Analyse, inform and activate

LAKA

Analyseren, informeren, en activeren

Stichting Laka: Documentatie- en onderzoekscentrum kernenergie

De Laka-bibliotheek

Dit is een pdf van één van de publicaties in de bibliotheek van Stichting Laka, het in Amsterdam gevestigde documentatie- en onderzoekscentrum kernenergie.

Laka heeft een bibliotheek met ongeveer 8000 boeken (waarvan een gedeelte dus ook als pdf), duizenden kranten- en tijdschriften-artikelen, honderden tijdschriftentitels, posters, video's en ander beeldmateriaal. Laka digitaliseert (oude) tijdschriften en boeken uit de internationale antikernenergie-beweging.

De catalogus van de Laka-bibliotheek staat op onze site. De collectie bevat een grote verzameling gedigitaliseerde tijdschriften uit de Nederlandse antikernenergie-beweging en een verzameling video's.

Laka speelt met oa. haar informatie-voorziening een belangrijke rol in de Nederlandse anti-kernenergiebeweging.

The Laka-library

This is a PDF from one of the publications from the library of the Laka Foundation; the Amsterdam-based documentation and research centre on nuclear energy.

The Laka library consists of about 8,000 books (of which a part is available as PDF), thousands of newspaper clippings, hundreds of magazines, posters, video's and other material.
Laka digitizes books and magazines from the international movement against nuclear power.

The catalogue of the Laka-library can be found at our website. The collection also contains a large number of digitized magazines from the Dutch anti-nuclear power movement and a video-section.

Laka plays with, amongst others things, its information services, an important role in the Dutch anti-nuclear movement.

Appreciate our work? Feel free to make a small donation. Thank you.

www.laka.org | info@laka.org | Ketelhuisplein 43, 1054 RD Amsterdam | 020-6168294

Phys. Perspect.

https://doi.org/10.1007/s00016-024-00319-4

The Search for Radiation Standards and Science Diplomacy in the Interwar Period

Aske Hennelund Nielsen* and Maria Rentetzi**

This paper argues that international cooperation on devising radiation standards and measuring devices has been an issue not only of national concern but of binational and international conflict in the interwar period. Moreover, the production of radiation safety standards and radiation units gradually became a diplomatic process that underlined national rivalries and depended on political and diplomatic interests. As a result of this diplomatic process, early major scientific actors on radiation research lost prominence. The need to decide on radiation standards that could address medical, military and industrial concerns was therefore acute long before the 1950s and the establishment of international organizations such as the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the International Atomic Energy Agency (IAEA), that took the lead in regulating the uses of ionizing radiation in the postwar period.

Key words: International Radiological Congress; Inter-war period; Science diplomacy; Scientific standards; Radiation protection; Radiology.

The pioneering work of Wilhelm Conrad Röntgen in 1895 led to a veritable scientific breakthrough through the introduction of "X-rays" also known as "Röntgen rays." As Bettyann Kevles wrote: "[…] it is hard to imagine how wonderful the x-rays seemed in the euphoric winter of 1896."[1] Indeed, X-ray images of the body did not only "help shift social and moral boundaries,"[2] they also helped establish new research groups and centers for the study of X-rays and ionizing radiation. In Paris, Pierre and Madame Curie[3] developed the science of natural radioactive minerals through their discoveries of radium and polonium. By the early 1900s, and especially after the couple jointly won the Nobel Prize for Physics in 1903, the Curie Laboratory was considered *the* most prominent scientific institution both nationally and internationally in the new science of radioactivity.[4] Throughout her career, Madame Curie trained a number of young scientists, male and female, who joined her from other European institutes. Some students would later go on to the US to set up new research centers and enterprises there. For example, Sabin

* Aske Hennelund Nielsen is postdoctoral researcher at the Chair of Science, Technology and Gender Studies at the Friedrich-Alexander-Universität.
** Maria Rentetzi is professor of the History of Science and head of the Chair of Science, Technology and Gender Studies at the Friedrich-Alexander-Universität, as well as being an ERC-grantee.

Published online: 08 November 2024

Arnold von Sochocky, the founder of the radium dial painting industry in the US, claimed to have been trained at the Curie Laboratory before moving to New Jersey in the late 1910s.[5] In Vienna, the Institute for Radium Research, established in 1910, followed suit and led research on ionizing radiation in Austria thanks also to the rich uranium resources of the Joachimsthal mines.[6] Like the Curie Laboratory, the Vienna Institute also provided expertise and skilled personnel to the emerging radium industry in the US.[7] As pioneers within the field of the science of radioactivity, both groups would also become leaders in the development of radiation units and standards,[8] also leading to rivalries between the two scientific communities in the 1910s and early 1920s.[9]

As with other early histories of standardization in the late nineteenth and early twentieth century, the first steps towards radiation standardization were not necessarily carried out by governmental agencies and bodies. Rather, the standardization was carried out by interested networks, communities and actors who perceived the act of standard making as a necessary practice to further their respective fields and to achieve further success.[10] These groups often met at international conferences or congresses, to negotiate and discuss the theoretical and practical aspects of standard making and to maintain social contacts and networks.[11] The early history of radiation standardization did not differ on these points. In 1910, the "International Commission for the Radium Standard" was set up to decide on an international radium standard called the "curie."[12] The group consisted of several prominent scientists, including Madame Curie of France, Ernst Rutherford of the United Kingdom and Stephen Meyer, head of the Vienna Institute[13] While the standard enacted by this group was disseminated and used from 1910 to the 1930s,[14] it was not until the first International Radiological Congress (IRC) in 1925 in London that international standards were drawn up for radiation exposure and the establishment of radiation units.[15]

The 1925 IRC gathered over 500 representatives from twenty-one countries[16] and represented a major step in international cooperation on producing common standards of radiation in medicine and radiology. As Albert Soiland, a key figure in establishing radiology as an independent medical faculty in the US, commented that same year: "The first International Congress of Radiology will go down in medical history as the greatest achievement of organized radiologists."[17] The Congress attracted not only the interest of a large number of radiologist but also "the most distinguished scientists from every civilized country in the world."[18] Even the strong anti-German sentiment that had existed in several European radiological communities following the First World War—with several attempted boycotts of German X-ray manufacturers and the exclusion of German scientists from learned societies in France and Britain in the early 1920s—was forgotten,

with the German delegates serving side by side with representatives from other countries.[19]

By the mid-1920s, new scientific centers in Sweden, Germany, the US, France and the UK had risen to international prominence, undertaking new initiatives for the international standardization of radiation units and protection initiatives at a grander scale than ever before. Notably, however, neither the Curies nor the Viennese Institute were represented at the 1925 or following Congresses in any meaningful capacity, seemingly overshadowed by the work of the new research centers.[20] While these new centers were not ignorant of the pioneering work of the Curies and the research undertaken in Vienna, and were even directly inspired by them in some cases, the new generation of radiological institutions did not directly involve these early actors in their search for radiation standards.

Recent scholarship has studied scientific standard making by international organizations.[21] With this article, we highlight that the interwar period was in many ways foundational for later developments within the standardization of radiation units as well as X-ray protection. Despite this, the interwar period has seen comparatively less scholarship than the preceding and following periods. Previous research has focused on various aspects of radiation standardization and radiation protection in the interwar period, mostly in national or regional contexts.[22] Notably, Daniel Serwer has provided an account on the "rise of radiation protection" from the late eighteenth century to before the Second World War, focused on Western Europe and the USA.[23] However, this research has not focused on how radiation standards and radiation protection were achieved in the international setting through scientific diplomacy carried out by various actors in the interwar period.

Our purpose with this article is therefore twofold. Firstly, we highlight how the early developments in radiation standardization and protection from around 1920–39 in many ways were not only the result of international scientific debate but also science diplomacy. We argue that these standards were the culmination of different radiological and X-ray communities and actors as they attempted to advance their national interests by promoting their own scientific conclusions to be superior to "competing" states and delegations.[24] Secondly, we study the formation of the international scientific communities, concerned with the practice and use of radiology and radium for primarily medicinal purposes, that would continue to function also after the Second World War.

Our point of departure is the International Radiological Committee (IRC) and its two most prominent committees, the International X-Ray Unit Committee (IXUR) and the International X-Ray and Radium Protection Committee (IXRPC), the predecessors to the International Commission on Radiation Units and Measurements and the International Committee for Radiation Protection respectively. We ask which institutional, organizational, transnational and scientific developments facilitated the rise to prominence of these new actors and national groups as well as what diplomatic relationships existed between them.

Why were the national groups in Sweden, the UK, the US, Germany and France so important in the interwar period, and why were the earlier scientific actors like the Curies and the Viennese Institute seemingly less important?

This article is based on several different sources including scientific publications, personal recollections, institutional histories, congress reports and archival materials. The archives of the IRC were mostly destroyed during the Second World War, as the materials had been transported to Germany in preparation for the 1940 congress in Berlin.[25] However, drawing on new archival sources related to Rolf Sievert and his domestic and international engagement, located at the Karolinska Institute in Stockholm, has allowed us to delve into negotiations that previously were inaccessible and unknown. These new sources reveal the breadth of national concerns and the malleability of radiation protection and radiation standards long before the establishment of the IAEA and the attempt to regulate nuclear energy on the the United Nations level.

The Radiant 1920s

The period from the late 1890s to the 1910s saw the formation and foundation of radiological clinics and institutions in several countries.[26] In Sweden, the first steps were taken by the physician Thor Stenbeck at the Seraphim Hospital in Stockholm.[27] Already in February 1896 Stenbeck had become interested in the discovery of X-rays just months after Röntgen's first publication in December 1895. Over the next years, Stenbeck specialized in medical radiology, applying for grants to buy new equipment as well as making international study trips.[28] Stenbeck would go on to garner much national acclaim, establishing a small private clinic in 1899 and producing several impressive results including what many within the Swedish radiological community have considered the first "successful" cancer treatment using radiation in history.[29] Stenbeck would continue to work as a radiologist until 1914, however it would be one of his assistants, the young physician Gösta Forssell, that would carry on Stenbeck's mantle and become the "founder of Swedish Medical Radiology."[30]

Forssell was born in 1876 and studied medicine at Uppsala University and Stockholm University in the late 1890s and early 1900s.[31] From 1899–1900, he was employed as an assistant to Stenbeck treating patients and writing a research paper on X-rays and human anatomy.[32] His fate changed when professor John Berg, director of the Seraphim Hospital, offered him leadership of the Röntgen Institute at the Seraphim Hospital's Department of Surgery in July 1906.[33] Forssell and Berg worked closely together trying to bolster radium and X-ray treatment in Stockholm.[34] As Forssell later claimed: "John Berg's great merit was that of understanding very early that radiotherapy could not be developed in a productive way without having its own clinic especially equipped for this purpose (see Fig. 1)."[35]

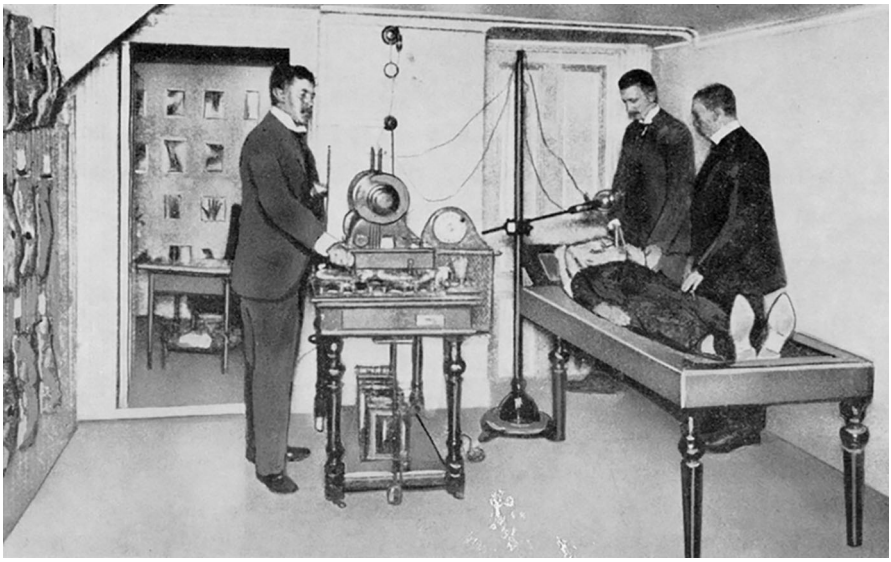

Fig. 1. Stenbeck's clinic in Stockholm, 1899. From left to right, Thor Stenbeck, Gösta Forssell and Georg Liljenroth and an unknown patient. It is characteristic of this period that patients are used for illustrative medical purposes, with attention only drawn to the medical actors. *Source*: *Wikimedia Commons* https://commons.wikimedia.org/wiki/Category:Thor_Stenbeck#/media/File:Thor_Stenbecks_r%C3%B6ntgeninstitut_1899.jpg. Cited September 27. 2023

At same time that the Viennese physicists were establishing the Institute for Radium Research in Vienna, Forssell and Berg institutionalized radiotherapy in Stockholm. Berg had contacted several of his friends and acquaintances to collect funds for his new institution, raising around 40,000SEK through these private benefactors.[36] In 1910, the pair purchased a building on Scheelegatan 10 in Stockholm to set up the first proper radiotherapy clinic for cancer treatment in the country under the name "Radiumhemmet",[37] with Forssell appointed as the clinic's director on the day of its inauguration: August 1, 1910.[38] Radiumhemmet, Swedish for "The Home of Radium," was constructed to provide a cozy and domestic atmosphere to put the patients at ease during their medical consultations and treatments.[39]

Already by 1916, the building at Schéelagatan became too small for Radiumhemmet's ever expanding activities. A new building at Fjällgatan 23 was acquired and fitted for clinical radiological work, doubling the amount of hospital beds.[40] Success at home was not enough without international visibility and support. Throughout the 1910s, Forssell was heavily involved in the international radiological community, visiting major radiological centers in Germany, Austria and France[41] at the same time he was continuing his research on X-ray imaging.[42]

One of Forssell's strongest qualities was his ability to seek out strong employees and talents.[43] Rolf Sievert was one of them. Sievert was born in 1896 in Sweden as the son of a wealthy German industrialist Max Sievert.[44] The younger Sievert developed an interest in physics and science and completed his bachelor of arts at Uppsala University in 1919. Also in 1919, Sievert would move to Stockholm and work as an assistant at the Nobel Institute's Academy of Sciences.[45] Five years later he completed his *filosofie licentiate*, equivalent to a doctorate, in physics at Stockholm University College (later Stockholm University).[46]

In 1920, Sievert undertook a private study trip to the US to study radiation physics. Around that time, Forssell was actively seeking out a physicist to plan and monitor radiation dosages at Radiumhemmet.[47] Forssell learned of the recently graduated Sievert through his colleague at Radiumhemmet, Gunnar Lundgren, who had heard of Sievert and his work on X-ray absorption at the Nobel Institute.[48] By happenstance, Forssell was also travelling in the US to study radiology, and Sievert and Forssell met by accident in New York.[49] Forssell and Sievert found they had a good rapport and decided to continue their tour in the US together. Following their return to Stockholm, Forssell made sure that Sievert was connected to Radiumhemmet, and by 1924 Sievert became the first director of the newly founded Radiophysics Laboratory.[50]

Establishing a radiophysics laboratory in a medical clinic was not an oddity. Although physicists and physicians had started a somewhat uneasy cooperation within the burgeoning field of radiology in the early 1900s,[51] by the 1920s, things had changed. The interdisciplinarity of radiotherapy required close cooperation of medical personnel, radiologists and physicists in order to communally address pressing questions on radiation protection and the standardization of radiation units. A major concern in this period was the intercomparison of dosimeters and the definition of a singular, practical radiation dose.[52] Guido Holzknecht, the leading Austrian physician in the field from the Vienna General Hospital,[53] had plied for the mobilization of physicists capable of addressing these issues in their laboratories already in 1915 as chair of a special commission of the German X-Ray Society on dosimeter comparison.[54] Forssell's decision to expand Radiumhemmet's activities by hiring Sievert was certainly also a step in this direction and was part of an international movement to refine and standardize radiological practice.

Indeed, Swedish radiologists had developed strong international connections to all major radiological centers in Europe and in the US. The most prominent of these countries was Germany, which by the 1920s had emerged as a leading radiology center,[55] with premier research institutions clustered around Hamburg with the Radiological Department of the General Hospital of St. George, the Physikalisch-Technische Reichsanstalt in Berlin and notably the University-Women's Clinic of Erlangen.[56] Swedish medical sciences were heavily aligned and oriented towards German research institutions in the interwar period, and, as such, developments taking place in Germany and the German-speaking countries also became important for Swedish radiologists.[57] It is indicative that a survey of all

publications* in the period from 1909–40 from Radiumhemmet's scientific personnel shows that 25% of all publications were published in German. The remaining texts were published in Swedish (26%), English (45%) and French (4%).[58]

A Tale of Two R-Units

At this junction, it is relevant to present the paradoxical situation, that by the mid-1920s, two different radiation standards, both named the "R-Unit" were being put forward by two of the main radiological centres of the world: France and Germany.** While both units were being propagated for the same reasons, namely the need to standardize radiation units and dosages through a single unified unit, their development also reveals national peculiarities that meant that not only were the standards technically incompatible, but also diplomatically.

To start with the chronologically first unit, the French unit had been developed by the French-Romanian medical physicist Iser Solomon in 1921, with strong support by the prominent French physician Antoine Béclère. As mentioned, France had been an early pioneer in the science of radiation through the groundbreaking work of the Curies and Henri Becquerel. However, by the mid-1920s, new medical actors—particularly Béclère and Solomon—seem to have taken over as the most prominent French representatives in the international scene.

The relationship between Béclère and Solomon was similar to that of Forssell and Sievert in Stockholm. Béclère had become a medical doctor in 1877 at the age of twenty-one,[59] and following the discoveries of Röntgen in 1895, had reoriented his career into the field of radiology. Béclère's strong engagement within the radiological community led him to be called "The father of French radiology."[60] Some of Béclère's accomplishments include being the co-founder of the French radiological society *Société de Radiologie Médicale de France* in 1908 as well as its first president,[61] and Béclère continued to be active within both the French and the international radiological community even after his retirement in 1921. Solomon had become a trusted colleague and aide to Béclère at the Saint-Antoine Hospital in Paris following the First World War.[62] Solomon was deeply interested in X-ray dosages, and would go on to become the director general of the Department of Radiology at Saint-Antoine in 1920.[63] In 1921, Solomon developed a radiation standard which he called the "R-unit," but which was also called the "Solomon-unit," to be measured through an "ionometer" instrument. This unit was calibrated

* This includes academic articles, non-academic articles, monographs and other contributions, as well as translations into other languages.

** In this article, we differentiate between the German and French "R-units" with an uppercase R, and the international "r-unit" as settled upon at the 1928 IRC, with a lowercase r.

to the emanations of a gram of radium through filtration,[64] and in this respect was a direct continuation of a French tradition dating back to the 1900s regarding radiation standardization. Various proposals, closely connected to or even suggested by Madame Curie herself, had been put forward in the first decade after the turn of the century, almost all tied directly to the emanations and weight of radium as their baseline.[65] With this R-unit, Solomon hoped that the many incompatible national standards could be unified through his instrument and radiation standard.[66]

Turning to Germany, the German "R-unit" also called the "Behnken-unit" was developed by the physicist Herman Behnken at the Physikalisch-Technische Reichsanstalt in Berlin in 1924. This radiation standard used an "air pressure chamber" of Behnken's design to measure the amount of radiation in the air and was constructed by the German company Siemens and Halske.[67] Like Solomon, Behnken hoped that with this new instrument and X-ray standard that a single unified unit could be settled upon, first within Germany through the standardization efforts of the German X-ray Society, and later, internationally.[68] Behnken's efforts to standardize dosages within Germany should be viewed in connection with the prevailing but controversial radiation unit the "unit skin dose," which by the early 1920s had become the de-facto radiation standard in clinical practice in Germany.[69] This dose, also known as the erythema dose and in German the *Hauteinheitdosis* (HED), referred to the exposure of a patient's skin to X-rays to elicit a distinctive reaction on the skin based on an arbitrary time scale. This was a simple and practical measurement that required no specialized equipment and allowed for rough comparisons between clinics.[70] However, the HED also led to conflict within the German radiological community between the physicians and physicists. The standard was well liked by the physicians because of its practicality, and disliked by the physicists, who found the dose imprecise. This led to persistent disagreements between the two sub-groups of the German radiological community. A foundational study from 1924 carried out by Leonhard Grebe and Heinrich Martius noted a four-fold difference of the radiation dosage administrated across different radiotherapy groups within Germany, all using the HED.[71] For the precision-minded medical physicists this was an unacceptable situation, with Grebe and Martius stating that based on their survey of fourteen German clinics the enormous difference observed meant that the HED was only usable when aligned with an "exact physical unit."[72] For their study, Grebe and Martius had used what they considered to be one such unit, namely Behnken's R-unit.

Returning to the prominence of German radiology in the interwar period, the case of the HED and the internal German debates provide an instrumental example. Sievert's work at Radiumhemmet in the 1920s confirms the heavy influence of the German medical debates in Sweden and internationally, as well as the burgeoning disagreements between the French and German radiologists on their respective R-units. In 1925, Sievert had travelled to the Physikalisch-

Technische Reichsanstalt in Berlin to calibrate the instruments of Radiumhemmet's Radiophysics Laboratory to Behnken's standard with the intention of introducing the German Unit to Sweden.[73] Upon his return to Stockholm, Sievert carried out a study of all radiological departments in Sweden using this new German unit, which was detailed in a 1926 paper.[74] Sievert was inspired by Grebe and Martius' 1924 study and similar research conducted by the American radiologist Ira J. Kaplan, that Sievert had read about in *The American Journal of Roentgenology*.[75] While Grebe and Martius had used the German R-unit, Kaplan, who had studied in both Germany and France with Béclère in the 1910s, had made a comparison of the HED as practiced in France and Germany using Solomon's R-unit, which he deemed to be the most suited to measure a "standard erythema dose."[76] Kaplan used a specially-calibrated ionometer to conduct his measurements that he had constructed in direct consultation with Solomon.[77] However, despite Kaplan's promotion of the French R-unit in his publications, Sievert chose to only highlight the German R-unit now familiar in the Swedish Medical System. Sievert went on to advocate for the introduction of single standard radiation unit, again only mentioning the German unit: "The Importance of the Introduction of a Standard Measurement, for instance the R-Unit [the German R-unit], can scarcely be underestimated. This introduction provides opportunities for direct comparisons of the knowledge on dosages gained at hospitals and laboratories, and thereby open the way for perfect statistical work, which of course are necessary steps for the investigation of any medical remedy."[78]

Sievert's and Forssell's interest in the standardization of radiation dosages led to the foundation of a new department at Radiumhemmet dedicated to periodic control of X-ray machines and dosages at all Swedish radiological departments.[79] In addition, Sievert was also engaged in a national Swedish committee at the Swedish Society for Medical Radiology on protection for working with X-rays and radium around this time.[80] As will become clear later, Forssell was positioning Sievert to gain experience and knowledge also to further the Swedish position in the international arena.

The differences between the French and German standards also revealed differences between the medical systems of each country and what was considered an appropriate medical dosage. These differences were summarized by Béclère at a speech at the Swiss Radiological Society in Lausanne in March 1925. In the speech, Béclère referred to the then recent study by Grebe and Martius from 1924, which he praised as very exact.[81] However, because of Grebe and Martius's use of the German-unit, Béclère could not help but point out the regrettable situation of having two standards both named the "R-unit" but based on totally different scientific principles. Building on Grebe and Martius's paper, Béclère also noted that there seemed to be a large difference between a single session of radiotherapy in France and one in Germany. Béclère highlighted that a German R-unit of "1"

was equivalent to "2.2" Solomon-units, and that the usual French dosage would be in the range of around 3,500 Solomon Units, equivalent to 1,590.9 German Units. Grebe and Martius, in their paper, had argued for a practical medical dose around 600 German units, or 1,320 Solomon units.[82] If these dosages were used in actual medical practice, this would have meant that a typical German dosage was less than half that administered in France.

The presence of the two R-units by the mid-1920s, sharing a name but based on vastly different principles and embedded within different national medical systems, was bound to cause conflict as the radiologists started to gather in the international arena. This was also the conclusion of Béclère at his speech in Lausanne. While decrying the now growing competition between the German and French radiologists and their differing R-units, Béclère was nonetheless optimistic. With the upcoming international radiological congress in London, he hoped an answer to the question of unifying radiation dosages could finally be found.[83] Unfortunately, Béclère would be disappointed.

The First Congress, 1925

The different standards, and the national interests vested in them, came to the forefront at the first International Congress of Radiology (IRC) held from June 30 to July 4, 1925 in London. The Congress was initiated by a cabal of British radiology groups, namely the British Röntgen Society, the Electro-Therapeutic Section of the Royal Society of Medicine and the British Institute of Radiology.[84] At this first meeting, several fundamental institutional and organizational decisions were enacted,[85] including the foundation of the IRC as an independent international body. The London Congress was heralded as "[…] a significant token of new collaboration between the nations for the promotion of common scientific work."[86]

Despite this importance, the Curie Laboratory and the Vienna Institute do not seem to have been represented at the Congress. France was represented by Béclère and Solomon,[87] which may explain the absence of the Curie laboratory. According to M. Campagnac, Principal Inspector of Administration at the French Hospital l'Assistance Publique to which the Sainte-Antoine Hospital belonged, Marie Curie was well-aware of Solomon and held him in high esteem.[88] Curie may therefore have felt that French interests, which in her mind were synonymous with the interests of the Curie Laboratory,[89] were already well represented at the IRC through Solomon's participation. Throughout the 1920s, Madame Curie was also very active within the "International Committee on Intellectual Cooperation" in the League of Nations,[90] possibly preventing her from taking part in another major international group at this time.

It seems no members of the Austrian Institute for Radium Research were present at the 1925 congress, at least none that gave papers.[91] Austria would be represented at the next congress in 1928 by Holzknecht,[92] but towards the end of

the 1920s Holzknecht was in very poor health and would undergo several surgeries before passing away in 1931,[93] unable to attend another congress (see Fig. 2).

While the ideals of scientific internationalism were very much present at the 1925 Congress, the impact of situated science diplomacy should also be considered. The issue of the unification of radiation standards and units were a battleground, especially for the French and German Delegations. At the congress on July 1, a special section was held on "Discussion on International Units and Standards for X-Ray Work". At this section, the tensions between the national approaches of the French, represented by Béclère, and the German Delegation, represented by Behnken, were realized and prompted a feud between these delegations. Both groups attempted to highlight what they considered to be the superior scientific principles of their own units, both arguing that their standard should be the considered as the "universal" unit. In his speech at the Congress, Béclère highlighted the Solomon-unit's precision and simplicity, while decrying the German Behnken-unit as complex and difficult to use. Béclère exalted the Solomon-unit as the universal standard, noting the practicality of using radium, a natural substance with a constant and unchanging radioactive emanation: "With a few milligrams of radium, the constructors and even the radiotherapists of all countries can themselves, with sufficient care, standardise their measuring instruments."[94]

Behnken responded in kind, highlighting that the German R-unit was designed to be reproduceable "anywhere and at any time."[95] While Behnken was not outwardly dismissive of the French standardization efforts, he nevertheless felt confident that his R-unit was the superior. Referencing the national image of German as practical and organized country, Behnken stated that: "[…] past experience tends to show that the German way is a practicable one and that it serves its purpose."[96] Compromise between the French and German Delegations seemed remote at this venture. However, this conflict also left the door open for the other participants of the congress to carry out negotiations to further their own ends.

As the 1925 congress drew to an end, it was decided that the IRC should convene every three years with the next congress to be held in Stockholm in 1928. Forssell was elected president of the IRC from 1925–28 as well as president of the executive committee for the 1928 Stockholm congress. This decision has been attributed to Forssell's strong standing within the international radiology community and his organizational abilities.[97] At the London Congress, it was also decreed that the British X-Ray Unit Committee should gather a group of experts to form the International X-Ray Unit Committee (IXUR)* to convene at the 1928 Stockholm Congress.[98] This decree has been characterized by Serwer as a reward

* From 1931 known as the International Commission on Radiation Units and Measurements (ICRU). In the interest of consistency, the abbreviation IXUR will be used in this article.

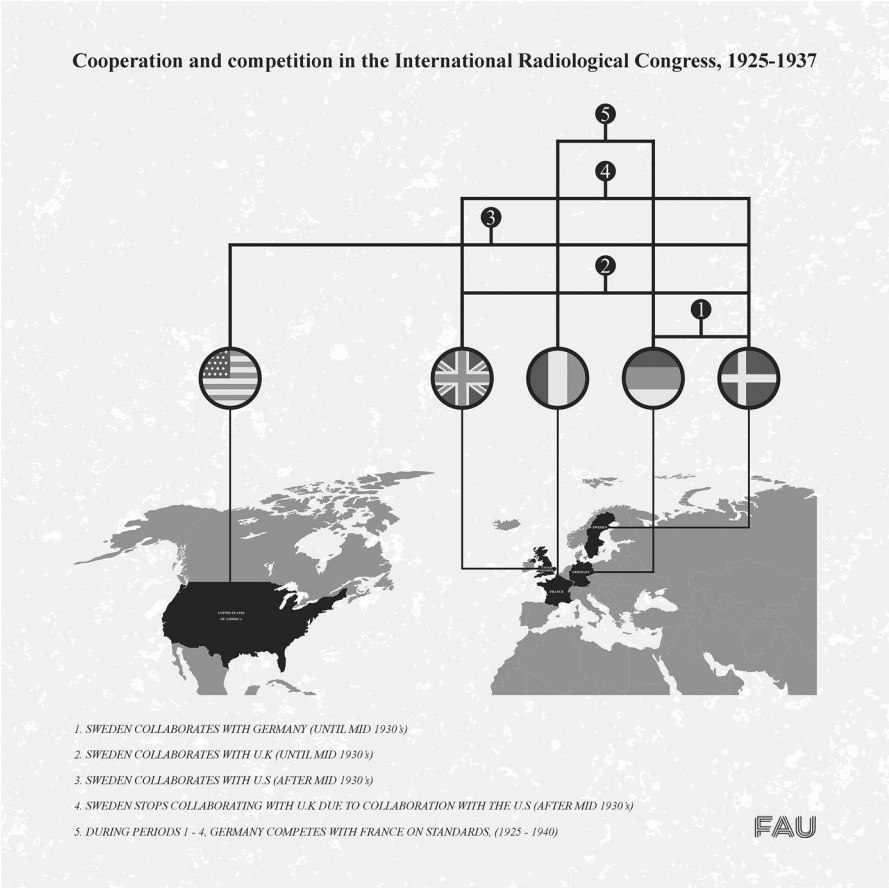

Fig. 2. Overview of collaborations in the International Radiological Congress in the interwar period. *Credit*: Commissioned by the authors from the designer Kyriacos Antoniadis

from the members of the IRC to the British delegation for not interfering in the feud between the French and German Delegations.[99] In effect, this allowed the British delegation to shape and appoint the first international group to formulate an X-ray unit that would be applied globally, a major scientific and diplomatic victory for the British. The British delegation quickly turned to another neutral but influential party of the Congress, namely, the Swedish delegation.

As part of the decrees from the London Congress, the secretary of the British Committee on Röntgen Measurement and Dosage at the British Röntgen Society E. A. Owen[100] was appointed to gather this new unit-committee. Owen wrote to Forssell sometime prior to May 29, 1926, requesting that Sweden, as one of the "principal countries of the world [on radiology]" should appoint two

representatives for the IXUR: "[one] a physicist and one a medical man."[101] Forssell replied to Owen on May 29 that the Swedish Society for Medical Radiology had appointed Nobel Prize winner Manne Siegbahn as the physicist and Sievert as the "medical man." Forssell asked Owen to direct further correspondence to Sievert, and noted that Sievert was not a physician, but in his capacity as leader of the Radiophysics Laboratory of Radiumhemmet, Sievert was in contact with "all the medical radiologists of the country [Sweden]."[102] Sievert was apparently not entirely satisfied with the "medical man" label as in a later letter to Owen in May 1931 he stated that "I remain the physical man."[103] Sievert's appointment to the IXUR granted the Swedish delegation a strong position in the international context to represent Swedish interests, particularly within the area of the standardization of radiation units, a topic both Sievert and Forssell were particularly interested in.

Prior to the 1928 Congress, negotiations were therefore already underway on radiation standardization within what would become the IXUR. However, the deeply intertwined issue of radiation protection was also becoming an international concern. In his letter from 1926, Owen had inquired with Forssell for information on the subject of "X-ray protection throughout the world," to which Forssell had replied that: "This question must undoubtedly be discussed at the International Congress in Stockholm 1928."[104] The subject was still on Forssell's mind a year later; in a letter to Owen from September 1927 Forssell pointed out that he expected the IXUR to formulate a proposal for the X-ray unit, and that he was interested in hearing about further developments on the topic of "the regulations for X-ray and Radium protection."[105] Forssell, and the Swedish delegation, were therefore actively pushing for the IRC to become engaged not only on radiation standardization but also on matters of radiation protection prior to the 1928 Congress.

Before and during the second Congress in 1928, negotiations on radiation protection and unit standardization continued. Between Sweden and Britain, respectful discussions were taking place, but the German and French feud on radiation units was still ongoing and flared up during a scientific controversy in 1926–27. In 1926, it was found that the German R-unit proposed by Behnken required different dosages to produce erythema of the skin in Germany and the USA,[106] calling into question the legitimacy and claimed universality of the German R-unit. During this conflict, Béclère and Solomon again attempted to put forward the Solomon unit as the more reliable and universal standard.[107] However, Behnken managed to avert the controversy by traveling to the US in 1927 and bringing the German and US instruments in line,[108] thereby reasserting the German R-unit's scientific legitimacy and universality.

* From 1931 this group would be called the International X-Ray and Radium Protection Commission and later the International Committee for Radiological Protection (ICRP).

The German–French feud did not go unnoticed by the other scientific actors. In a letter from Sievert to Owen in October 1927, Sievert noted that: "It seems as if steps are being taken in France to endeavour in a somewhat underhand manner to carry [Iser] Solomon's unit, but the general opinion in this country [Sweden] is not favourably disposed to towards it."[109]

Despite the controversy, the German R-unit was therefore still gaining favour in the international community. Sweden had already adopted the German unit through Sievert's standardization efforts following his visit to the Physikalisch-Technische Reichsanstalt in 1925. Just as importantly, as can be seen from Sievert's letter, the French unit was not appreciated in Sweden, a sentiment shared by the British delegation. In Sievert's letter to Owen, Sievert highlighted that the Swedish delegation was anticipating the "English stand-point [sic]," as the Swedish and British proposals for the 1928 congress were apparently very similar in content,[110] indicating that the British and Swedish agreed on the superiority of the German R-unit.

At the 1928 congress, no doubt disappointing Forssell, the IXUR's suggestions for X-ray and radiation standards were not finalized and explicitly labelled as "provisional."[111] Despite this, the IXUR felt confident enough to suggest a unit called the "Röntgen" designated by the lowercase "r" and based on Behnken's unit,[112] to be used as an interim standard. Siegbahn was named chairman of the IXUR, with Owen and Hermann Holthusen of the St. George Hospital of Hamburg serving as honorary secretaries.[113] Once again, this gave the Swedish delegation a leading position regarding the standardization of radiation units in the international arena. However, this was far from the only major development in Stockholm that year.

As president of the Executive Committee of the IRC, Forssell suggested that a new committee should be founded: the International X-Ray and Radium Protection Committee (IXRPC).*[114] Sievert was named chairman of the committee, with the other members being George W. C. Kaye and Stanley Melville of the UK, Giulio Cresole of Italy, G. Grossmann of Germany, Solomon as well as Lauritson S. Taylor of the USA. As an interim precaution, a set of protection regulations from the British X-Ray and Radium Protection Committee were accepted, to be further revised at the next congress in Paris in 1931. This suggestion came not surprisingly from Owen,[115] once again giving the British delegation a major stake in shaping international radiological developments through the support from the Swedish delegation.

The chairmanship of the IXRPC, especially for the 1928 congress, has in later histories been characterized as an honorific position, bestowed upon a member of the host country of the current congress. In practice, this meant that Kaye, not Sievert, dealt with the responsibilities of the chairman position from 1928 to the

* In the prewar period, the primary radiological journal of the host country was tasked with publishing materials from the congress.

next congress in 1931.[116] While this honorific aspect no doubt was present at the 1928 Congress, Sievert's appointment should also be seen in the larger diplomatic context of the Swedish push for international engagement in the IRC. Forssell was here a driving force, taking care to promote Sievert, his trusted colleague and collaborator, to several international positions. The IXRPC was founded on Forssell's initiative, with Sievert as chairman, and Sievert was appointed as the "medical member" of the IXUR despite Sievert having no medical background. Sievert's promotion to chair of the IXRPC should be interpreted as Forssell favorably positioning the Swedish delegation to have their interests represented at future congresses.[117] By 1928, the Swedish delegation was in leading positions of both the IXUR and the ICPRC, marking them as a major international actor within radiology.

The 1931 Congress held in Paris would mark a turning point for the question of radiation standards and protection. Béclère had been chosen as president of this congress, with Madame Curie serving as honorary president. In his opening speech, Béclère thanked Madame Curie for accepting the presidency as a rightful honor for her foundational research on radiation.[118] However despite this, Madame Curie does not seem to have been an active participant at the congress and curiously, she does not appear in any of the published photos of the congress in the French radiological journal *Journal de Radiologie et D'Electrologie*.*

At the 1931 Paris conference, the r-unit proposed at the 1928 congress was accepted and was deemed "satisfactory" as both Sievert and Serwer put it, in judgements expressed independently forty years apart.[119] The interim British radiation protection standards were also not substantially contested.[120] The only resistance to the IXUR's adoption of the German R-unit came, perhaps unsurprisingly, from the French delegation. In August 1931, just a month after the Paris Congress, Solomon published an article on "New ionometric research" in the *Journal de Radiologie et D'Electrologie*.[121] In this article, Solomon highlighted that new research as well as the controversies of the Stockholm Congress had been the impetus for him to draw new conclusions from previous research. Among several other aspects, Solomon highlighted that despite the objections he had raised prior to the Stockholm Congress, the IRC had still adopted the international r-unit based on the German standard.[122] Solomon criticized this adotion, stating that it was scientifically provable that his standard was more reliable than the German Behnken-unit.[123]

However, despite these objections, the French radiologists were increasingly being forced to adapt to the new international r-unit, for very material reasons. While the Solomon-unit continued to be the most widespread standard in France, by 1932 the international r-unit was increasing being adopted by manufacturers of small ionization chambers used in clinical practice in several countries.[124] With the proliferation of new instruments and equipment calibrated to the international r-

* This section is based on Taylor's later recollections of this period.

unit, the French radiological clinics were forced to make direct comparisons of the French and international standards, in order to correlate the international dosage given by the instruments they were using to the Solomon-unit which they were accustomed to.[125] Despite the reluctance of the French delegation, the international r-unit standard started to co-exist alongside the Solomon-unit towards the mid-1930s in France, further signaling an end to the heated debates of the 1920s.

By the fourth International Radiological Congress in Zürich in July 1934, there was less overt debate in the IXUR and the IXRPC regarding radiation standards, dosages and protection than in the Congresses of the 1920s. With the settlement of the r-unit, an imperfect but serviceable standard, as well as the new protection initiatives from the 1931 congress, the members of the IRC believed they had resolved the pressing questions of their community and could now move on from the heated debates of the 1920s.[126]

Enter, the Americans

The relative calm that had settled by the third and fourth congresses would be upset by the arrival of a new, unified, American delegation in the early 1930s. One actor was here central, namely, the aforementioned Lauritson S. Taylor.

Despite the many central radiological organizations in the US, the US delegation had found it difficult to establish common ground at the congresses of 1920s.* The reason for this was that no consensus existed within the USA, as different groups were feuding on what should be considered the proper approach. Especially the two main radiological institutes, the American Roentgen Ray Society and the Radiological Society of North America, disagreed on several foundational aspects.[127] The lack of any collected opposition by the US delegation at the Stockholm congress in 1928 had also allowed the British delegation in the IXRPC to put forward their radiation protection initiatives unopposed,[128] a major defeat for the Americans as they considered the British the main rivals in this context. For the US delegation, Sweden was seen as a more neutral party, that potentially could be persuaded to support other groups, as the British delegation had successfully done at previous Congresses (see Fig. 3).[129]

The US delegation's ascension must be ascribed to the herculean organizational efforts of Taylor. Taylor was not member of any of the feuding US groups, rather, he was an outsider who would come to play a decisive role in the US radiological system.[130] Taylor had joined the US National Bureau of Standards (NBS) in 1927 and was elected to represent the NBS at the Stockholm Congress the following year. Following what Taylor described as the "poor showing" of the US delegation in the IXRPC in 1928, Kaye had suggested that countries with more than one central institution on radiology should appoint a committee to represent their

* This Committee would later go on to become the National Committee on Radiation Protection (NCRP).

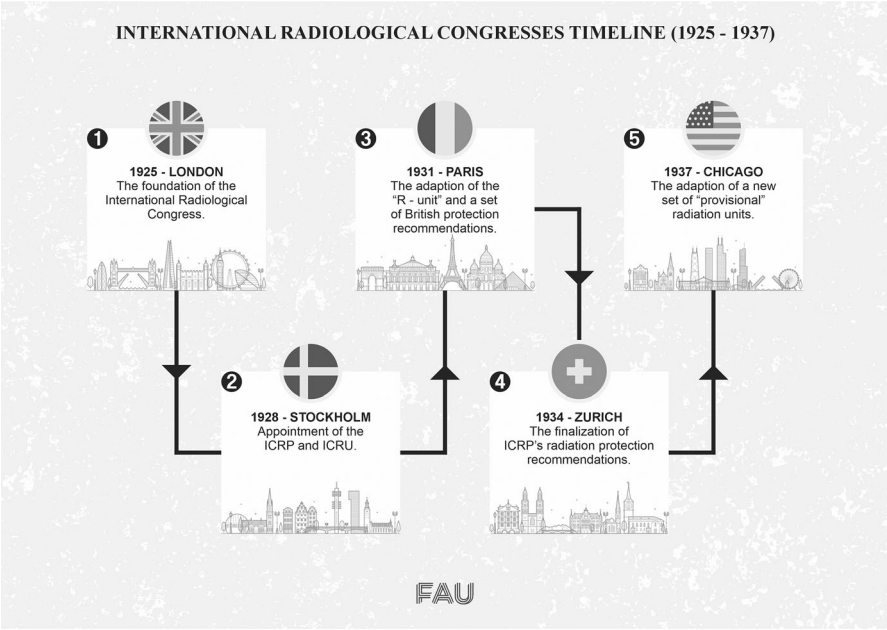

Fig. 3. Timeline of the International Radiological Congresses in the interwar period with major decisions. *Credit*: Commissioned by the authors from the designer Kyriacos Antoniadis

national interests at the IXRPC.[131] Taylor, as the US representative at the IXRPC, was tasked to mediate the discussions between the various US groups. He did just this. In September 1929, the Advisory Commi.ttee on X-Ray and Radium Protection* under the NBS was founded, and shortly thereafter Taylor was named its chairman.[132] The group included a physicist and radiologist from the American Roentgen Ray Society, the Radiological Society of North America, the American Medical Association, one representative from the NBS (Taylor) and two representatives from the X-Ray manufacturers.[133] A further "consolidation," again using Taylor's term, happened around 1935, where the committees on standardization and protection of the American Radium Society, the Roentgen Ray Society and the Radiological Society of North America all agreed to join together into one committee, once again chaired by Taylor under the NBS. By the 1930s the various groups and societies on radiation protection and standards in the US were now in total agreement,[134] guided by the leadership of Taylor. Taylor's ability to negotiate and mediate the interests and activities of various institutions and his strong connections to the US radiological community would also serve him well in the international landscape of the IRC.

In January 1931, Taylor was selected to represent the US at the IXUR along with E. C. Ernst.[135] As mentioned, Taylor was already a member of the IXRPC, meaning that the US was now well-represented in both of the IRC's main committees. Taylor wasted little time and already in February 1931 contacted Siegbahn to discuss "a number of features of X-ray standardization" as he hoped to present a paper on a comparison of standards between England, Germany, France and the US at the Paris congress.[136]

Prior to the fifth Congress in Chicago in September 1937, Taylor had assumed the role of secretary in a small but important sub-committee of the IXRPC that had been appointed at the Paris congress and held its first meeting in Zürich in 1934. The sub-committee was tasked with dealing with specific issues for the main committee, and consisted of Solomon as chairman, Taylor as secretary and Behnken, E. Pugno-Vanoni, Owen and Sievert as members.[137] However, while Solomon was the chair of the group, it seems that Taylor was playing a leading role, which was not appreciated by all members of the group. Following a January 1936 letter from Taylor to the members of the IXUR containing revisions of the committee's rules and regulations,[138] Sievert and Owen corresponded over their dissatisfaction with parts of the proposal as well as with Taylor's "leadership" of the group. Key to Owen's and Sievert's displeasure was Taylor's suggestion to increase the number of members of the executive committee of the IXUR from six to eight, of which four were supposed to come from members of the IRC and four from the individual national laboratories. Sievert characterized this as "a great mistake,"[139] as he felt that the work of IXUR should be confined to the "medico-physical experts" and exclude the outside interests of the national laboratories. Owen agreed.[140] Even more worrying for Owen and Sievert was Taylor's approach to these proposed changes. In his January letter, Taylor had suggested that the IXUR would go forward with these revisions "If no reply is received within a reasonable time."[141] Owen and Sievert believed this was a power-grab from Taylor, with Owen stating that: "[…] I was afraid when I was Zurich [at the 1934 IRC] that Taylor would like to have the matter in his own hands, and I have therefore not cared to interfere with him."[142] Owen added that he feared that Taylor's actions would be too headstrong and jeopardize the work already achieved by the IXUR. It should be noted, however, that Taylor was acting on instructions from the president of the 1937 congress A. C. Christie, who had found the rules and regulations of the IXUR "too loosely worded."[143] Perhaps Owens, as part of the British Delegation, also had ulterior motives to weaken Taylor's position within the IXUR, as will be detailed below.

Sievert would soon voice his concerns to Taylor directly in a letter written on behalf of himself and Elis Berven, the director of Radiumhemmet.[144] In the letter, Sievert highlighted that while the Swedish delegation agreed with the majority of Taylor's January proposal, the suggestion to increase the number of members from six to eight in the executive committee and to include the national

laboratories was untenable. Sievert and Berven reasoned that the work of the IXUR was "of a highly practical medical nature" and should therefore not be put in the hands of the "purely physical point of view of the National Laboratories." In addition, Sievert and Berven opined that Taylor's suggestion to pass any changes to the IXUR's rules and regulations, if no response was received in a timely matter, was unsatisfactory, arguing that: "No resolutions should be passed in the Main Committee [of the IXUR] except at meetings during the congresses."

Taylor responded to Sievert and Berven, stating that their objections were in accord with the other members of the IXUR, and the proposal would therefore not be passed. Taylor did however defend himself concerning the suggestion that if no response was received in "a reasonable time" the revision should be accepted, stating that some members of the IXUR rarely replied to or even acknowledged Taylor's communications, and that the work of the committee "require[d] positive advance action."[145]

Despite their disagreements, Taylor was still keen to have Sievert attend the 1937 Chicago Congress. However, Sievert was reluctant to do so because of the extensive reconfiguration of Radiumhemmet's laboratories and premises in the late-1930s, as Radiumhemmet was made part of the Karolinska Hospital.[146] Sievert had written as much to Gioacchino Failla, his friend and colleague of the Memorial Hospital in New York, stating that it was vital for him to stay in Stockholm to finalize the new institute. From Failla, Taylor learned that Sievert was not planning to attend the Chicago meeting and urged him to reconsider. In a letter that Taylor stressed was "personal" dated April 8, 1937, Taylor wrote that he considered it "very distressing news" that Sievert was not planning to attend in Chicago "in view of the very important matters that will come up before the I.C.R.U. [the IXUR]."[147] In particular, Taylor was concerned that Sievert's place on the sub-committee would have to be filled by another member, and worryingly for Taylor: "Also, there is the matter of the radium dosage unit. The English [the British delegation] are planning to push the adoption of the present roentgen and it will take some real opposition to prevent this. I personally feel that the use of the roentgen in this way is not yet justified and its present adoption may cause much future trouble."[148]

Taylor was therefore looking to persuade Sievert to side not with the British, as the Swedish delegation had done at earlier congresses, but with Taylor and the US delegation. The rivalry between the US and UK Delegations from the 1920s Congress was coming to the forefront again, and visible for all to see.

The British coup came just a month after Taylor's letter to Sievert. In May 1937, Taylor wrote to all members of the IXUR that: "1. I have just received from the British delegate a complete revision of the I.C.R.U [IXUR] Recommendations as adopted in Zurich [in 1934]. This includes a new definition of the roentgen, changes in quality specifications, radium dosage, and list of treatment factors."[149] Taylor pointed out that in fact, the British proposal had come too late to be

formally considered at the next IXUR meeting, however, "it is evident that they [the British delegation] wish to push for its adoption at this late date," forcing "every phase of the work […] to be reopened."[150]

Central to the disagreement between the US and UK Delegations was the issue of the level of specificity of the already adopted r-unit. The British proposal argued: "[…] that satisfactory evidence now exists for the adoption of a single unit, the röntgen [the r-unit], as the unit of quantity not only of X rays [sic] of all wavelengths, but also of gamma rays."[151] Taylor and the US delegation disagreed, arguing that the implementation of a specific, single unit for X-ray and gamma radiation was counterproductive. Taylor and the US delegation started a counteroffensive focusing on two main areas. Firstly, the US delegation tried to discredit the British group's scientific findings by highlighting apparent inconsistencies in the British experiments. Secondly, Taylor and the US delegation argued that the implementation of a new definition of the r-unit was unnecessary and of little practical importance.

In a communication to all members of the IXUR, Taylor forwarded statements made by the Memorial Hospital in New York as well as the American Roentgen Ray Society Standardization Committee regarding the British proposal in June 1937.[152] The Memorial Hospital focused on the British experiments, arguing that the experiments were in "substantial disagreement" with themselves and therefore could not support the proposed new r-unit definition. Specifically, it was argued that the results of the ionization emanations given in the British proposal were incompatible, and required further investigation in order to be wholly verified. The American Roentgen Ray Society instead focused on the "impracticality" of the British proposal, stating that: "[…] the need for a common unit for X-ray and gamma ray dosage is purely an academic question, of little or no clinical use."[153]

The American Roentgen Ray Society further argued that they did not agree with the British contention that sufficient evidence existed to show a common unit for X-ray and gamma radiation existed, ending their statement by highlighting that: "The general from of the report [the British proposal] is agreeable but its new material appears to be technically unsound in most cases."

Taylor and the US delegation prevailed with their counteroffensive against the British, as they succeeded in persuading Sievert, and thereby the Swedish delegation, to side with the US delegation ahead of the 1937 Chicago Congress. In a letter from August 18, 1937, just a few weeks before the inauguration of the Congress in Chicago, Sievert wrote to Taylor that: "As regards an international unit for radium dosage, I am still definitely of the opinion that the use of the r-unit is unsuitable, and attach the greatest importance to the memorandum, dated 29 June 1937, from the Memorial Hospital. I think that the recommendation of an international unit that is not suitable in every way would be deplorable, and for my part I hope that the Unit Committee [the IXUR] will desist from making any definite recommendations regarding γ-ray-units."[154]

Sievert added that Taylor should point out at the Congress that it would be "regrettable" for any adoption of an X-ray unit to proceed against the advice of two of the most experienced radiological institutions, those being the Memorial Hospital and Radiumhemmet.[155] Sievert therefore put the full scientific authority of the Swedish delegation behind Taylor and the US delegation, arguing against the British delegation's suggestion for the new r-unit. With Sievert's reorientation in 1937, the long-standing Swedish support of the British delegation in the IRC also ended.

The result of the fifth congress in 1937 was a compromise. The British proposal was not wholly rejected, as the 1937 proposal from the IXUR included the assertation from the British proposal that sufficient evidence existed for the r-unit to cover both x-ray and gamma radiation. However, the proposal also differed from the British in its technical details, and it was stressed that: "It is proposed that this definition [at the 1937 congress] be regarded as provisional and that a more exact definition to include all classes of radiation be prepared for the next Congress."[156]

With negotiations stalled, members of the IXUR wished to continue their discussions at the next congress to be held in July–August 1940 in Berlin. Behnken, as one of the organizers of the 1940 Congress, wrote to all the members of the IXUR in July 1939, highlighting the still unresolved issue of the r-unit standard inherited from the 1937 Chicago Congress.[157] In his letter, Behnken stressed that this issue required special attention from the group. However, with the outbreak of the Second World War in Europe, the 1940 Congress was prevented from taking take place, leaving the r-unit issue unresolved.

Conclusion

The case of the International Radiological Congress in the interwar period shows that the scientific practice of standard setting is far from a neutral process. Rather, standard making in an international context is also a deeply diplomatic activity, where actors and groups negotiate and compromise, as well as using different diplomatic tactics like persuasion and calls to (scientific) authority to achieve their goals. Alliances were made and broken, and scientific actors resisted and contested other actors' findings, experimental methods and suggestions in order to further their own scientific agendas. The search for standards is therefore not only a deeply scientific process, but also a diplomatic one.

After the formation of the first centres of research and standard setting in radiation with the Curie Laboratory and the Austrian Institute for Radium Research in the late 1890s and early 1900s, new centres came to prominence in both national and international contexts. The period from the 1900s to the 1910s saw the foundation of several clinics and research institutions concerned with radiation and radiology, with groups in Germany, France, Sweden, the USA and Great Britain becoming instrumental. With the International Radiological

Congress in London in 1925, founded on a British initiative, the first major steps for international cooperation on standard setting and radiation protection were being undertaken. In 1928, by setting-up the International X-Ray Unit Committee (IXUR) and the International X-Ray and Radium Protection Committee (IXRPC), the International Radiological Congress had taken major steps in assigning and appointing members and experts to tackle the difficult questions of how to standardize, measure and protect against radiation in a clinical and radiological context.

Despite the prominence of the early scientific actors like the Curies and the Austrian Institute, these groups and scientists seem to have fallen into the background and did not play any major role in the ensuing scientific and diplomatic negotiations. Instead, it was the new centres, often led by a newer generation of physicists and physicians, like Solomon, Behnken, Sievert and Taylor, that would take charge. These new groups and actors in the USA, France, Sweden, Germany and the UK would establish bilateral connections, carrying out negotiations both at and prior to the congresses to seek out support and help to promote their own standards and goals within the sub-committees of the International Radiological Congress.

During the first three congresses in 1925, 1928 and 1931, the British delegation remained outside the heated discussions of the German and French delegations, relying on the support of the Swedish delegation to achieve their goals. Through a mutually beneficial exchange, the British delegation paved the way for the Swedish radiologists to be represented at central positions at the congress, for instance by inviting the Swedish delegates to sit on the International X-Ray Unit Committee. The British and Swedish groups were largely in agreement throughout the 1920s, in sharp contrast to the German and French delegations, who openly feuded on the issue of radiation standards for almost a decade. At the 1931 congress, with the consensus on the "r-unit" standard based on the German unit developed by Behnken, it seemed that the debates of the 1920s would subside. However, the advent of the unified US delegation led by Lauriston S. Taylor would disrupt this equilibrium. The US delegation seemed opposed to the British radiation protection initiatives from 1928, and was even more vehemently against the British suggestion of expanding the r-unit to include gamma radiation prior to the 1937 congress in Chicago. Through a counteroffensive, the US delegation led by Taylor succeeded in convincing Sievert and the Swedish delegation to oppose the British suggestion, ending the decade long alliance between the Swedish and British groups.

What the consequences of the new alliance between the Swedish and American delegations would have led to at the Berlin congress must remain unknown because of the outbreak of the Second World War. It seems probable that like Béclère and Solomon returning to the fray in 1926, the British delegation would have again attempted to push forward their suggestion for an inclusive r-unit that would combine X-ray and gamma radiation. It seems equally probable that the

Swedish and American delegations would have continued to oppose this. Whether a compromise could have been reached—and what form this would have taken—is difficult to say. The Second War World meant that many of the leading actors of the interwar period were called to assist their respective countries during the war, and others passed away just before or during the war. The French delegation suffered two serious blows, as both Solomon and Béclère died in 1939, in January and February respectively. Sievert and Taylor were both called to help in the war effort of their respective countries, preventing them from continuing their work on radiation standardization and protection.[158] During the war, Taylor assumed the responsibility for both the IXUR and the IXRPC,[159] however, the work of these groups was essentially dormant. This is not to say that there were no developments on radiation standardization and protection in these countries, rather that these developments were mostly divorced from any international collaboration.[160] However, the foundational initiatives of the interwar period would also be present postwar, as many of the same actors and groups reinitiated their work on radiation standardization and radiation in an international context after the end of the war.[161] .

Acknowledgements

This publication is part of the "Living with Radiation: The Role of the International Atomic Energy Agency in the History of Radiation Protection" (HRP-IAEA) project that has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (Grant agreement No770548).

Funding

Open Access funding enabled and organized by Projekt DEAL.

References

[1] Bettyann Kevles, *Naked to the Bone: Medical Imaging in the Twentieth Century* (New Brunswick: Rutgers University Press, 1997), 2. The literature on the history of X-rays is vast. For illustrative examples see: Richard Mould, *A Century of X-Rays and Radioactivity in Medicine* (London: CRC Press, 1993); Christiane Nockels Fabbri, *From Anesthesia to X-Rays: Innovations and Discoveries That Changed Medicine Forever* (London: Bloomsbury Academic, 2017); W. David Lee, Jeffrey Drazen, Phillip A. Sharp and Robert S. Langer, *From X-Rays to DNA: How Engineering Drives Biology* (Cambridge: MIT Press, 2014); Matthew Lavine, *The First Atomic Age* (New York: Palgrave Macmillan US, 2013); Jeffrey Womack, *Radiation Evangelists: Technology, Therapy and Uncertainty at the Turn of the Century* (Pittsburgh: University of Pittsburgh Press, 2020).

[2] Kevles, *Naked to the Bone* (ref. 1), 2.

[3] In accordance with Professor Marie Curie's own wishes, we refer to her as "Madame Curie." See Stanley W. Pycior, "'Her Only Infidelity to Scientific Research': Marie Skłodowska Curie and the League of Nations," *The Polish Review* **41**, no. 4 (1996), 449–67, on 451.

[4] Maria Rentetzi, *Trafficking Materials and Gender Experimental Practices: Radium Research in Early Twentieth Century Vienna* (New York: Columbia University Press, 2007), 2.

[5] Maria Rentetzi, *Seduced by Radium: How Industry Transformed Science in the American Marketplace* (Pittsburgh: University of Pittsburgh Press, 2022), chapter 6.

[6] Maria Rentetzi, "Gender, Politics, and Radioactivity Research in Interwar Vienna: The Case of the Institute for Radium," *Isis* **95**, no. 3 (2004), 359–93, on 363–65; Rentetzi, *Trafficking Materials* (ref. 4), 34

[7] Rentetzi, *Seduced by Radium* (ref. 5), 35–36, 190.

[8] Rentetzi, "Gender" (ref. 6), 365; Soraya Boudia, "The Curie Laboratory: Radioactivity and Metrology," *History and Technology* **13**, no. 4 (1997), 249–65.

[9] Boudia, "The Curie Laboratory" (ref. 8), 257–58.

[10] Thomas Mougey, "Negotiating the Norms of an International Science: Standardization Work at the International Geological Congress, 1878–1891," *The British Journal for the History of Science* **56**, no. 4 (2023), 435–51, on 436–37; Anne G. Hanley, "Men of Science and Standards: Introducing the Metric System in Nineteenth-Century Brazil," *Business History Review* **96**, no. 1 (2022), 17–45, on 19–20.

[11] N. B. Uvelius Hansson, T. Halling and F. H. Moll, "'Warum besucht man Kongresse?': Deutsch-schwedischer Wissenstransfer am Beispiel des DGU-Kongresses in München 1929," *Der Urologe* **57** (2018), 198–206, on 204.

[12] Boudia, "The Curie Laboratory" (ref. 8), 256.

[13] Maria Rentetzi, "Designing (for) a New Scientific Discipline: The Location and Architecture of the Institut Für Radiumforschung in Early Twentieth-Century Vienna," *The British Journal for the History of Science* **38**, no. 3 (September 2005), 275–306, on 283–84.

[14] Boudia, "The Curie Laboratory" (ref. 8), 261.

[15] Cynthia Gillian Jones, "A Review of the History of U.S. Radiation Protection Regulations, Recommendations, and Standards," *Health Physics* **88**, no. 6 (2005), 697–716, on 698.

[16] "The First International Congress," *British Journal of Radiology* **30**, no. 301 (August 1925), 283–94, on 283–84.

[17] Albert Soiland, "First International Congress of Radiology," *Radiology* **5**, no. 3 (1925), 261–62, on 261.

[18] Soiland, "First International Congress" (ref. 17), 261.

[19] Daniel Paul Serwer, *The Rise of Radiation Protection: Science, Medicine and Technology in Society 1896–1935* (Upton, Brookhaven National Laboratory, 1976), 202–3 and 216.

[20] Maria Rentetzi, "Living with Radiation or Why do we need a Diplomatic Turn in History of Science," *Kjemi* **6**, (2017), 21–24.

[21] In particular, the ERC-funded project "Living with Radiation" has focused on the importance of international organizations like the International Atomic Energy Agency (IAEA) in the postwar period in creating radiation standards and radiation protection initiatives on a global scale. See Maria Rentetzi, "A Diplomatic Turn in History of Science or How a 2 Million Euro European Research Council Grant Offers New Perspectives on the History of Radiation Protection," *Newsletter of the History of Science Society* (2018); Maria Rentetzi, "The Politics of Radiation Protection," *NTM Zeitschrift Für Geschichte Der Wissenschaften, Technik Und Medizin* **30**, (June 2022), 125–35; Aske Hennelund Nielsen, "From Radiology to a World-in-Crisis: Rolf Sievert and the Re-Orientation of the International Commission on Radiation Protection in the Post-War Period," *Medical History* (Upcoming).

[22] See, for instance, Vivien Hamilton "X-ray Protection in American Hospitals," in *Inevitably Toxic: Historical Perspectives on Contamination, Exposure, and Expertise*, eds. Janet Farrell Brodie, Brinda Sarathy, and Vivien Hamilton (Pittsburgh: University of Pittsburgh Press, 2018), 23–49; Charles Hayter, "Tarnished Adornment: The Troubled History of Québec's Institut du Radium," *Canadian Bulletin of Medical History* **20**, no. 2 (2003), 343–65; Ornella Moscucci, "The 'Ineffable Freemasonry of Sex': Feminist Surgeons and the Establishment of Radiotherapy in Early Twentieth-Century Britain," *Bulletin of the History of Medicine* **81**, no. 1 (2007), 139–63; Maurice Tubiana, Jean Dutreix and Bernard Pierquin, "One Century of Radiotherapy in France 1896–1996," *International Journal of Radiation Oncology, Biology, Physics* **35**, no. 2 (1996), 227–42. For a general introduction to the development of radiology and radiotherapy in first decades of the twentieth century, see John V. Pickstone, "Contested Cumulations: Configurations of Cancer Treatments through the Twentieth Century," *Bulletin of the History of Medicine* **81**, no. 1 (Spring 2007), 164–96 and Charles R. Hayter, "The Clinic as Laboratory: The Case of Radiation Therapy, 1896–1920," *Bulletin of the History of Medicine* **72**, no. 4 (1998), 663–88.

[23] Serwer, *The Rise of Radiation Protection* (ref. 19).

[24] Boudia, "The Curie Laboratory" (ref. 8), 258.

[25] Otha W Linton, "History," *International Society of Radiology*, https://web.archive.org/web/20120424025448/http://www.isradiology.org/isr/about_02.php. Archived by the Internet Archive from the International Society of Radiology website. Linton incorrectly states that the congress was supposed to have taken place in 1941 and not 1940.

[26] Rentetzi, *Trafficking Materials* (ref. 4), 60–71.

[27] Moritz Simon, "Stray Remarks on the History of Medical Radiology in Sweden," *Acta Radiologica* **7**, nos. 1–6 (1926), 476–90, on 476–77.

[28] Simon, "Stray Remarks" (ref. 27), 477.

[29] Bo Lindell, *Pandora's Box* (Nordic Society for Radiation Protection, 2019), 57.

[30] Hans Weinberger, *Sievert: enhet och mångfald* (Stockholm: KTH, 1990), 19.

[31] Åke Åkerlund, "Gösta Forssell, 1876–1950: To the Memory of His Life and Work," *Acta Radiologica Supplement* **45**, no. 131 (1956), 2–50, on 6–7.

[32] Åkerlund, "Gösta Forssell" (ref. 31), 6.

[33] Weinberger, *Sievert* (ref. 3), 20.

[34] Åkerlund, "Gösta Forssell" (ref. 31), 8.

[35] Gösta Forssell, "The Early History of the Jubilee Clinic," *Acta Radiologica Supplement* **20**, no. 38 (1939), 5–11, on 5.

[36] Forssell, "The Early History of the Jubilee Clinic" (ref. 35), 5; Elis Berven, Sven Hultberg, Hans-Ludvig Kottemier, Rolf Sievert, Lars Santesson, Bengt Sylvén, "The First Fifty Years: Radiumhemmet 1910–1937 and King Gustaf V. Jubilee Clinic 1938–1960," *Acta Radiologica Supplement* **250** (1965), 1–198, on 18.

[37] Berven et al., "The First Fifty Years" (ref. 36), 16, figure 4.

[38] Berven et al., "The First Fifty Years" (ref. 36), 18. Åkerlund, "Gösta Forssell" (ref. 31), 7–8. Forssell directed Radiumhemmet until 1920. Note that Åkerlund says that Radiumhemmet was opened on July 1.

[39] Weinberger, *Sievert* (ref. 30), 21.

[40] Fjällgatan continued to form the premises for Radiumhemmet until 1937/38, when Radiumhemmet was moved to the premises at the Karolinska Hospital, the main hospital system of Stockholm. As part of this move, Radiumhemmet was also made part of the newly founded King Gustaf V Jubilee Clinic. See Berven et al., "The First Fifty Years" (ref. 36), 32–38.

[41] Åkerlund, "Gösta Forssell" (ref. 31), 8; Weinberger, *Sievert* (ref. 30), 20.

[42] For instance defending his master's thesis: *Über die Beziehung der Röntgenbilder des menschlichen Magens zu seinem anatomischen Bau* in 1913. See Åkerlund, "Gösta Forssell" (ref. 31), 9–10.

[43] For instance, the Red Cross Sister and nurse Alma Wallengren, who was the manager of Radiumhemmet from 1909–23 and was described as Forssell's "right hand." See Åkerlund, "Gösta Forssell" (ref. 31), 8; Berven et al., "The First Fifty Years" (ref. 36), 17, figure 6.

[44] Weinberger, *Sievert* (ref. 30), 27–28.

[45] Weinberger, *Sievert* (ref. 30), 33.

[46] Weinberger, *Sievert* (ref. 30), 29–30.

[47] Berven et al., "The First Fifty Years" (ref. 36), 25.

[48] Weinberger, Sievert (ref. 30), 33, need to.

[49] Weinberger, Sievert (ref. 30), 33. Berven et al., "The First Fifty Years" (ref. 36), 25,.

[50] Weinberger, Sievert (ref. 30), 38. Åkerlund, "Gösta Forssell" (ref. 31), 12.

[51] Rentetzi, *Trafficking Materials* (ref. 4), 60 and 69.

[52] An overview by Gleßmer-Junike shows over twenty-five different dosimeters developed in the period from 1896–1926. Simone Gleßmer-Junike, "X-Strahlen, Radiometer und Hauteinheitsdosis: die Entwicklung der Messverfahren und Maßeinheiten für Röntgenstrahlung in der medizinischen Physik von den Anfängen bis zur internationalen Standardisierung" (Staats- und Universitätsbibliothek Hamburg Carl von Ossietzky, 2015), PhD Dissertation, 203.

[53] Rentetzi, "Gender" (ref. 6), 366.

[54] Vorsitzenden [Guido Holzknecht], "Arbeiten und Verhandlungen der Sonderkommission für Dosimetervergleich der Deutschen Röntgengesellschaft," *Fortschritte auf dem Gebiete der Röntgenstrahlen* **23**, no. 1 (1915–16), 213–14, on 213.

[55] Serwer, *The Rise of Radiation Protection* (ref. 19), 15. For the foundational work in Austria, see Rentetzi, "Gender" (ref. 6), 365–66.

[56] The Women's Clinic of the University of Erlangen served as a major experimental center for determining and defining radiation doses. See Wolfgang Frobenius, *Röntgenstrahlen statt Skalpell* (Erlangen, Universitätsbund Erlangen-Nürnberg e.V., 2003).

[57] This is consistent with the findings of Nils Hansson, Friedrich Moll, Thorsten Halling and Bengt Uvelius, "Scientific language trends among Swedish urologists and surgeons 1900–1955," *World Journal of Urology* **37** (2019), 979–81.

[58] Publications culled from Berven et al., "The First Fifty Years" (ref. 36), 141–57.

[59] "Obituary: Dr. Antoine Béclère," *The British Journal of Radiology* **12**, no. 137 (May 1939), 319–20 on 319.

[60] R. Ledoux-Lebard, "Antoine Béclère: Le Père de la Radiologie française (1856–1939)," *Journal de Radiologie et D'électrologie* **23**, no. 12 (1939–1940), 529–32, on 530.

[61] Gösta Forssell, "Antoine Béclère," *Acta Radiologica* **20**, no. 6 (1939), 521–36, on 534.

[62] Antoine Béclère, Georges Bourguignon, Cottenot and M. Campagnac, *I. Solomon 1880–1939* (Imp. Lahure, 1939), 6.

[63] Béclère et al., *I. Solomon* (ref. 62), 7.

[64] Serwer, *The Rise of Radiation Protection* (ref. 19), 206–7 and 222–23.

[65] Boudia, "The Curie Laboratory" (ref. 8), 255–56.

[66] Iser Solomon, "Dosage des rayons de Röntgen par la méthode ionométrique," *Journal De Radiologie* **10** (1921), 49–59, on 55.

[67] Serwer, *The Rise of Radiation Protection* (ref. 19), 168–69; Hermann Behnken, "Die Eichung von Dosismessern in absolutem Maße in der Physikalisch-technischen Reichsanstalt," *Fortschritte auf dem Gebiete der Röntgenstrahlen* **32** (1924), 92–94, on 93.

[68] Behnken, "Die Eichung von Dosismessern in absolutem Maße" (ref. 67), 94.

[69] Serwer, *The Rise of Radiation Protection* (ref. 19), 166.

[70] Serwer, *The Rise of Radiation Protection* (ref. 19), 166

[71] Serwer, *The Rise of Radiation Protection* (ref. 19), 166–167 and 186.

[72] L. Grebe and H. Martius, "Vergleichende Messungen über die Größe der zur Erreichung des Hauterythems gebräuchlichen Röntgenstrahlenmengen," *Strahlentherapie* **18** (1924), 396–409, on 409. Translation by the authors.

[73] Weinberger, *Sievert* (ref. 30), 42–43.

[74] Rolf M. Sievert, "Untersuchungen über die an verschiedenen Schwedischen Krankenhäusern zur Erreichung des Hauterythems Gebräuchlichen Röntgenstrahlenmengen, unter Einführung der R-Einheit," *Acta Radiologica* **7**, nos. 1–6 (1926), 461–472 on 461–462.

[75] Weinberger, *Sievert* (ref. 30), 42–43. For Kaplan see Sidney Rubenfeld, "Ira I. Kaplan, M.D.," *Radiology* **81**, no. 1 (1963), 138–139.

[76] Ira J. Kaplan, "Comparison entre la Dose Érythème française et la dose érythème Allemande: Mesurée par l'iontoquantimètre Solomon," *Journal de Radiologie et D'électrologie* **9**, no. 2 (1925), 88–90, on 88.

[77] Kaplan, "Comparison" (ref. 76), 90.

[78] Sievert, "Untersuchungen" (ref. 74), 463 and 472. "Die Bedeutung der Einführung eines Standardmasses [sic], wie z. B. der R-Einheit, kann kaum überschätzt werden. Sie gibt die Möglichkeit zu direkten Vergleichen der an den Krankenhäusern und Laboratorien in Bezug auf die Dosierung gemachten Erfahrungen, und eröffnet somit den Weg für einwandfreie statistische Arbeiten, welcher Weg ja bei den Untersuchungen eines jeden Heilmittels notgedrungen betreten werden muss." Translation by the authors.

[79] Weinberger, *Sievert* (ref. 30), 43.

[80] Letter from Sievert to Hansen, dated September 6, 1927 in Karolinska Institute: Institutionen för radiofysik 1924–1965. Archive number 49:2, F2, package number 1. Hereafter referred to as "Karolinska."

[81] Antoine Béclère, "L'érythème cutané et la dose dite d'érythème en radiothérapie," *Journal de Radiologie et D'électrologie* **9**, no. 6 (1925), 275–83.

[82] Béclère, "L'érythème" (ref. 81), 280–81.

[83] Béclère, "L'érythème" (ref. 81), 282.

[84] "Editorial Notes: The First International Congress of Radiology in London, June 30th–July 4th 1925," *Acta Radiologica* **4**, no. 4 (1925), 386–88, on 387. Serwer, *The Rise of Radiation Protection* (ref. 19), 214.

[85] Serwer, *The Rise of Radiation Protection* (ref. 19), 220.

[86] *Acta Radiologica*, "Editorial Notes" (ref. 84), 386.

[87] "International Congress of Radiology," *British Journal of Radiology* **30**, no. 299 (1925), 199–239, on 210 and 218; Gösta Forssell, "Erster Internationale Radiologen-Kongreß," *Fortschritte auf dem Gebiete der Röntgenstrahlen* **33** (1925), 797–800, on 797.

[88] Béclère et al., *I. Solomon* (ref. 62), 25–26.

[89] Boudia, "The Curie Laboratory" (ref. 8), 252–53.

[90] Pycior, "Her Only Infidelity" (ref. 3), 449.

[91] *The British Journal of Radiology*, "International Congress of Radiology" (ref. 87), 199–218.

[92] "General Programme," *Acta Radiologica Supplement* **9**, no. 3.1 (1928), 10–18, on 12.

[93] "Professor Holzknecht," *The British Journal of Radiology* **4**, no. 48 (1931), 723–24, 723.

[94] Antoine Béclère, "On International Standardisation of Measures in Röntgentherapy," *The British Journal of Radiology BIR Section* **23**, no. 91 (1927), 66–72, on 70–71.

[95] Hermann Behnken, "The German Unit of X-Radiation," *The British Journal of Radiology BIR Section* **23**, no. 91 (1927), 72–77, on 72.

[96] Behnken, "The German Unit" (ref. 95), 77.

[97] Lindell, *Pandora's Box* (ref. 29), 122; Åkerlund, "Gösta Forssell" (ref. 31), 12.

[98] Letter from Owen to Sievert, dated November 18, 1926 in Karolinska, F2, package number 1.

[99] Serwer, *The Rise of Radiation Protection* (ref. 19), 218.

[100] Lindell, *Pandora's Box* (ref. 29), 118.

[101] Owen to Sievert (ref. 98). It seems Owen's original letter to Forssell has not been archived, but Forssell's reply has.

[102] Owen to Sievert (ref. 98).

[103] Letter from Sievert to Owen, dated May 20, 1931 in Karolinska, F2, package number 1.

[104] Letter from Forssell to Owen, dated May 29, 1926 in Karolinska, F2, package number 1.

[105] Letter from Forssell to Owen, dated September 25, 1927 in Karolinska, F2, package number 1.

[106] Serwer, *The Rise of Radiation Protection* (ref. 19), 221–22.

[107] Serwer, *The Rise of Radiation Protection* (ref. 19), 222–23.

[108] Serwer, *The Rise of Radiation Protection* (ref. 19), 223.

[109] Letter from Sievert to Owen, dated October 1, 1927 in Karolinska, F2, package number 1.

[110] See also Lauritson S. Taylor, "Reminiscences About the Early Days of Organized Radiation Protection," in *Health Physics: A Backward Glance*, eds. Ronald L. Kathren and Paul L. Ziemer (New York: Pergamon Press, 1980), 113.

[111] "Recommendations of the International X-Ray Unit Committee," *Acta Radiologica Supplement* **9**, no. 3.1 (1928), 60.

[112] Serwer, *The Rise of Radiation Protection* (ref. 19), 223,.

[113] "Protocols for the Meetings of the Executive Committee of the International Radiological Committee 23rd, 24th, 25th, 26th and 27th July, 1928," *Acta Radiologica Supplement* **9**, no. 3.1 (July 1928), 46–49, on 48,.

[114] *Acta Radiologica*, "Protocols" (ref. 113), 48–49.

[115] *Acta Radiologica*, "Protocols" (ref. 113), 47–48.

[116] Bo Lindell, "The History of Radiation Protection," *Radiation Protection Dosimetry* **68**, no. 1/2 (1996), 83–95, on 84; R.H. Clarke, and J. Valentin, "The History of the ICRP and the Evolution of its Policies," *Annals of the ICRP* **39** (2009), 75–110, on 78.

[117] This seems especially likely, since several of the other members of what would become the IXRPC, notably Kaye, Melville and Taylor, had been in active discussions on radiation protection prior to the IXRPC being formed. Sievert was less involved until after he became a member of the group, suggesting that the position was offered to him by Forssell and Sievert did not seek it out independently. Taylor, "Reminiscences" (ref. 110), 113.

[118] Antoine Béclère, "III Congrès International de Radiologie: Séance inaugurale du lundi 27 Juillet 1931," *Journal de Radiologie et D'électrologie* **15**, no. 11 (1931), 615–20, on 615.

[119] Serwer, *The Rise of Radiation Protection* (ref. 19), 224; Letter from Sievert to Owen, dated January 16, 1931 in Karolinska, F2, package number 1.

[120] Letter from Sievert to Kaye, dated January 15, 1931 in Karolinska, F2, package number 1.

[121] Iser Solomon, "Nouvelles Recherches Iconométriques," *Journal de Radiologie et D'électrologie* **15**, no. 8 (August 1931), 432–41, on 432. The authors' translation.

[122] Solomon, "Nouvelles Recherches Iconométriques" (ref. 121), 437.

[123] Solomon, "Nouvelles Recherches Iconométriques" (ref. 121), 439.

[124] A. Gunseet and J. Meyer, "L'ionomètre de Hammer et le rapport entre l'unité R-Solomon et l'unité R-Internatonale," *Journal de Radiologie et D'électrologie* **16**, no. 2 (1932), 53–58, on 53–55.

[125] Gunseet and Meyer, "L'ionomètre de Hammer" (ref. 124), 54–55.

[126] J. Samuel Walker, *Permissible Dose: A History of Radiation Protection in the Twentieth Century* (Berkely: University of California Press, 2000), 8.

[127] Lauriston S. Taylor, "Brief History of the National Committee of Radiation Protection and Measurements (NCRP) Covering the Period 1929–1946," *Health Physics* **1,** no. 1 (1958), 3–10, on 3; Taylor, "Reminiscences" (ref. 110), 112.

[128] Taylor, "Brief History" (ref. 127), 3.

[129] Taylor, "Reminiscences" (ref. 110), 113.

[130] Lauritson S. Taylor, *X-Ray Measurements and Protection 1913–1964: The role of the National Bureau of Standards and the National Radiological Organizations* (Washington DC: National Bureau of Standards, December 1981), 28–29.

[131] Taylor, "Brief History" (ref. 127), 4. Taylor erroneously lists Kaye as the chairman of the IXRPC in this publication.

[132] Taylor, "Brief History" (ref. 127), 4.

[133] Taylor, "Brief History" (ref. 127), 4,.

[134] Taylor, "Reminiscences" (ref. 110), 117.

[135] Letter from Albert Soiland to Siegbahn, dated January 29, 1931 in Karolinska, F2, package number 1.

[136] Letter from Taylor to Siegbahn, dated February 4, 1931 in Karolinska, F2, package number 1.

[137] Report of the Executive Committee of International Commission on Radiological Units in Karolinska, F1, package number 84, file V-D 4a.

[138] Letter from Taylor to members of the International Committee on Radiological Units, dated January 14, 1936 in Karolinska, F1, package number 84, file V-D 4a.

[139] Letter from Sievert to Owen, dated April 18, 1936 in Karolinska, F1, package number 84, file V-D 4a.

[140] Letter from Owen to Sievert, dated May 2, 1936 in Karolinska, F1, package number 84, file V-D 4a.

[141] Taylor to Members (ref. 138).

[142] Owen to Sievert (ref. 140).

[143] Taylor to Members (ref. 138).

[144] Letter from Sievert and Benner to Taylor, dated May 4, 1936 in Karolinska, F1, package number 84, File V-D 4a.

[145] Letter from Taylor to Sievert, dated June 20, 1936 in Karolinska, F1, package number 84, file V-D 4a.

[146] Bo Lindell, *The Sword of Damocles* (Nordic Society for Radiation Protection, 2019), 38.

[147] Letter from Taylor to Sievert, dated April 8, 1937 in Karolinska, F1, package number 84, file V-D 4a.

[148] Taylor to Sievert (ref. 147).

[149] Letter from Taylor to members of International Committee on Radiological Units, dated May 8, 1937 in Karolinska, F1, package number 84, file V-D 4a. Underlined words in original. The British proposal to the fifth congress was published as: "International Recommendations for Radiological Units," *The British Journal of Radiology* **10**, no. 114 (1937), 438–44.

[150] Taylor to members (ref. 149).

[151] "International Recommendations for Radiological Units" (ref. 149), 438.

[152] Letter from Taylor to members of International Committee on Radiological Units, dated June 29, 1937 in Karolinska, F1, package number 84, file V-D 4a.

[153] Taylor to members (ref. 152).

[154] Letter from Sievert to Taylor, dated August 18, 1937 in Karolinska, F1, package number 84, file V-D 4a.

[155] Sievert to Taylor (ref. 154).

[156] "Recommendations of the International Committee for Radiological Units (Chicago, 1937)," *Radiology* **29**, no. 5 (1937), 634–35, on 634. *The British Journal of Radiology* arrived at a similar conclusion in March 1938, see "X-Ray and Radium Protection," *The British Journal of Radiology* **11**, no. 123 (1938), 188.

[157] Letter from Behnken to members of the IXUR, dated July 15, 1939 in Karolinska, F1, package number 84, file V-D 4b.

[158] Lindell, *The Sword of Damocles* (ref. 146), 69; Weinberger, *Sievert* (ref. 30), 82–83.

[159] Bo Lindell, *The Labours of Hercules* (Nordic Society for Radiation Protection, 2020), 85.

[160] For instance, protection of workers at the Manhattan project: Walker, *Permissible Dose* (ref. 126), 9.

[161] Hennelund Nielsen, "From Radiology to a World-In-Crisis" (ref. 21).

,

Chair of Science, Technology and Gender Studies
Friedrich-Alexander-University
Werner-Von-Siemens-Str. 61
91052 Erlangen, Germany
e-mail: aske.h.nielsen@fau.de
e-mail: maria.rentetzi@fau.de

Accepted: 27 September 2024