

This must surely be the origins of the film badge. Unfortunately, Wagner's new practice was too late for him, for he had already developed cancer, and he died six months later, in 1908.

Wagner's idea was adopted in 1918 by the British Medical Physicist, Sidney Russ (1879–1963) from the Middlesex Hospital, London, who asked operators of x-ray machines to carry small photographic plates in lead protected holders with circular exposure areas, which Russ and his team offered to supply and to calibrate regularly. This was the first film badge service for personnel monitoring in a hospital (in the U.K.).

Several events increased the need for protection after 1908. High voltage generators were improved and the tube output increased dramatically when Coolidge's hot-cathode tube was introduced in 1913: these innovations heralded the modern era of high doses and short exposure times.

The greatly increased demands of the First World War brought new challenges. An inexhaustible supply of radiographs was urgently needed to deal with thousands of cases of fractures and retained bullets. Additional apparatus and emergency staff were quickly called into service. Much of the apparatus was primitive and dangerous, and many of the operators were untrained. The military command was concerned with fulfilling demand, and not with protection; and soon there were protests.

The British Roentgen Society (the world's first radiology society), founded in March 1897 in London, took the lead. At a June 1915 meeting, a discussion took place on protective devices for x-ray operators. Sidney Russ, who was appointed the first Chair of Medical Physics at London University, was concerned that many operators, particularly the novices recruited into x-ray work for the war, were likely to suffer injuries from hazards which had already been identified and could be avoided. In conclusion, the Roentgen Society passed a resolution to ensure the safety of operators by universal adoption of strict rules. This is the first British code of practice that provided information about the long-term effects and the general risk of all sorts of x-rays. It protected qualified and professional medical practitioners doing the work and gave specific instructions regarding x-ray tubes, fluorescent screens, and operating personnel. For example, it strictly prohibited the use of the hand or any portion of the body of the operator to test the hardness or the quality of the x-ray tube.

Simple as they are by modern standards, these recommendations provided a sound basis for users of x-rays, and more importantly, signified an active organisational interest in x-ray protection.

Russ went on to point out that in addition to obvious effects such as dermatitis, there were hidden biological dangers, including chronic blood changes, which were first noticed by the German Roentgen pioneer Max Levy-Dorn (1863–1929) in Berlin in 1905. He and his medical colleague Colwell later defined these dangers as:

» Injuries to the superficial tissues (usually hands) which might become ulcerated or even cancerous;
» Prejudicial changes of the blood which might progress to fatal anaemia *and*
» Derangements of internal organs, notably the reproductive organs.

Robert Knox, a British radiology pioneer from King's College Hospital, London, an adviser to the Ministry of Health in the U.K., and a member of the War Office X-ray Advisory Committee, suggested more stringent measures, including the regular inspection of all hospital departments by acknowledged experts. The Roentgen Society's wartime code of practise and other advice had to be acted upon, and the medical profession intended to provide the leadership. Knox announced the appointment of a standing committee of radiologists, physiologists and physicists to investigate and report the following:
» The changes induced in tissues by x-rays, and particularly on the blood
» The properties of the x-rays and the best means of controlling their actions
» The equipment of x-ray and electrical departments with particular regard to the protective measures employed
» Recommendations for guidance of the assistants in these departments, particularly regarding the hours of work and the need for fresh air and change

Thus in 1921 the British x-ray and Radium Protection Committee was born. The late Sir Humphry Rolleston (1862–1944) became its first chairman and chaired the committee for over 20 years (1921–1943). Rolleston was a remarkable member of the British medical establishment, being a medical professor at Cambridge University as well as president of the Royal College of Physicians, president of the Royal Society of Medicine, and physician to King George V. Under Rolleston's leadership, and largely financed by him, the first memorandum was issued in July 1921 and the first detailed report followed in 1923. The first memorandum included a rather lengthy section specifically concerned with radium protection. The code was welcomed by all classes of radiological workers and formed the basis for similar recommendations in most countries and for subsequent international recommendations. The committee regularly met at the Royal Society of Medicine in London and made the following recommendations for x-ray personnel

1) No more than seven working hours a day
2) Sundays and two and a half days off each week, to be spent outdoors if possible
3) One month of holiday per year

Parallel to this initiative, the Roentgen Ray Protection Committee of the United States of America, which was founded in 1920, published similar recommendations in September 1922.

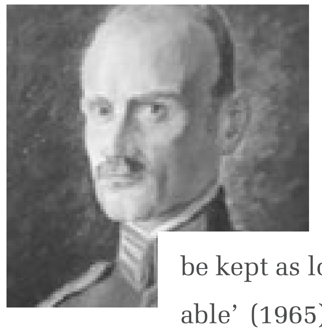
In September 1924, Arthur Mutscheller, a physicist of German descent working in the USA, was the first person to recommend a 'tolerance' dose rate for radiation workers, which was considered the maximum dose which would not cause harm. He based his recommendation on observations of physicians and technicians who worked in shielded areas, who each month were exposed to roughly one percent of the dose that would irritate the skin, which worked out at 70 rem (0.7 Sv)

per year. The Swedish physicist Rolf Sievert (1896–1966) also suggested a tolerance dose in the same year.

The second decade of the twentieth century marked the beginning of a series of major breakthroughs. One important step towards modern radiation protection was the discovery of x-ray mutagenesis. The American geneticist Hermann Muller (1890–1967) introduced the conceptual and empirical basis for modern molecular biology. Breeding huge numbers of the fruit fly Drosophila Melanogaster, he demonstrated that exposure to x-rays can cause mutations in the genes and chromosomes of living cells, and warned that radiation could cause mutations in the human genome as well. This finding, published in 1927, established Muller as an international figure. It also formed the nucleus of a new discipline: radiation genetics. For his research, Muller was awarded the Nobel Prize for Medicine in 1946.

In 1925, the first International Congress of Radiology, held in London, recognised the need for international standardisation of units and measurements and appointed the International X-ray Unit Committee, which later became the International Commission on Radiation Units and Measurements (ICRU). At the second International Congress of Radiology, held in Stockholm in 1928, the International Commission on Radiological Protection (ICRP) was founded, and within a few years it issued quantitative recommendations for the limitation of dose received by radiation workers. These served as the basis for radiation protection until 1950. In subsequent years the commission emphasised that unnecessary exposure should be avoided, and that all doses should

HERMANN BEHNKEN (1889–1945)



be kept as low as 'possible' (1950), 'practicable' (1958), 'readily achievable' (1965) and, eventually, 'reasonably achievable' (ALARA 1973). The ICRP today sees its role as considering the fundamental principles upon which radiation protection measures can be based, while leaving the detailed application to national authorities. The ICRP has invited a hundred individual experts to participate in its committee and task group activities. In addition, the commission maintains close working relationships with a number of international and regional organisations that are concerned with radiation protection.

From the start, the difficulties were mainly on the quantitative side. There was no standard unit of measurement for x-rays to use as a basis of dosage until the mid-1920s. At the second International Congress of Radiology in 1928, an international agreement on the definition of a new unit of x-ray dose, the 'Roentgen', was reached, based on measurements made with air-filled ionisation chambers. From a scientific point of view the best definition of this unit was given in 1924 by the German Physicist Hermann Behnken (1889–1945). The recommendation of one Roentgen per week as a maximum permissible dose for those engaged in radiological work was a fairly arbitrary decision, because it was not really known what the reaction of any biological entity to a dose of one Roentgen was.

In his presidential address to the Roentgen Society in 1916, J.H. Gardiner said: "It is a curious thing, but it often happens, that nature appears to resent an intrusion into her secrets, and will sometimes make the intruder pay dearly. It was so in the case of x-rays, not only was the beneficent provision that we call pain (which tells us that something is wrong if there is time to remedy it) withheld, but the harm that was being done gave no warning, and thus was continued until after some weeks' interval the result of the accumulated indiscretions became apparent. I will not pursue this unhappy subject further; enough to say that the most active and earnest of our workers were the worst victims, and the result was seen in empty chairs at our councils and in the vanishing of familiar figures at our meetings. All honour to their memory."

In 1936 the German Roentgen Society, at the suggestion of Professor Hans Meyer (1877–1936) of Bremen, erected a monument to the x-ray and radium martyrs of all nations. The monument stands beside the radiological department of St. George's Hospital, Hamburg – the hospital of Heinrich Albers-Schoenberg, the German radiology pioneer who succumbed to his radiation injuries in 1921. Much of the Martyrs' Memorial is inscribed with the names of 169 x-ray and radium martyrs from 15 countries, who by then had died; the highest tolls recorded were 14 British, 20 German, 39 American, and 40 French citizens. Twenty-eight more British names were later added.

At the unveiling ceremony on April 4, 1936, the celebrated French pioneer Antoine Béclère (1856–1939) said: "I come to bow with deference before this monument which was piously erected to the victims of x-rays and radium. I come to salute their memory, and honour their sufferings, their sacrifices and their premature deaths."

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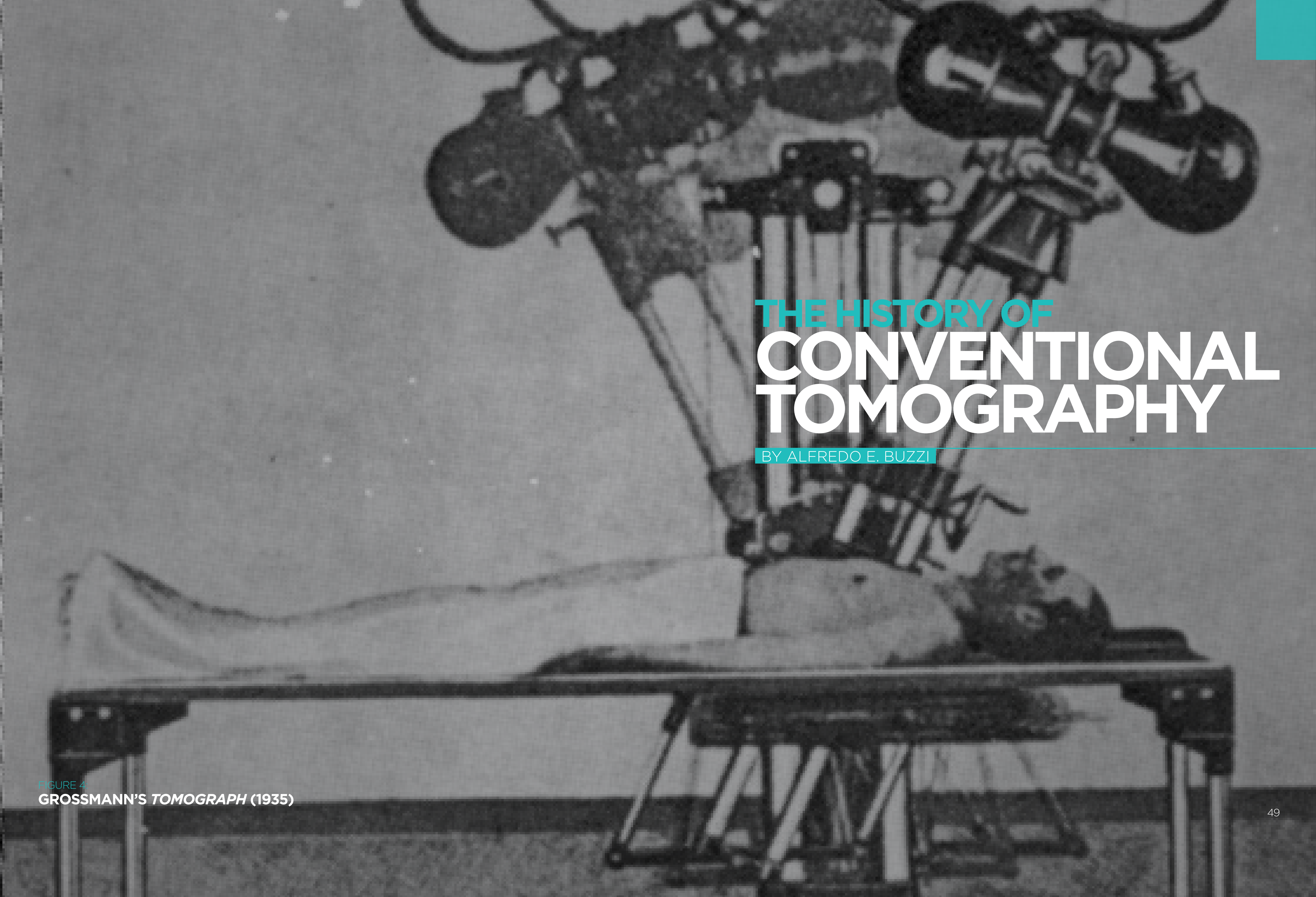
SEVERE X-RAY BURN WITH SCARRING AND ATROPHY FOLLOWING RADIATION TREATMENT

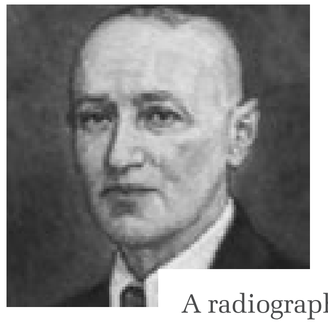


THE HISTORY OF CONVENTIONAL TOMOGRAPHY

BY ALFREDO E. BUZZI

FIGURE 4
GROSSMANN'S *TOMOGRAPH* (1935)

KAROL MEYER (1882–1946)



A radiographic image is the sum of the shadows of all the objects located between the x-ray tube and the film. It is thus the bidimensional projection of a tridimensional object. The shadow of one dense object, such as a bone, can obscure the fainter shadows of tissues above and below it.

Investigators in the early part of the twentieth century shared the common goal of finding some means of separating the superimposed shadows recorded when complex structures within the human body are imaged on a standard radiograph. Various techniques were recommended to solve this problem: multiple projections; fluoroscopy; changing the density by introducing more or less opaque contrast material; and optical separation of superimposed images using stereoscopy.

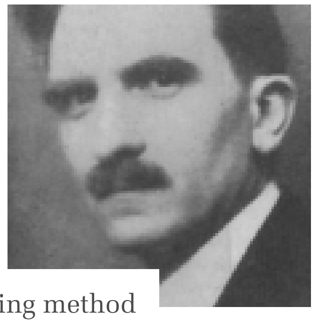
But the most promising method for separating superimposed shadows was found in the principle of body-section radiography or tomography. In body-section radiography a layer of tissue from within the body is imaged as an isolated section with overlying structures outside of this section excluded from the picture.

The early history of conventional tomography reflects the level of poor communication, during that era, between scientists of the same discipline living in separate countries, a shortcoming that explains why the basic principle of body-section radiography evolved independently among several researchers in different settings.

To accomplish body-section radiography in a mechanical system, two of three elements (tube, patient, and film) must move synchronously during the x-ray exposure. Many techniques for moving these elements have been explored, but the most popular and enduring method depends on the synchronous movement of the x-ray tube and film in opposite directions, with the patient remaining stationary during the x-ray exposure. The movement applied may be linear, circular, elliptic, figure of 8, hypocycloidal, or spiral.

THE STORY OF RADIOLOGY
THE HISTORY OF CONVENTIONAL TOMOGRAPHY

ANDRÉ BOCAGE (1892–1953)

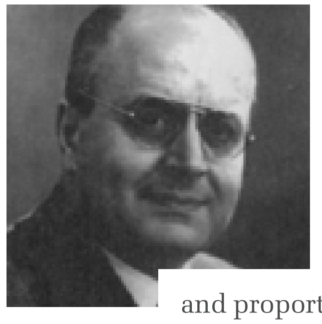


Karol Mayer's (1882–1946) work in Poland must be regarded as a precursor of classical tomography. Working in Poznan, he described a procedure to keep images of the heart free of superimposed structures, in which the x-ray tube was moved while the object to be recorded and the film or x-ray screen remained stationary. He published his method in 1916 in his paper *Differential Radiologic Diagnosis in Diseases of the Heart and Aorta*. However, true tomography had not yet been achieved by mobilising just one of the parameters of the triad (tube-patient-film).

In Florence, Carlo Baese described a procedure with a similar purpose in a patent granted in 1915, which was entitled *Method of, and apparatus for, the localisation of foreign objects in, and the radiotherapeutic treatment of, the human body by X-rays*. His method, used by medical staff during the First World War to localise the projectiles inside soldiers' bodies, was only used in radioscopy (tomoscopy) because the Italian engineer didn't realise that the technique was able to 'erase' the projected shadows that were so unwelcome during radiography.

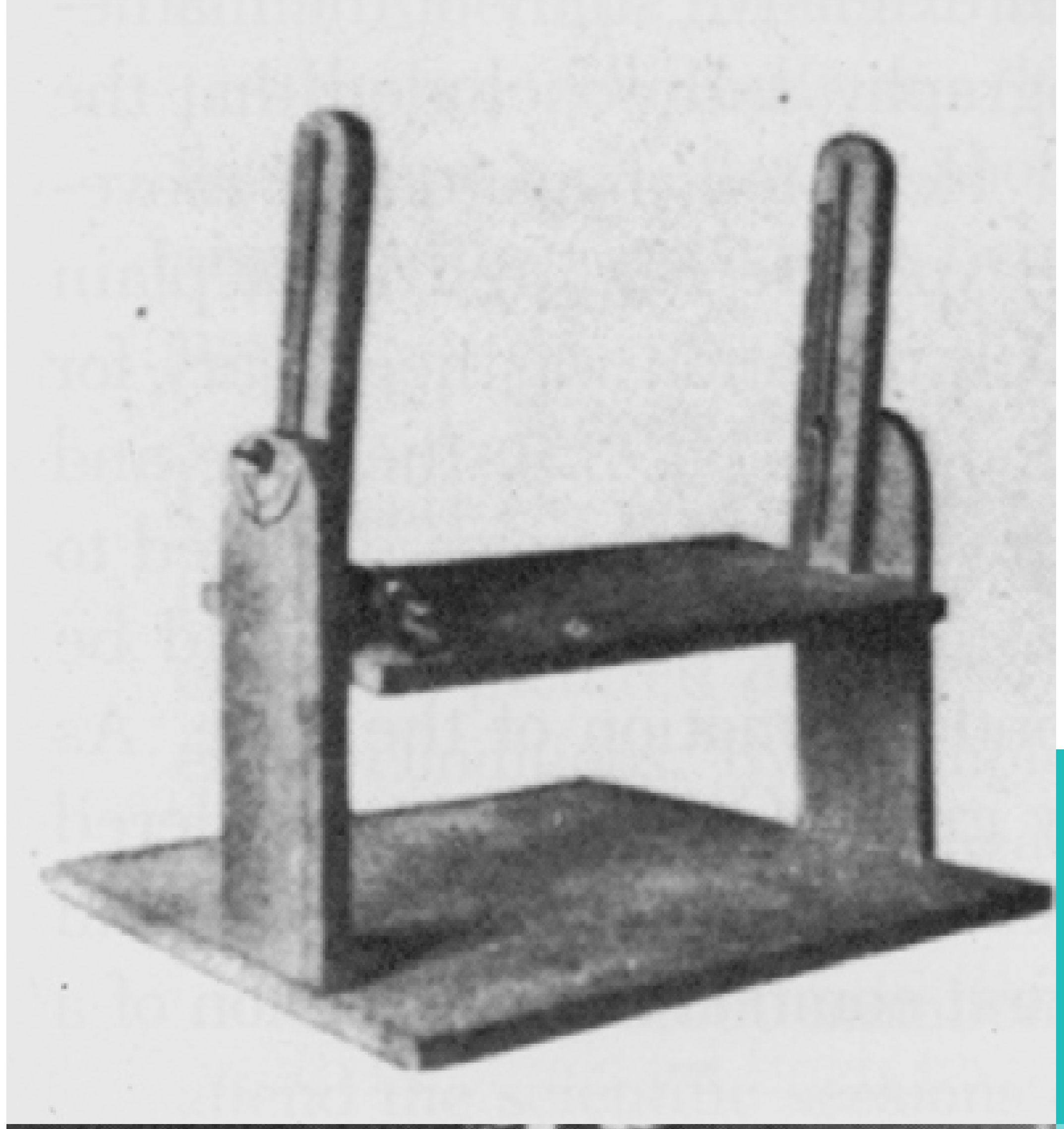
The Parisian physician André Bocage (1892–1953) could be considered the father of tomography. He was the first to describe the basic principles of a device for moving both an x-ray tube and a plate reciprocally

ALESSANDRO VALLEBONA (1899–1987)



and proportionately in a patent specification in 1921. He conceived the idea in 1917 while serving in a radiological unit in the First World War and perfected the principles while interning at the Salpêtrière Hospital in Paris. Bocage described the basic design principles for changing section levels and suggested using multidirectional or pluridirectional tube-film movement (circles and spirals). He also pointed out the need to maintain a constant ratio between tube and film during the movement and identified the fact that the object plane would always be parallel to the film. On top of this, Bocage described the need to eliminate secondary rays (scatter) through a grid mechanism, and he alluded to the possibility of axial transverse tomography and pantomography, while indicating the importance of providing a small focal spot for the x-ray beam. His invention contained almost all the essential features of modern tomographic devices, but for 17 years he was unable to get a workable unit constructed. The apparatus *(biotome)* was available in 1937 thanks to the company of Georges Massiot. Bocage merits credit for the invention of radiography in slices.

There is a great difference between a concept and its practical applications. Allesandro Vallebona (1899–1987), from Genoa, first put the theory into action, and obtained his first radiotomographic image in 1930. He called his method stratigraphy (from 'stratum', meaning a layer). He described two techniques. In the first one, the system (tube and film) remains immobile and the patient rotates around an axis at the level at which one wants to obtain the image. This was the basic principle of auto-tomography. In the second technique the subject remains immobile and the system (x-ray tube and plate) pivots around an axis at the level of the slices (Fig. 1).



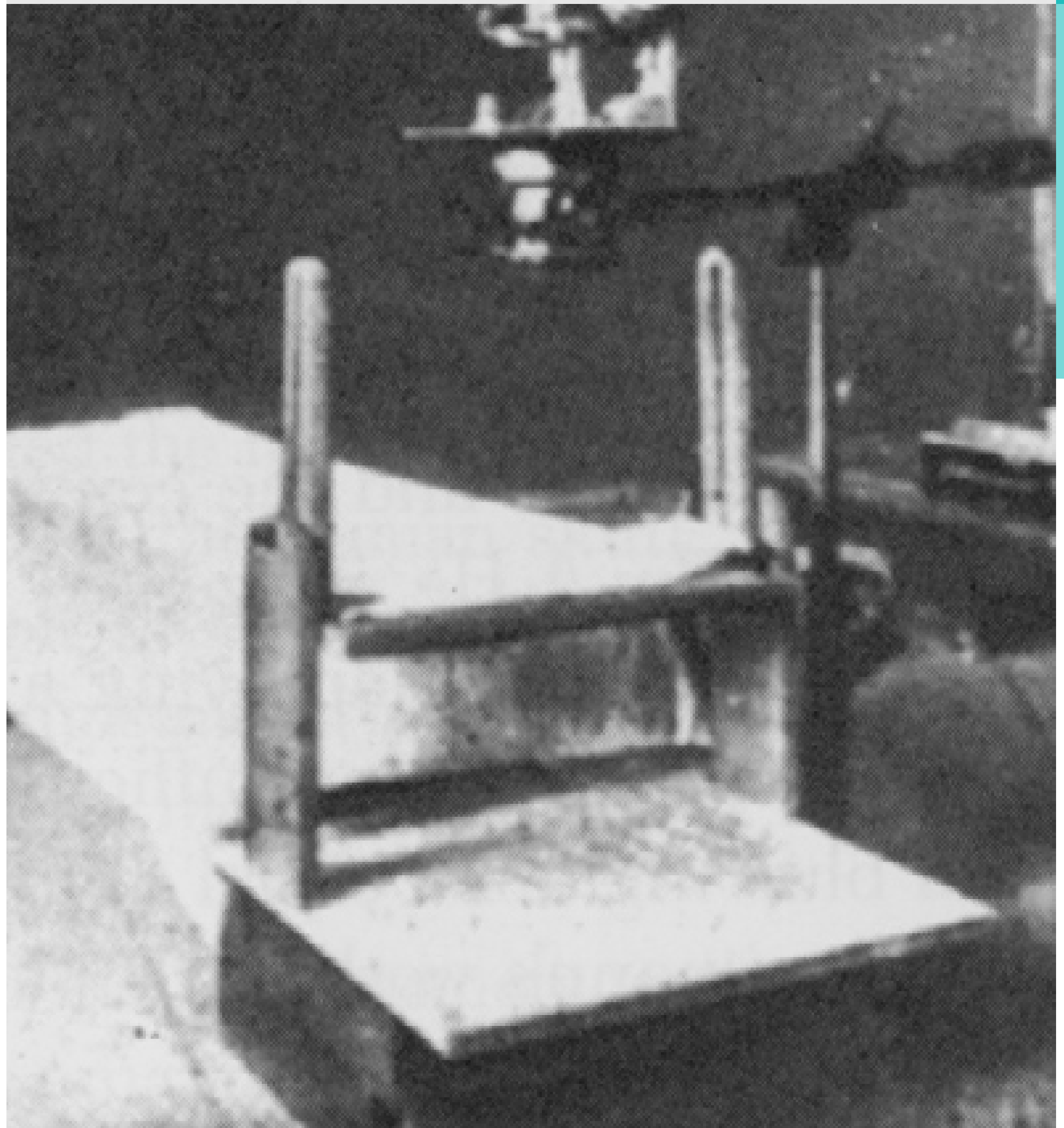
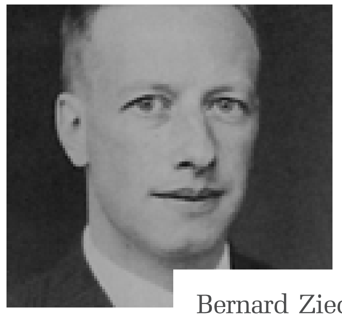


FIGURE 1:
PHOTOGRAPHS OF VALLEBONA'S ORIGINAL STRATIGRAPHIC APPARATUS (1930)

BERNARD ZIEDSES DES PLANTES (1902–1993)



Bernard Ziedses des Plantes (1902–1993), from Amsterdam, was the second great pioneer to present a working model of tomography . He was an engineer who became a medical student, and his work was the most elaborate in the field. His tomographic principle occurred to him during his first year of medical study and was inspired by the histologic slices used for microscopic examinations. Ziedses des Plantes discussed his ideas with his radiology teacher, who told him that the method had no practical applications, so he abandoned his plans to develop it. In 1928, while a resident in neuropsychiatry, he overlooked a defect in a radiograph of the base of the skull, which later proved to be a tumour. This experience again impressed upon him the need for sectional imaging, and he resumed his efforts. He presented his tomographic principle, which he called planigraphy (from *planus*, meaning flat), in his Dutch doctoral thesis in 1931 (Fig. 2).

In 1936, the French company Massiot et Cie constructed the first commercial device based on the design principles described by Ziedses des Plantes (Fig. 3). In his design the tube and the film moved in horizontal planes and described spiral, circular, or linear paths. The central ray was directed toward the same point on the film at all times during the exposure by rotating the tube simultaneously. The focal plane was changed by raising or lowering the mechanical point of rotation. To accurately note the focal plane being projected, Ziedses des Plantes attached a simple wood cylinder phantom, in which metal numerals had been placed, each indicating its own height.

He suggested that a pluridirectional movement, such as the spiral, was a basic requirement for satisfactory tomography, which could not be fulfilled with a simple linear movement.

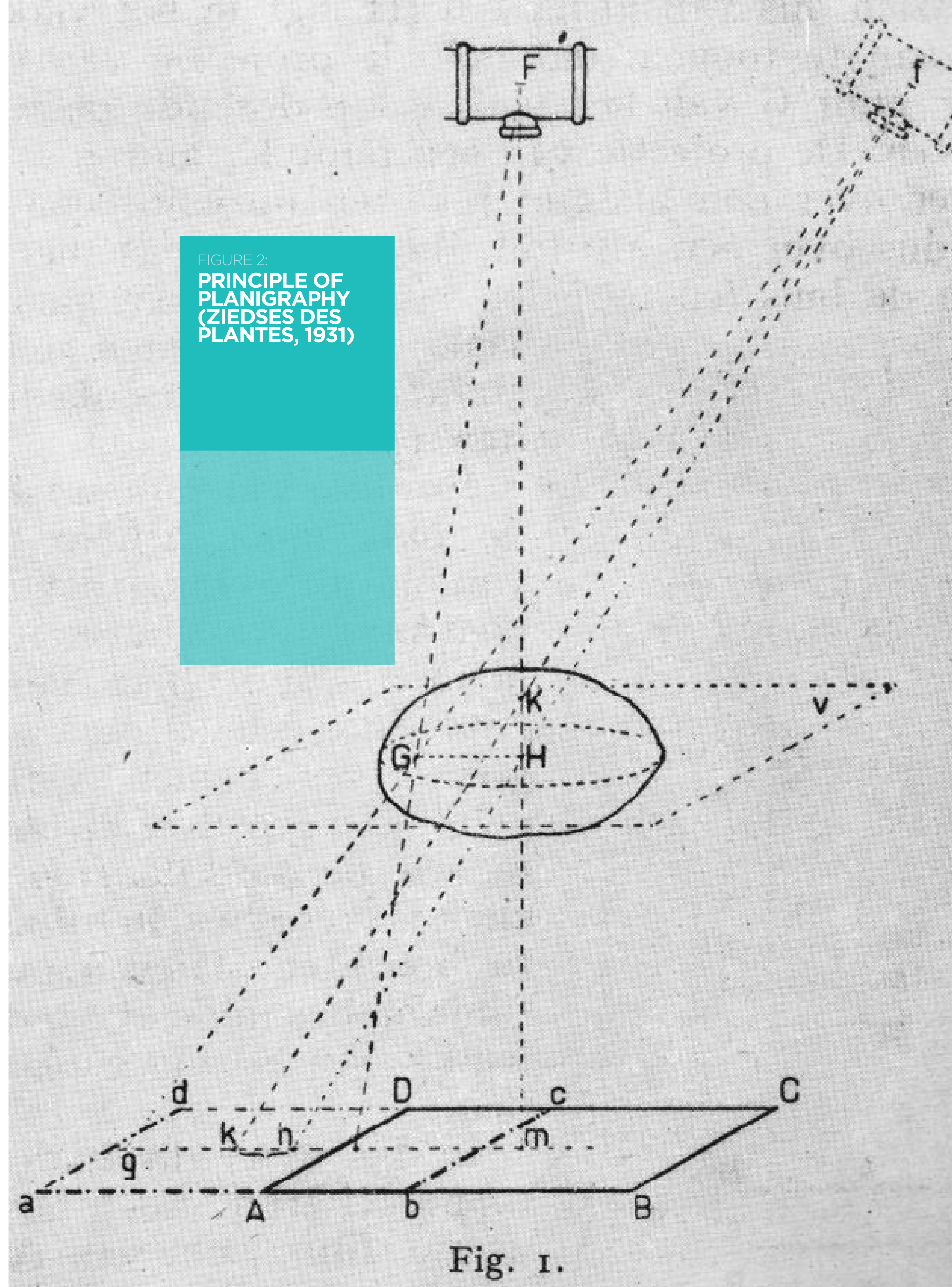


FIGURE 2:
PRINCIPLE OF PLANIGRAPHY (ZIEDSES DES PLANTES, 1931)

GUSTAV GROSSMANN (1878–1957)

Ziedses des Plantes' other original contributions to radiology include simultaneous tomography (multisection or book cassette), autotomography with encephalography, air myelography with tomography, orthotomography, stereoscopy, serioscopy (tomosynthesis), and subtraction.

Meanwhile, while still unaware of the work of the others, another Dutchman, Dirk Leonard Bartelink, from Nijmegen, built a radiotomographic apparatus which produced its first images in 1930. In November 1931, at a radiology meeting in Amsterdam, Ziedses des Plantes presented his equipment and Bartelink showed the results obtained with his technique. Bartelink's system was similar but it was not as practical.

In Berlin, the German manufacturer Gustav Grossmann (1878–1957), made an extensive study of the mathematical and geometric principles of tomography and concluded that the available equipment was too complicated. He noted that circular movements required three to five times the normal exposure required for a plain radiograph, and that 10 to 15 times as much radiation was necessary for the spiral movement. So, in his apparatus, the film moves horizontally while the tube describes an arc in a vertical plane. This avoids partial shading of the film by grid elements (and longer exposure) which occurs with spiral and circular paths. Although the blurring is unidirectional, his rigid apparatus, with its pendular type of rectilinear motion, achieves accurate coordination of tube movement and film movement, resulting in preservation of detail throughout the desired plane. The work of Grossmann led to the first commercial production of a body-section

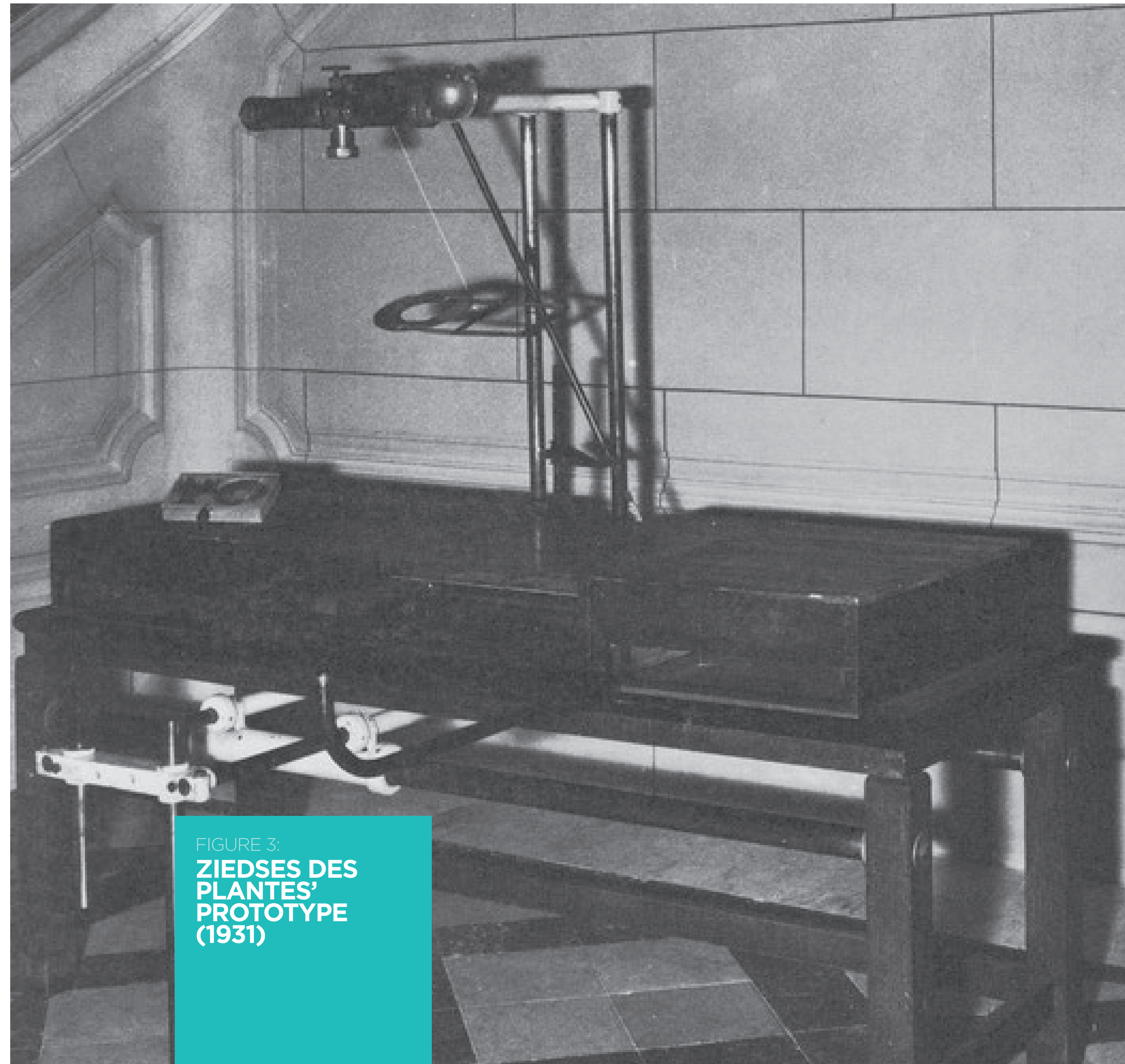
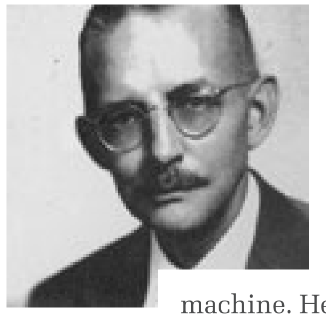


FIGURE 3:
ZIEDSES DES PLANTES' PROTOTYPE (1931)

JEAN KIEFFER (1897–1972)



machine. He coined the term 'tomography', composed of the two Greek words *tomos* (slice) and *graphein* (draw), and patented a device called the tomograph in 1934 (Fig. 4, see page 48). Passing into history as the Grossmann principle, this accurate movement of tube and film became a design feature of several subsequent units, including the polytome.

The work of Grossmann and his collaborator, the Lebanese radiologist Henri Chaoul (1887–1964), was generally accepted at the time as providing the simplest and most economical approach to tomography and initiated the trend of using only linear movement.

Studies by the Franco-American technologist Jean Kieffer (1897–1972), again independent from work of other researchers, also investigated the principle of planigraphy in 1928, during a stay as a patient in a sanatorium in Connecticut. By the time he entered the scene, the principle had already been independently 'discovered' in four countries by at least eight investigators and had been patented five times. His objective was to produce radiographic images to visualise his own pulmonary and mediastinal lesions (he suffered from tuberculosis).

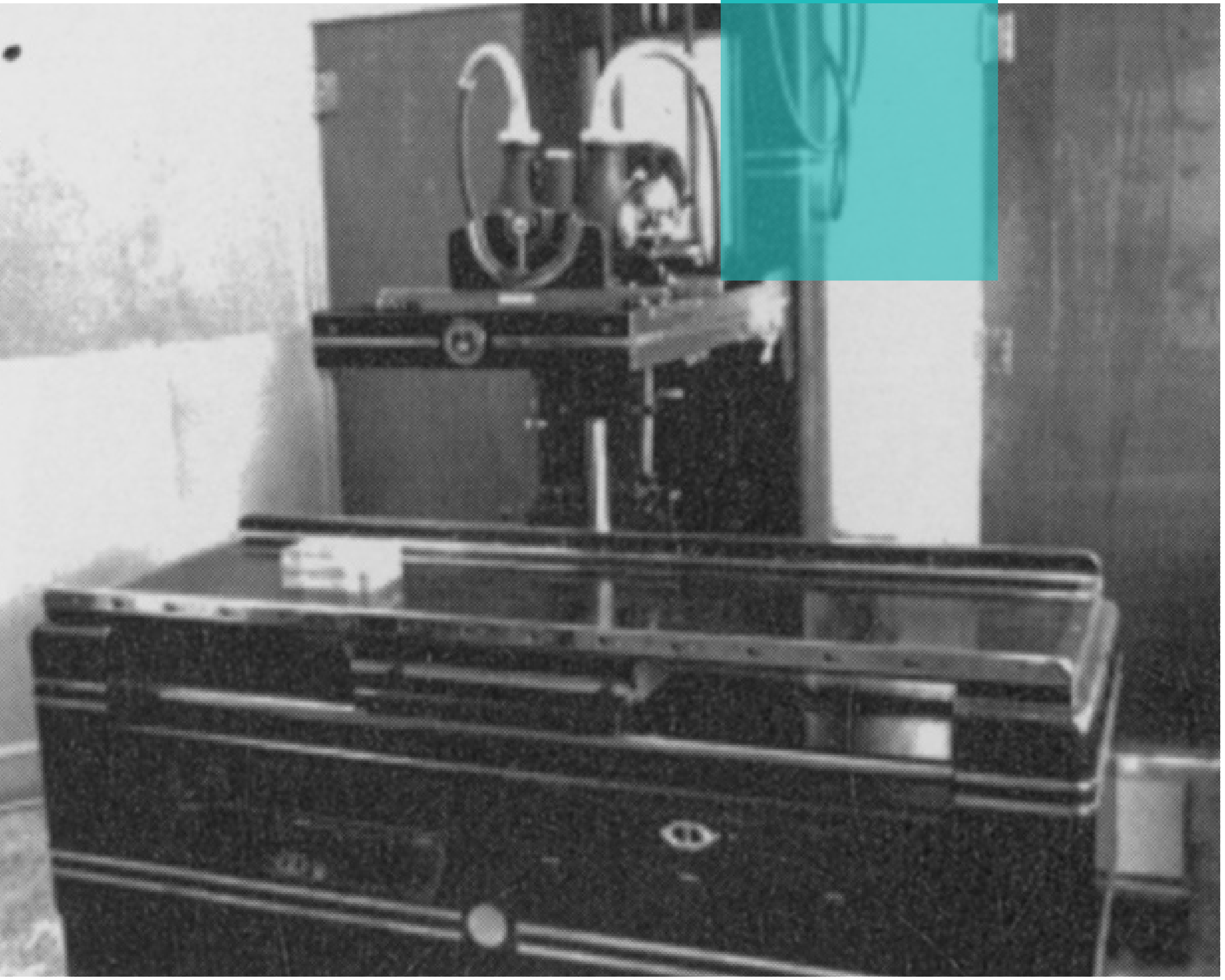
In Kieffer's device (which he called an x-ray focusing machine) the tube and the film were linked together by a pivoted system somewhat resembling a seesaw. By moving the pivot point or fulcrum in one direction or the other, he could bring into focus any desired plane of the object under study. The linked tube and film, moreover, could be moved back and forth, or in a circle, or along a sine curve or spiral, or in any combination of these paths. The motions always remained reciprocal and proportional. This wide variety of motions allowed for more complete erasure of the unwanted shadows, which could occur in various circumstances. The thickness of the out-of-focus section could be changed by varying the amplitude of the movement. The greater the amplitude of the movement of tube and film, the thinner the section reported on the film without blurring and the more complete the erasing of shadows cast by objects above and below that plane. Kieffer even worked out a way to combine his device with a Potter-Bucky grid.

His theoretical design of a tomographic device lay dormant until 1934, when it was patented. In 1936, Kieffer met J. Robert Andrews, a radiologist at the Cleveland University who published a seminal review of tomography describing in detail the progress which, up to that time, had all been made by Europeans. Andrews introduced Kieffer to Sherwood Moore (1880–1963), a radiologist from Washington University and director of the Mallinckrodt Institute of Radiology, and as a result of this meeting the first and only American tomographic device with pluridirectional blurring capabilities (spiral and circular) was developed. In 1938 the Keleket X-ray Company put an apparatus on the market which was called the laminagraph (from *lamina,* a thin plate), a name coined by Moore (Fig. 5). It is thanks to Kieffer that tomography came into general use in the USA.

Kieffer decided that no single type of focus movement was best for all laminagraphic problems, but Moore believed in the advantages of the spiral motion. The superior quality of these pluridirectional images went unnoticed for twenty years while linear techniques became the procedure of choice, especially in the chest. The reasons most fre-

THE STORY OF RADIOLOGY
THE HISTORY OF CONVENTIONAL TOMOGRAPHY

FIGURE 5:
THE *LAMINAGRAPH* DESIGNED BY KIEFFER, COMMERCIAL MODEL MANUFACTURED BY THE KELEKET COMPANY



quently given for using linear methods were that linear devices were less costly, less complicated to build, and exposure times were shorter. Had radiologists and industry listened more carefully to the principles of Ziedses des Plantes and Moore, the radiology community would have benefited from pluridirectional tomography much earlier.

Kieffer described, but did not construct, an apparatus to permit axial transverse tomography. In 1936, the German radiologist Heinz Vieten (1915–1985) conceived a design to obtain transverse tomographic images. But it was a British radiographer, William Watson (1895–1966), who was the first to devise the technique of non-computed axial transverse tomography, in which cross-sections are obtained perpendicular to the long axis of the body (in the same orientation as today's computed tomography sections). He called his device the sectograph.

Another variation was the pantomograph, developed in 1949 by the Finnish researcher Yrjö Paatero (1901–1963), who was at the time working at the University of Washington in Seattle. Using the pantomograph a curved layer of the subject was sharply imaged on a curved film, with both being vertical and rotating in opposite directions. This device, marketed commercially as Panorex, was employed primarily in studies of teeth and temporomandibular joints.

Edward W. Twinning (1887–1939), a British radiologist, became interested in tomography in the late 1930s, at a time when Grossmann's linear system had gained great popularity in Europe. He felt that Grossmann's device, the tomograph, was over-complicated and expensive.

In 1936 he built a home-made instrument that could be attached to the Potter-Bucky diaphragm of standard radiographic tables. His invention was later produced commercially.

The 1950s marked the transitional years from the relatively crude apparatus of the early inventors to the sophisticated pluridirectional devices marking the modern era of conventional tomography. The introduction of the first modern pluridirectional unit, the polytome, marked the turning point in the history of tomography (Fig. 6). Radiologists began seeing tomographic images that were infinitely more accurate than any previously encountered. The sections, made with a hypocycloidal blurring pattern, were thin (1mm) and had relatively high contrast and excellent spatial resolution (five line pairs per mm). They now represented a new dimension in diagnostic radiology.

The first experimental polytome was developed in 1949 by engineers Raymond Sans and Jean Porcher in the tool shop of the Salpêtrière Hospital in Paris, and the first production model was built by Massiot et Cie in 1951. Thoyer-Rozat and J. Moussard published the first clinical results from the polytome in 1953. In the United States the adoption of this technique was slow. The first article in American literature on clinical experiences with polytome tomography appeared ten years later (1963).

The Japanese radiologist Shinji Takahashi (1912–1985) produced extensive experimental evidence and basic knowledge on axial transverse tomography which must be regarded as a precursor to computed tomography. His work included at least five methods. His 1969 book, *An Atlas of Axial Transverse Tomography and its Clinical Applications,* unquestionably represents the most comprehensive illustrated publication on conventional axial transverse tomography, approaching the images obtained later with computed tomography.

In 1968, the Belgian engineers André Moenaert and Erik Majeans of the Antwerp company De Man developed a serious challenger to the polytome: the stratomatic. This tomograph was also multidirectional and was based on the original principle of planigraphy studied by Bocage and Ziedses des Plantes by using spiral movement, thus avoiding crossing in its trajectory.

Up to the early 1960s, the terminology of body-section radiology was thoroughly confusing. Various different terms for the method were used in the homelands of the many inventors: Vallebona, in Italy, and his stratigraphy; Ziedses des Plantes, in Holland, and his planigraphy; Grossmann, in Germany, and his tomography; and Kieffer, in the United States, and his laminagraphy. The issue of deciding on a general term for body section radiology was resolved in 1962 with the appointment of a committee of the International Commission of Radiologic Units and Measurements (ICRU), which selected the generic term tomography, a designation later adopted throughout the world.

Beginning in the early 1970s, investigators examined several different techniques designed to reconstruct a conventional tomogram from digital data acquired by different methods. These efforts opened the door to a new era in diagnostic radiology and paved the way for the more advanced beginnings of the newest sectional imaging techniques to date: computed tomography (CT) and magnetic resonance imaging (MR).

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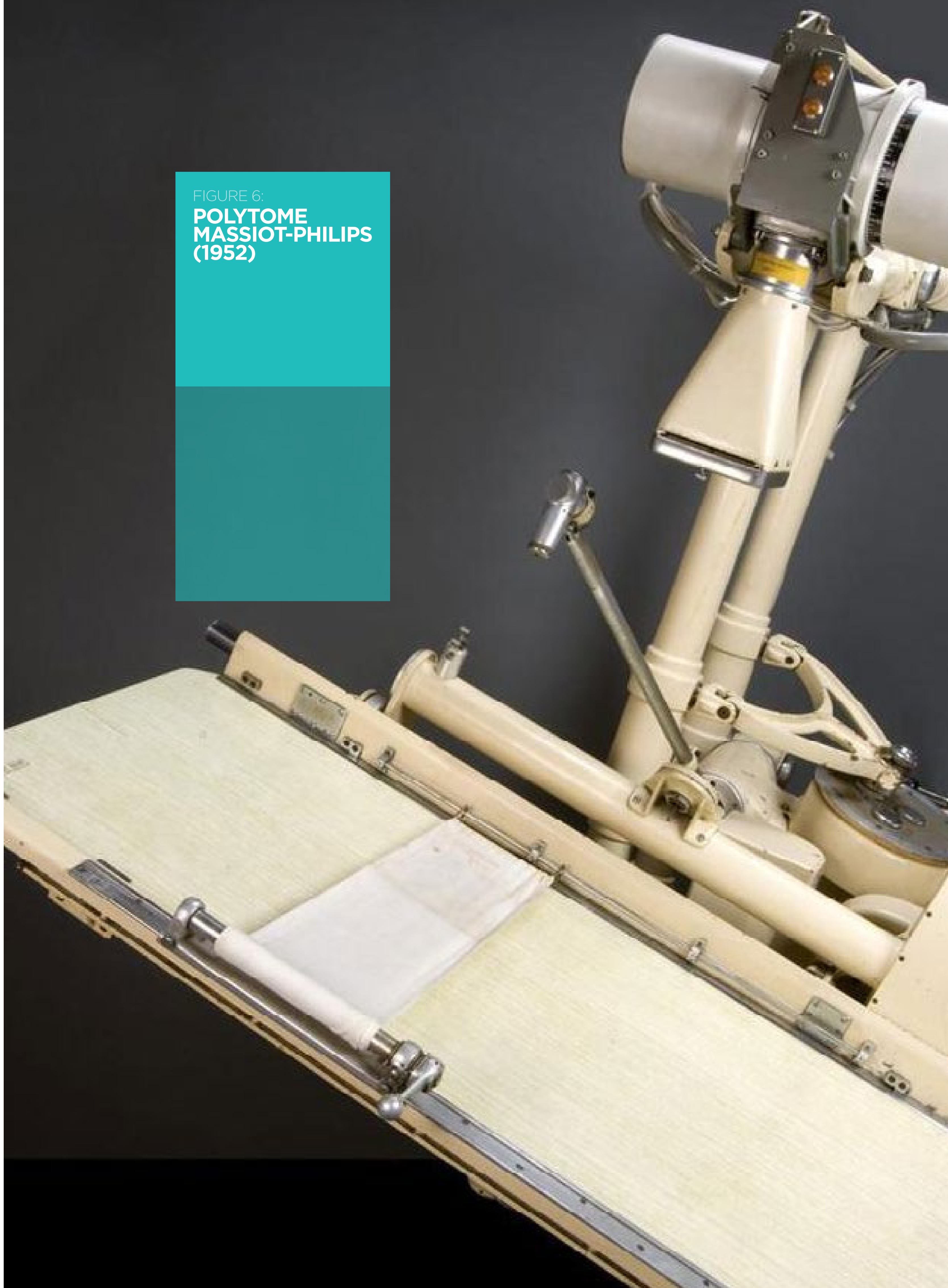


FIGURE 6:
POLYTOME MASSIOT-PHILIPS (1952)

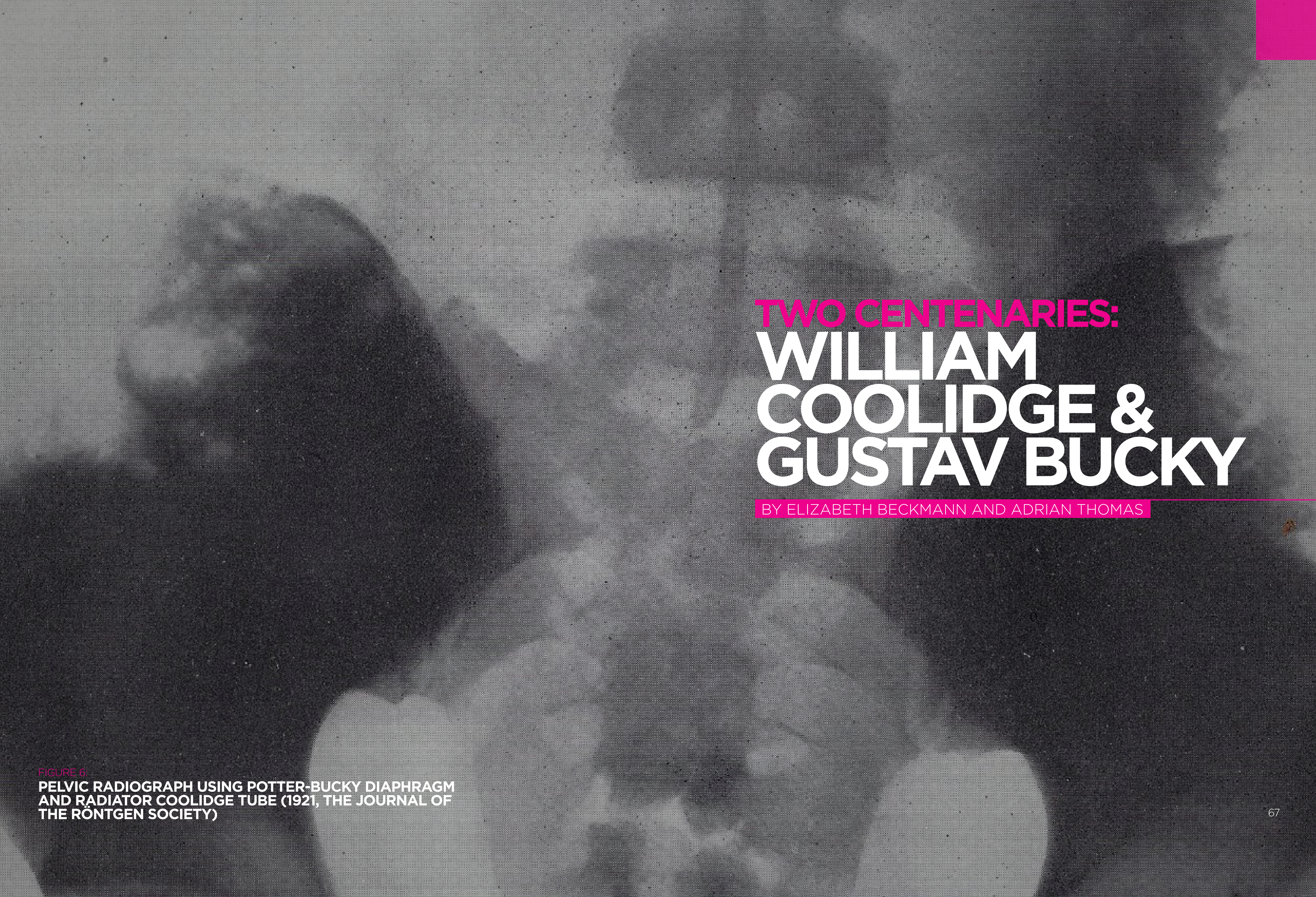


FIGURE 6:
PELVIC RADIOGRAPH USING POTTER-BUCKY DIAPHRAGM AND RADIATOR COOLIDGE TUBE (1921, THE JOURNAL OF THE RÖNTGEN SOCIETY)

TWO CENTENARIES: WILLIAM COOLIDGE & GUSTAV BUCKY

BY ELIZABETH BECKMANN AND ADRIAN THOMAS

Following the discovery of x-rays in 1896, early radiographs produced good images of the periphery of the body. However, examination of the denser portions, including the abdomen and chest, remained problematic. This was due to several reasons; the first was the relatively low power and unpredictable output of the early generation of gas and ion x-ray tubes. The second problem was the scattering of radiation from the body itself, producing a generalised degradation of the images. These problems were solved by the work of two men of genius: William Coolidge and Gustav Bucky, and it was by chance that both discoveries were announced in the same year, 1913. These two inventions were major contributions to the development of conventional radiography prior to the digital revolution.

WILLIAM COOLIDGE (1873–1975)

This year marks the centenary of the development of the hot cathode Coolidge x-ray tube. All of our modern x-ray tubes are based on this design and variations of it.

The early x-ray tubes were gas or ion tubes. The cathode was a simple cup and the anode was set at an angle, hence the name focus tubes. The working of these x-ray tubes depended on the ionisation of the gas inside the glass bulb. They worked well, but their function was unpredictable and the radiographer needed to know the individual tube, and how a particular tube functioned in use. The function of the tube varied with its use and before use the tube needed to be seasoned. It was not uncommon for one tube to be reserved for extremity work and the other for chest radiography.

WILLIAM COOLIDGE (1873–1975)

THE STORY OF RADIOLOGY
TWO CENTENARIES: WILLIAM COOLIDGE & GUSTAV BUCKY

William David Coolidge (1873–1975)[1, 2] (Fig. 1) was born in Hudson, Massachusetts, on October 23, 1873. In 1905, he joined the General Electric Company Research Laboratory and he worked there until he retired in 1944.

In 1906, Coolidge made a major contribution when he discovered how to make molybdenum and tungsten ductile. Prior to this, these metals were thought of as being unworkable because they were far too brittle. The ductile tungsten was useful since it could be made into incandescent lamp filaments, replacing the earlier carbon filaments.

It was when working with x-ray tubes[3] that Coolidge found a particular tube that worked well when the cathode became heated. Coolidge then collaborated with Irving Langmuir, who was studying electron emissions from hot tungsten filaments. It was found that even in the highest vacuum the electron emission was stable and reproducible. It occurred to Coolidge that this could be adapted for use in an x-ray tube. On December 12,1913 Coolidge wrote that "I L (Langmuir) tells me that in his study of the Edison Effect, current from the hot cathode is greater with vacuum of .01 or .02 micron than at higher pressure (except in case of argon). I will try this at once in an x-ray tube in which I can heat the cathode."

The Edison effect (also known as thermionic emission) is the emission of electrons from a hot cathode within a vacuum tube. This effect had initially been reported in 1873 by Frederick Guthrie in Great Britain. Guthrie was working with electrically charged objects. He found that

FIGURE 1:
WEDGWOOD JASPER PALE BLUE PLATE CELEBRATING WILLIAM COOLIDGE, PRODUCED FOR CLIMAX MOLYBDENUM COMPANY, NEW YORK

a positively charged red-hot iron sphere would discharge, but that this did not happen if the sphere had a negative charge. This effect was rediscovered by the American Thomas Edison on February 13, 1880, when he was trying to find why the filaments in his incandescent lamps were always breaking.

The team at GE then developed a high-vacuum tube with a heated tungsten filament acting as the cathode (Figs. 2&3), and a tungsten disc as the anode. The tubes were evacuated and initially the green fluorescence of the glass, which always took place when x-ray tubes were operated, was observed. As the vacuum increased the fluorescence disappeared and the tube became stable and controllable. The ions in the tube that were previously needed became unnecessary. The limitations of the older gas tubes were largely secondary to the presence of these ions.

The first of these new tubes with a heated cathode was used by the well-known US radiologist Lewis Gregory Cole, from New York. The new tube was first demonstrated at a dinner in a New York hotel on December 27, 1913. It was enclosed in an open-topped lead glass bowl for radiation protection. Up to this point the x-ray generators had an output considerably higher than the older x-ray tubes could endure and this was changed at a stroke. With his characteristic modesty, William Coolidge wanted to call the new design of tube the ‘GE Tube’, however Lewis Cole proposed the name of ‘Coolidge Tube’ and this is the name that stuck (Fig. 4).

THE STORY OF RADIOLOGY
TWO CENTENARIES: WILLIAM COOLIDGE & GUSTAV BUCKY

FIGURE 2:
COOLIDGE TUBE

FIGURE 3:
SPIRAL CATHODE (LEFT) AND TUNGSTEN ANODE (RIGHT). NOTE THE ELEGANT SHAPE OF THE ANODE AND THE ANODE ANGLE OF 45 DEGREES BEFORE THE DEVELOPMENT OF LINE FOCUS.

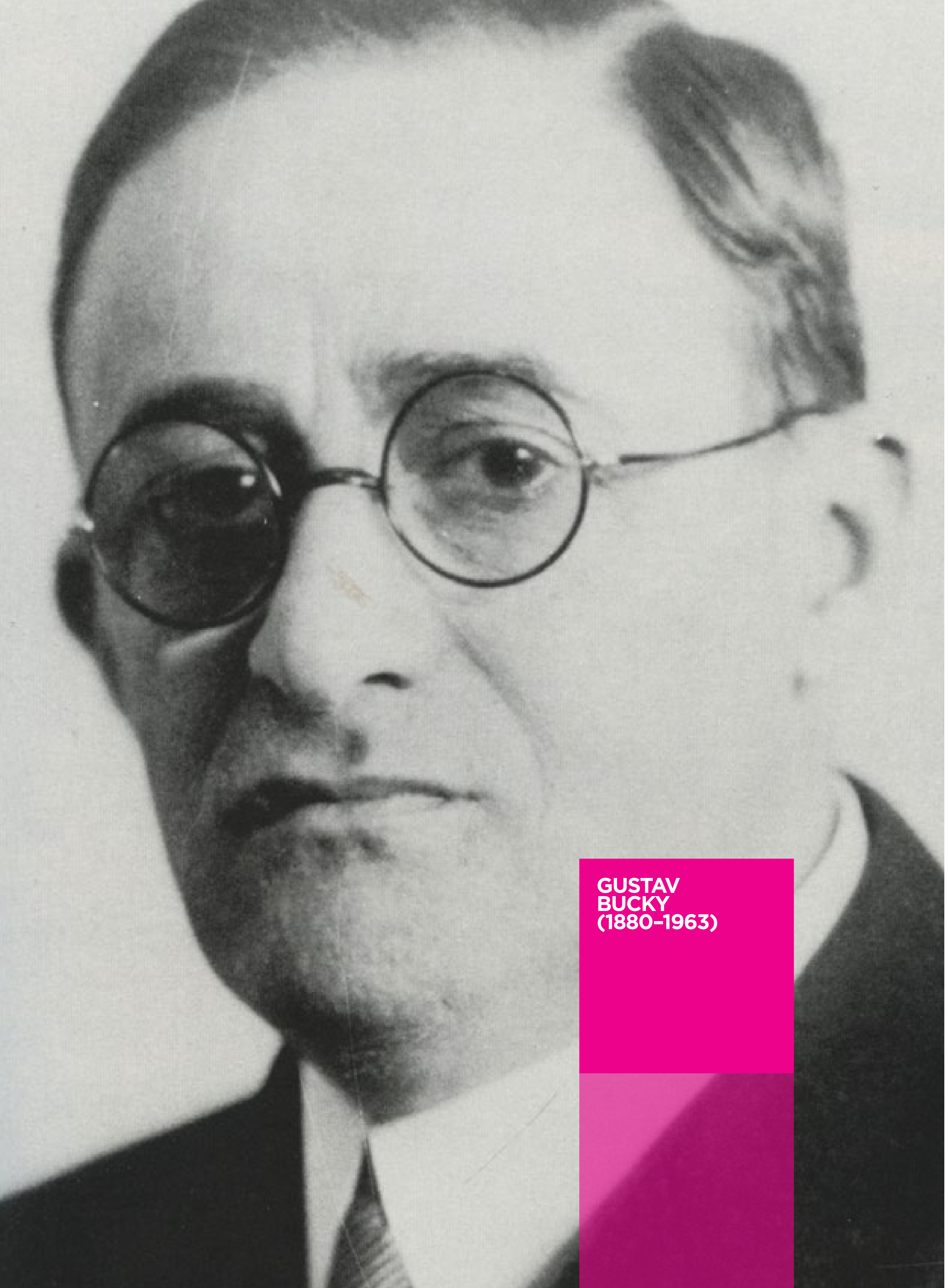
Coolidge wanted to test his new tube designs on human subjects and decided rather unwisely to use himself as a test subject, as so many had done before him with disastrous effects. Whilst this went well initially, Coolidge became concerned when the hair on his back started to fall out. Coolidge therefore obtained an embalmed leg from a local physician to use as a phantom. When Coolidge had finished his experiments he took the leg to the company's incinerator for disposal and threw the leg into the incinerator without informing anyone. When the operator opened the incinerator as the covering came apart, he was horrified to see a human leg. He was convinced that he had come across a dreadful crime and so he called the police. A detective then visited Coolidge and he had to give a very lengthy explanation.

Further experiments by Coolidge and his team on the new tube resulted in the observations that the radiographic contrast depended on the tube voltage and that the resolution depended on the size and position of the focal spot.

During the First World War, Coolidge became involved in producing a dependable and portable radiographic unit for military use. The individual elements were of necessity simple, light and easily transportable. There was a petrol-driven generator attached to provide the current. The new tube had many benefits for military use and could be operated for long periods of time without over-heating.

It might be imagined that the new Coolidge tube would rapidly sweep away the old ion/gas tubes. In fact the gas tubes survived for a consider-

FIGURE 4:
"THE COOL-EDGE TUBE" (1916) AS ILLUSTRATED BY GEORGE MORROW IN 1913



able period of time. The older designs were readily available and also quite cheap. For example, in GC Aimer's catalogue, a standard gas tube retailed at seven pounds and 15 shillings (£7.75), whereas the Coolidge tube sold for £40. Aimer was forced to admit that "the Coolidge tube has certain advantages over the gas tube".

Coolidge continued to work with x-rays and in the 1930s developed a 900,000-volt tube. He was also deeply involved in non-destructive testing and industrial radiography.

Coolidge received many honours but remained very modest. He said "such honours as this I accept only if I can somehow share them with many others, since the entire staff of our research laboratory contributed to the success of this work."

GUSTAV BUCKY (1880–1963)

Gustav Peter Bucky[4] was born on September 3, 1880 in Leipzig, Germany. He wanted to be an engineer, however at the insistence of his parents he transferred to study medicine at the University of Leipzig, graduating in1906.

The combination of his interest in photography at school, his ambition to be an engineer and his parent's insistence that he study medicine would lead him into the relatively new technical branch of medicine which was to be called radiology.

In 1908, he began his training in radiology at the Röntgen-Zentral-Institut at the Rudolf Virchow Hospital in Berlin, qualifying in 1910. In 1913, he became director of radiology at the municipal Children's Hospital. He became director of radiology at the Universitätsklinik in Berlin and head of the department of radiology at the Institute of Forensic Medicine at the University of Berlin following the First World War.

THE BUCKY DIAPHRAGM

In 1896, Arthur Wright, from Yale University, noted blurring on x-ray film. In 1903, Ernst Pasche, working in Germany, noted the radiographic effects of x-ray emissions, which explained the loss of definition and contrast of the radiological image.

However, it was Gustav Bucky who realised that the main problem was finding a way to reduce the scattered radiation that was responsible for the loss of definition of the radiological image from reaching the film. However, this had to be achieved with minimum impact on the primary x-ray beam. Bucky had his original idea on how to achieve this in 1909, but it took some years of experimenting for him to develop his design.

Bucky described his original design for the 'Bucky Diaphragm' as a 'honeycomb' lead grid, but with individual elements being square in shape, rather than hexagonal. He used lead since it was a material which absorbed x-rays. In this design the lead strips were thick and spaced 2cm apart, running both parallel to the length and width of the film. This resulted in the lines of the grid being visible on the x-ray film. Despite this, the grid was effective and did remove scatter and improve image contrast.

THE STORY OF RADIOLOGY
TWO CENTENARIES: WILLIAM COOLIDGE & GUSTAV BUCKY

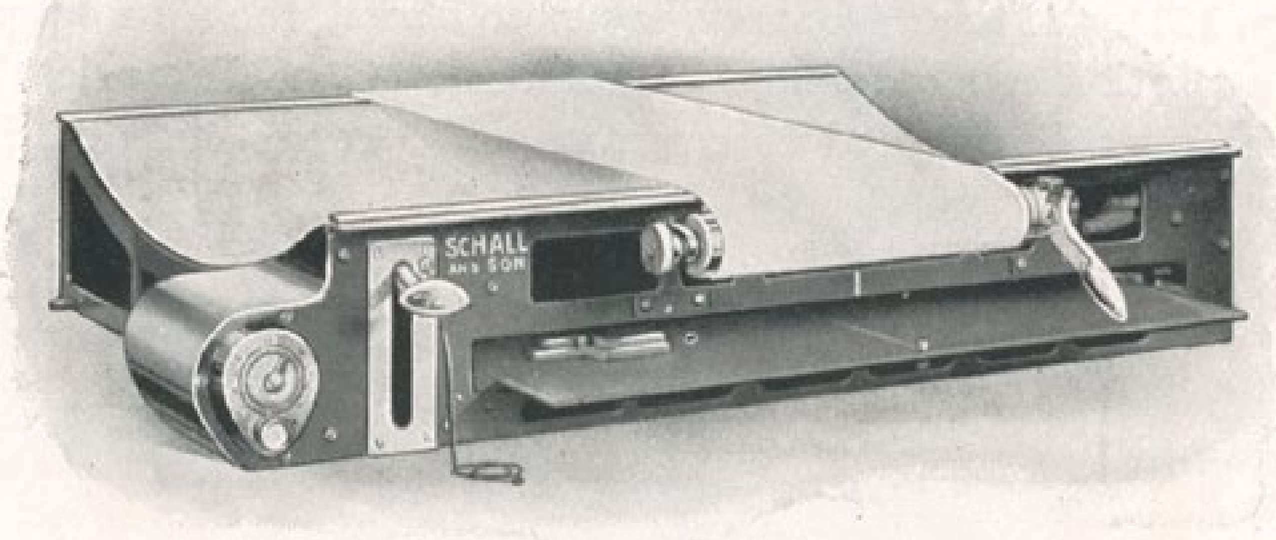
Bucky presented his results during the 1913 Berlin congress and they were impressive. However, the audience were sceptical, and a doctor accused Bucky of having retouched the negative.

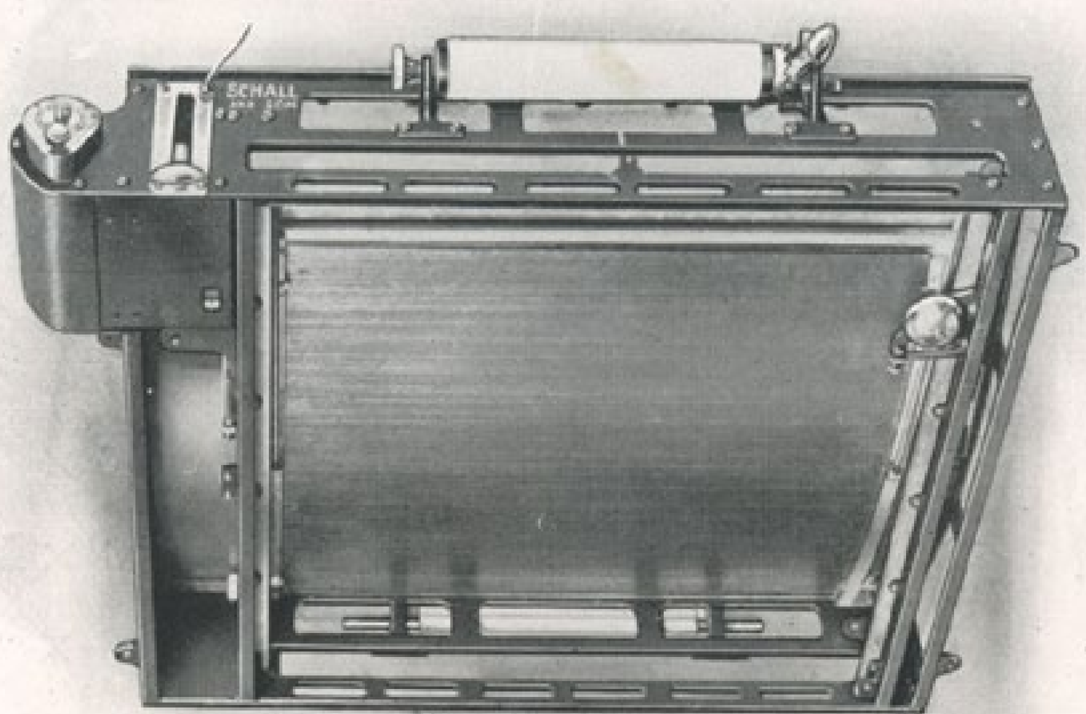
He applied for a patent in the United States for his diaphragm grid on February 3, 1914, and over the following years he developed several variations on the diaphragm.

THE POTTER-BUCKY DIAPHRAGM

In 1920, the American Hollis Potter further developed the grid[5, 6]. Potter aligned the lead strips so that they now ran in one direction only, and he also made the lead strips thinner so that they were less visible on the image. Potter also proposed moving the grid during exposure, which blurred out the image of the lead strips on the radiographic image (Fig. 5). The resulting moving grid, based upon the work of Bucky and Potter, became known as the Potter-Bucky grid. Combined with the new Coolidge tube the quality of radiography showed a significant improvement [Figs. 6 (see page 66), 7] and led to the development of conventional radiology.

The Potter-Bucky grid, or diaphragm, has remained a standard part of x-ray systems ever since and there have been continuous improvements. Prior to the development of the Bucky Grid the radiographic





No. 26195 (Curved).

No. 26196 (Flat).

FIGURE 5:
THE CLASSIC POTTER-BUCKY DIAPHRAGM, FLAT AND CURVED

plates were kept small, usually 4 x 5 inches, since without the grid, the larger the plates, the greater the amount of blurring due to scattered radiation.

Grids have developed over the years with a range of grid ratios (defined as the ratio of the height of the lead strips to the distance between the strips) to suit different radiation energy levels.

Since the scattered radiation, due to Compton scattering, increases as the x-ray energy (kVp) increases, scatter becomes a greater problem at higher energy levels and grids are therefore more important.

The major disadvantage of using a grid is the increased exposure for the patient, due to the absorption of the scattered radiation by the grid. Even with the use of grids, image quality can vary and errors can occur, particularly with the misalignment of the grid, which can result in an underexposed film.

Since the introduction of modern digital imaging, grids have remained important, but with digital systems moiré effects can occur, requiring grids with specific grid line spacing or software to suppress and remove the moiré lines.

OTHER INVENTIONS

Gustav Bucky made other contributions, including the Bucky radiographic table used in dosimetry and radiation protection.

While working at the Institute of Forensic Medicine, Bucky was asked to help in a criminal case where a woman had confessed to shooting and burying her husband who had disappeared four years earlier. When she led them to his grave the body was exhumed and radiographed by Bucky. The radiograph showed a bullet fragment in his cervical vertebra and confirmed that he had been shot from behind. This is an early example of forensic radiology.

Bucky's name was also given to the 'Bucky factor' which was a ratio measurement of the x-rays that hit the grid compared to those that pass through the grid. This is the factor by which the exposure, and hence patient dose, must be increased when a grid is used to create a good image.

In June 1923, Bucky emigrated to the USA, receiving American citizenship in 1929. He became head of the department of radiology at Brownsville Hospital in Brooklyn, the Hospital for Joint Diseases and the Beth Israel Hospital in New York City.

In 1930, Bucky was offered the post of director at the central department of radiology and the Institute for Cancer Research at the Rudolf Virchow Hospital in Berlin, which he accepted and returned to Berlin.

BUCKY AND EINSTEIN

In 1933, Bucky met up again with his friend Albert Einstein[7, 8] when he arrived in New York. When on holiday together Gustav and Albert would go for a long walk together each day, discussing and developing

FIGURE 7:
PELVIC RADIOGRAPHY WITH AND WITHOUT THE USE OF A GRID

new ideas. One such idea was for a special woven fabric with threads of cellophane or other synthetic material, or a pre-impregnated ordinary thread woven tightly. This would prevent drops of water from passing from the outside of the fabric to the inside but allow the smaller sized perspiration vapour particles to pass from the inside out. This idea for such a fabric predates the successful patent for Gore-Tex some 40 years later.

Probably the most famous collaboration between Bucky and Einstein was the idea of 'a light intensity self-adjusting camera' with a US patent granted on October 27, 1936. Einstein wrote to Bucky on November 3, 1936 saying, "I am very happy that the moveable automatic diaphragm has been patented; I have however, not given this thing any of my brain fat at all. I must really stress it." However, it was Einstein's name not Bucky's that appeared in the headline in the New York Times on November 27, 1936, as the "inventor of Camera device" with Bucky's name only appearing in a subheading.

It is a sign of the close relationship between Bucky and Einstein that Bucky visited Einstein every day during his final illness and was at the hospital only hours before Einstein's death in April 1955.

Bucky received many awards and honours. In 1923, he was the seventh person in the history of the State of New York to receive an honorary licence to practice medicine. In 1925, he was chosen as a representative of the USA at a cancer congress in London. He was an honorary member of the Rudolf Virchow Medical Society in New York and the

German Röntgengesellschaft. In September 1962, he was made an honorary member of the International College of Surgeons, an honour he highly treasured.

He continued his research in his private laboratory until his death at the age of 82 on February 19, 1963.

Gustav Bucky was a friendly, modest, undemanding person who made a lasting and significant contribution to radiology. For 21st century radiology the impact of the invention for which Gustav Bucky is most remembered – the Bucky Grid – continues. The grid is as important in modern digital detection systems, like computed radiography (CR) plates or digital radiography (DR) detector systems, as it was with x-ray film in the 1920s.

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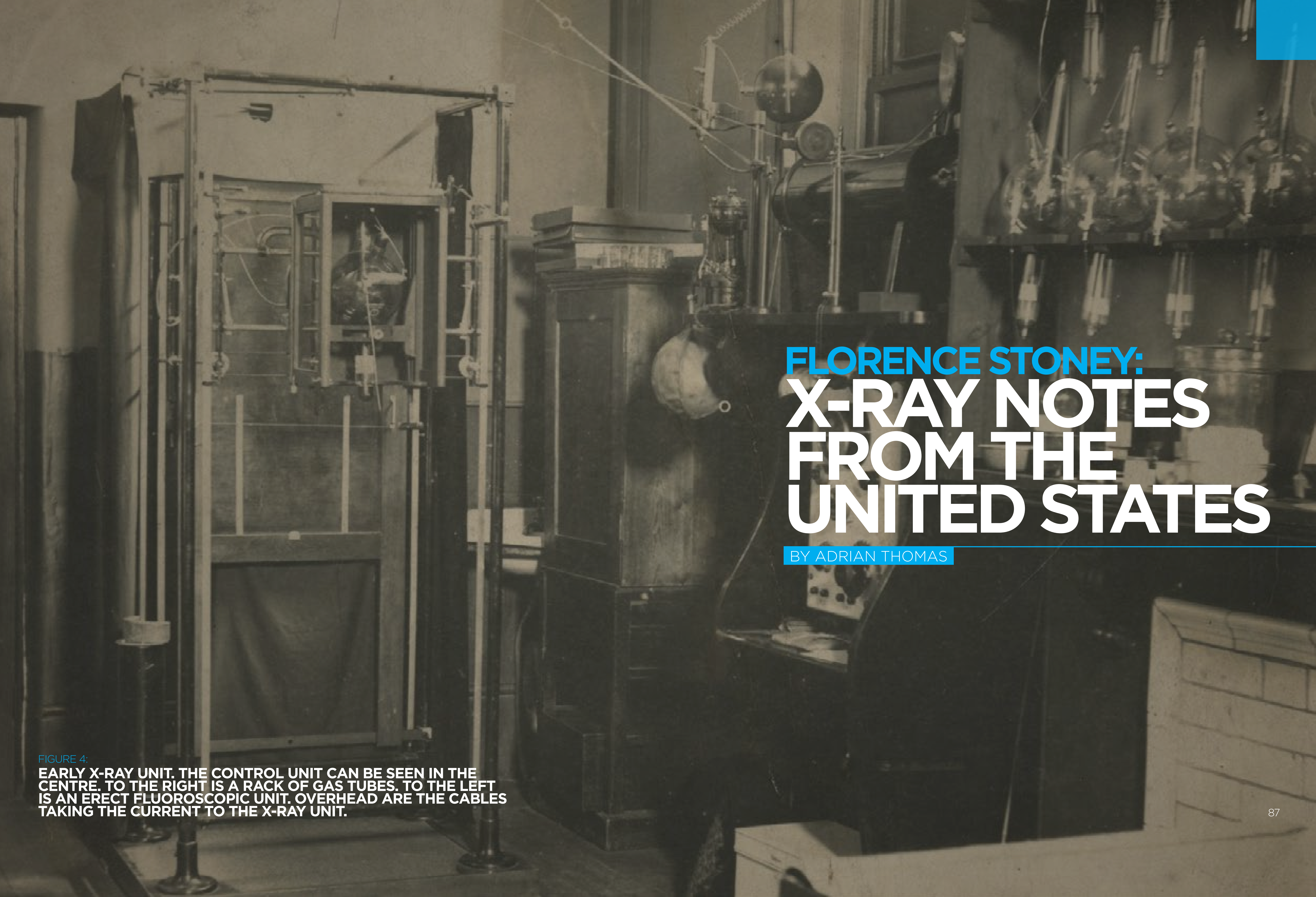

FIGURE 4:

EARLY X-RAY UNIT. THE CONTROL UNIT CAN BE SEEN IN THE CENTRE. TO THE RIGHT IS A RACK OF GAS TUBES. TO THE LEFT IS AN ERECT FLUOROSCOPIC UNIT. OVERHEAD ARE THE CABLES TAKING THE CURRENT TO THE X-RAY UNIT.

FLORENCE STONEY: X-RAY NOTES FROM THE UNITED STATES

BY ADRIAN THOMAS

INTRODUCTION

Florence Stoney (1870–1932) was the UK's first female radiologist.[1] Her life story is inspirational. She was of the pioneering generation of women doctors. As she was unable to study medicine in Ireland she travelled to England, where she attended the London School of Medicine for Women (LSMW), graduating in 1895. As an established radiologist she visited the United States 100 years ago this year. Her observations make interesting reading.

EARLY LIFE

Florence Ada Stoney[2] was born in 1870, and grew up in Dublin, Ireland, which was then part of the United Kingdom. Stoney was educated at home, and then at the Royal College of Science. In the Cambridge Higher Local examinations she achieved first class honours in natural science and first class honours in mathematics. Her father was Dr. G. Johnstone Stoney FRS, who fully supported the higher education of women and saw no reason why women should not be suited for medicine, law and even the church. He was involved in the founding of Girton College, which was the first residential college for women at the University of Cambridge and offered education for women to degree level. Her brother was an engineer and her sister was a physicist. Stoney was unable to study medicine at Dublin University as women were not being admitted to medical degrees in Ireland at the time.

FIGURE 1:
THE LONDON (ROYAL FREE HOSPITAL) SCHOOL OF MEDICINE FOR WOMEN, HUNTER STREET, LONDON

THE LONDON SCHOOL OF MEDICINE FOR WOMEN

Stoney therefore came to England[3], attending the London School of Medicine for Women (Fig. 1), and then the Royal Free Hospital (Fig. 2), completing her degree in medicine with honours (MB BS) in 1895. She was an excellent student, and received the Mackey prize for the best student in her year. She subsequently obtained her MD in 1898.

The London School of Medicine for Women had been founded in 1874 by Miss Sophia Jex-Blake, and had been linked to the Royal Free Hospital in 1877.[4, 5] The London (Royal Free Hospital) School of Medicine for Women was founded as part of the movement to admit women into the medical profession. This was a hard fought struggle and took many years. A start was made in 1858 when Elizabeth Blackwell was practicing in London under an American diploma. The Medical Registration Act of that year had allowed all doctors in practice to be admitted onto the Medical Register, and since Elizabeth Blackwell was already practicing she was therefore admitted.

Elizabeth Garrett Anderson, one of the first female medical practitioners, was dean of the London School of Medicine for Women from 1883 to 1903, covering the period during which Stoney was there.[6] Garrett Anderson was the first woman in Britain to legally qualify as a physician and a surgeon, and was the first woman dean of a medical school. Her example would have been inspiring to the young Stoney. Garrett Anderson applied to the Society of Apothecaries and they allowed her to qualify as a doctor. However, the society did not allow any more women to qualify. In 1868, Sophia Jex-Blake and five other

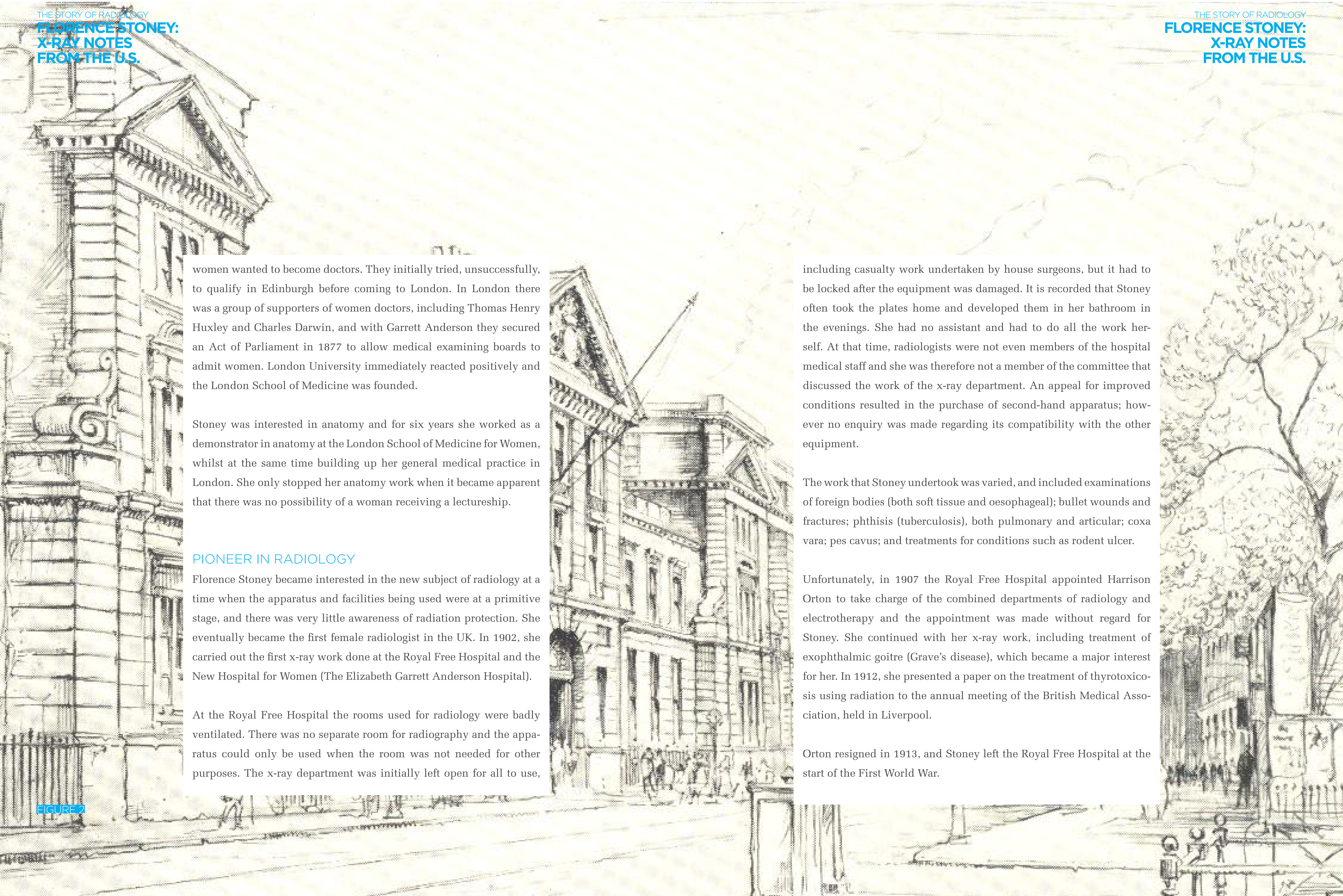

FIGURE 2

women wanted to become doctors. They initially tried, unsuccessfully, to qualify in Edinburgh before coming to London. In London there was a group of supporters of women doctors, including Thomas Henry Huxley and Charles Darwin, and with Garrett Anderson they secured an Act of Parliament in 1877 to allow medical examining boards to admit women. London University immediately reacted positively and the London School of Medicine was founded.

Stoney was interested in anatomy and for six years she worked as a demonstrator in anatomy at the London School of Medicine for Women, whilst at the same time building up her general medical practice in London. She only stopped her anatomy work when it became apparent that there was no possibility of a woman receiving a lectureship.

PIONEER IN RADIOLOGY

Florence Stoney became interested in the new subject of radiology at a time when the apparatus and facilities being used were at a primitive stage, and there was very little awareness of radiation protection. She eventually became the first female radiologist in the UK. In 1902, she carried out the first x-ray work done at the Royal Free Hospital and the New Hospital for Women (The Elizabeth Garrett Anderson Hospital).

At the Royal Free Hospital the rooms used for radiology were badly ventilated. There was no separate room for radiography and the apparatus could only be used when the room was not needed for other purposes. The x-ray department was initially left open for all to use, including casualty work undertaken by house surgeons, but it had to be locked after the equipment was damaged. It is recorded that Stoney often took the plates home and developed them in her bathroom in the evenings. She had no assistant and had to do all the work herself. At that time, radiologists were not even members of the hospital medical staff and she was therefore not a member of the committee that discussed the work of the x-ray department. An appeal for improved conditions resulted in the purchase of second-hand apparatus; however no enquiry was made regarding its compatibility with the other equipment.

The work that Stoney undertook was varied, and included examinations of foreign bodies (both soft tissue and oesophageal); bullet wounds and fractures; phthisis (tuberculosis), both pulmonary and articular; coxa vara; pes cavus; and treatments for conditions such as rodent ulcer.

Unfortunately, in 1907 the Royal Free Hospital appointed Harrison Orton to take charge of the combined departments of radiology and electrotherapy and the appointment was made without regard for Stoney. She continued with her x-ray work, including treatment of exophthalmic goitre (Grave's disease), which became a major interest for her. In 1912, she presented a paper on the treatment of thyrotoxicosis using radiation to the annual meeting of the British Medical Association, held in Liverpool.

Orton resigned in 1913, and Stoney left the Royal Free Hospital at the start of the First World War.

THE STORY OF RADIOLOGY
FLORENCE STONEY: X-RAY NOTES FROM THE U.S.

FIGURE 3:
GE (GENERAL ELECTRIC COMPANY), RESEARCH LABORATORY, SCHENECTADY, NEW YORK.

VISIT TO THE USA

In 1913, just prior to outbreak of the First World War, Stoney made a visit to the United States to see x-ray work being conducted. She visited several cities, which included Schenectady, New York, and gave a very interesting account in the *Archives of the Roentgen Ray* (the forerunner of the *British Journal of Radiology*) in October 1914.[7] She found that the doctors in America, both in the hospital departments and in private practice, were very willing to allow her to see the work in their departments, and that women were not being excluded to the extent that they were in England.

She saw the newly invented Coolidge x-ray tube in frequent use. The Coolidge tube is the modern type of tube with a hot spiral cathode and high vacuum, which replaced the older cold cathode gas tubes. The Coolidge tube was developed by William Coolidge in the GE Research Laboratory at Schenectady, New York (Fig. 3), where Florence visited. Significantly, Stoney brought back a new Coolidge x-ray tube, which was only the second to arrive in England.

RADIATION PROTECTION

She noted major concern in the United States about radiation protection. By 1913 there was considerable awareness of the harmful effects of radiation and there had been a number of tragedies involving the radiology pioneers.

There was, therefore, considerable concern about radiation protection. Nowhere was the operator left exposed to radiation apart from fluoroscopy and there was only limited use of fluoroscopy. The controlling switchboard was invariably placed behind a metal screen, which was generally made of lead, although Stoney observed in one hospital that iron was used because of its low cost. The separate rooms, or cubicles, in the department were separated using lead partitions. She found this to be the case in both hospitals and private practices.

TRANSFORMERS

Stoney spent some considerable time describing the use of transformers in the United States. She found that in most places a transformer was used rather than an induction coil, usually with an output of between 2 and 4 kW, which was enough for most radiological uses. Occasionally a 10 kW transformer was used.

She gives the advantages of transformers as:

» Allowing rapid radiographic exposures of 1/10 of a second and 100 mA, and therefore instant radiography of a chest and abdomen. This produced good views of moving organs such as the stomach and colon for gastrointestinal bismuth contrast studies. Bismuth was used prior to the introduction of barium.

» Being much easier to use than the coil and easier to keep in good working order.

» Operable using either alternating or direct current.

However, transformers were found to be noisy and resulted in an increased wastage of x-ray tubes.

Somewhat surprisingly she described the use of Wimshurst static machines in x-ray departments, including one designed for Francis Williams at Boston City Hospital. This latter machine could provide enough current for the entire department.

OVERHEAD WIRES

The x-ray tubes were supplied with current via an overhead system of wires which Stoney described as both elaborate and excellent. Using the overhead wires the tube could be activated with the operator standing behind the switchboard.

She felt that the wires were quite well insulated and observed that they were not constantly leaking current and sparking. It should be remembered that this was in a time before shock-proofing, and although the tubes had some protection from radiation, the high tension was supplied via a use of rheopores from the cables running along the ceilings. Touching the tube or cable would result in fatal electrocution.

Figure 4 (see page 86) shows an example of an x-ray unit from that period. The control unit can be seen in the centre. To the right is a rack of gas tubes. To the left is an erect fluoroscopic unit. Overhead are the cables taking the current to the x-ray unit.

FLUOROSCOPY

At this time there was considerable caution about exposing operators to radiation, and fluoroscopic examinations were carried out relatively infrequently. At Massachusetts General Hospital, Stoney observed gastrointestinal work using bismuth, prior to the more widespread use of barium sulphate, and fluoroscopy was carried out with palpation using a spoon designed by Guido Holzknecht.

It was felt that fluoroscopic work was too dangerous for the operator, and in one private practice she observed the fluorescent screen being reflected into a mirror so the operator could remain behind his lead partition, even while setting the photographic plate in position. She thought this was an improvement and very efficient as the aperture could be narrowed down to include only the actual region being observed and obtain a more detailed image.

RADIOGRAPHY

Stoney visited Boston, New York, Washington, Baltimore and Philadelphia and reported on the very highest standard of radiography that she encountered. She found that in the hospitals radiography took place with little if any fluoroscopy. The practice in some large hospitals was for one assistant to radiograph extremities and another to radiograph the chest and abdomen. This was because in the days before widespread use of the Coolidge tube, certain tubes were better suited to some examinations than to others.

Stoney found that gastrointestinal radiology was far in advance of the work that was being done at that time in London. Bismuth (not barium at that time) was used as a contrast agent and between 6 and 40 radiographs were taken to diagnose gastric or duodenal ulcers. This was before modern endoscopy. It was common practice to include a reduced-size print of the abnormality along with the written report. The newly invented Coolidge x-ray tube was in frequent use.

RADIOTHERAPY

Most of the hospitals did not practice treatment with radiation, and even the cancer hospital in Boston only performed radiography. Florence Stoney also saw treatment with irradiation. This was mainly carried out using radium emanation, which was contained in small metal needles that were inserted directly into the tumour.

She visited Philadelphia and observed radiotherapy with x-rays. She was impressed by the treatment of a 36-year-old woman with breast cancer, who was treated directly after surgery. She said that they used heavy doses, heavily filtered and frequently repeated. The surface was carefully marked out in sections, with each one exposed in turn and multiple beams being directed at the tumour from as many points as possible.

She observed cases of cancer of the cervix that had been treated and also cases of abdominal cancer. She described patients with inoperable cancer who had the bulk of the tumour removed, followed by treatment with radiation. She also observed patients with advanced malignancy with a fixed mass that became mobile following radiation treatment and was then treated with surgery.

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Radium was used for various uterine conditions and she also observed the treatment of Graves' disease.

1914

In the spring of 1914, Stoney and her sister Edith had a complete portable x-ray installation prepared, including the Coolidge tube that she had acquired in the USA.[2] They had this apparatus put together so that they could give medical assistance in the event of a possible rebellion in Ireland, which both sisters anticipated. On August 4, 1914, the day Britain declared war on Germany, Florence and Edith Stoney were able to offer their services to the British Red Cross at the War Office in London. However, their offer was refused because they were women. By this time, Stoney had thirteen years of experience in radiology. They joined the author Mrs. St. Clair Stobart in organising a voluntary women's unit, and Florence organised the medical part of the surgical unit entirely staffed by women. However, this is another story.

CONCLUSION

Florence Stoney had a firm faith in the potential capacity of women to fill positions of the highest responsibility and remains an inspiration today. She felt that women should develop their powers to the highest possible extent and then, if opportunity failed them, they should make their own opportunity. She had a gentle kindness and deep sympathy for suffering.

Stoney was a keen constitutional suffragist (suffragette) and she took part in many demonstrations and processions. This was a key struggle at this time. One hundred years ago this year, on June 8, 1913, Emily Wilding Davidson threw herself under the King's horse, Anmer, on Derby Day in protest against women's disenfranchisement. It was partly the example of women working in the First World War that led to the granting of the vote to women in Great Britain in 1928.

Stoney was shy and introverted with a quiet manner. This was in contrast with her iron will and undaunted courage. Her gentle graciousness disarmed opposition and gained cooperation. According to her obituary "few had dreamt of the ardour existing beneath that demure and gentle exterior".[3] In professional matters she was very keen to pass on all that she learnt to a younger generation. She was innovative in her approach to radiology and was involved in many early x-ray developments. Her life remains an inspiration.

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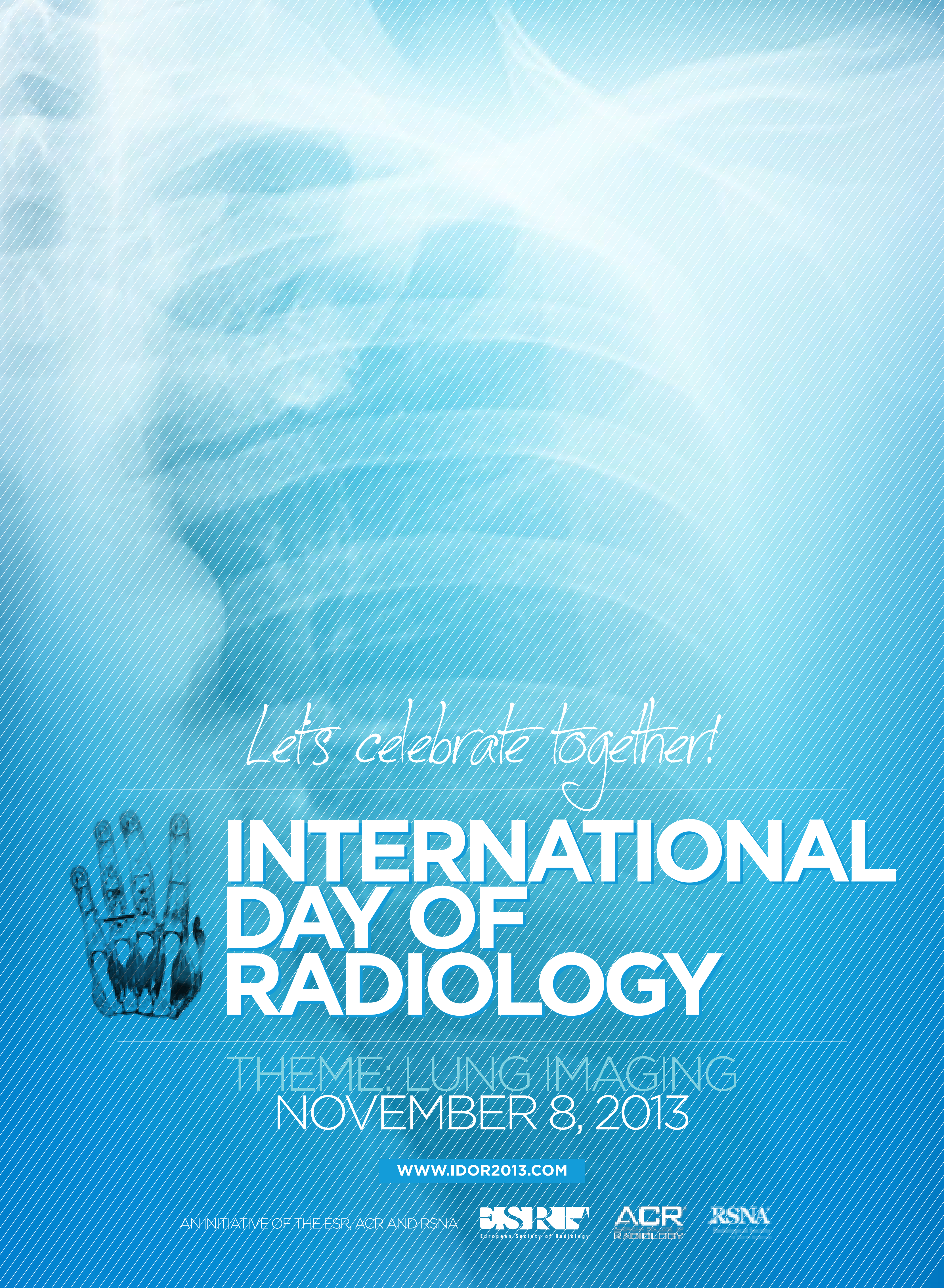
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