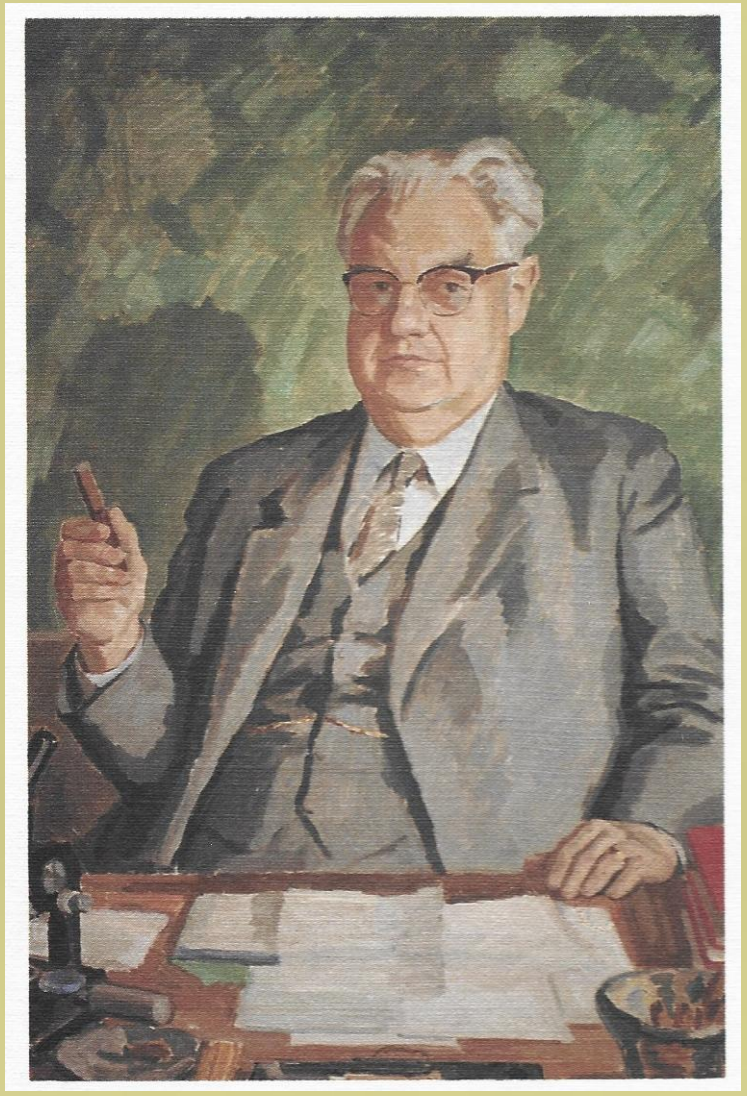


HANS WEINBERGER

Sievert: unit and diversity

A biography of Rolf Sievert - the Swedish founder of radiation physics, radiation biology and radiation protection

Sievert: unit and diversity

by Hans Weinberger

Translated by Andrzej Wojcik with assistance of ChatGPT
Stockholm, 2026

Translation authorized by the author

Published and distributed as an open access pdf document by the
International Commission of Radiological Protection (ICRP)
on the occasion of the 100-year anniversary of ICRP, founded in Stockholm, Sweden in 1928

www.icrp.org

Cover illustration:
Portrait in oil of Rolf Sievert at age 67 painted by Erik Kinell.
The painting is kept at the Kiruna Geophysical Observatory, Sweden

Information from the original book

HANS WEINBERGER
Sievert: enhet och mångfald
En biografi över den svenska radiofysikens, radiobiologins och strålskyddets grundare Rolf Sievert

Stockholm Papers in History and Philosophy of Technology, TRITA-HOT 2021 ISSN 0349-2842
Editor: Svante Lindqvist
SSI rapport ISSN 0248-4434

Detta examensarbete vid Kungliga Tekniska Högskolan är utarbetat, finansierat och tryckt i samarbete mellan Statens strålskyddsinstitut, SSI och Avdelningen för teknik- och vetenskapshistoria, KTH. Arbetet ingår i forskningsprojektet »Den tekniska forskningens förändrade natur: Teknikhistoriska perspektiv på den svenska utvecklingen under efterkrigstiden» vid Avdelningen för teknik- och vetenskapshistoria. Arbete är tryckt med bidrag från Riksbankens jubileumsfond.

STOCKHOLM 1990

Master of Science Thesis at the Royal Institute of Technology, Stockholm 1990

© 1990 Hans Weinberger ISSN 0349-2842
ISSN 0282-4434
ISBN 91-7170-015-3

Typsnitt: Bembo 10/13
Grafisk formgivning: Jerk-Olof Werkmäster
Tryckt hos Almqvist & Wiksell Tryckeri, Uppsala 1990

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Foreword

The use of X-rays and radioactivity, ever since their discovery in 1895 and 1896, has in many respects altered the conditions of human life. Radiation and radioactivity today constitute both a significant aid to the practice of medicine and a threat to all humanity. Rolf Sievert, who thirteen years after his death gave his name to the SI unit for biological radiation dose, was one of Sweden's leading scientists in the middle of the twentieth century. His work spans the years 1920 to 1966 and includes the creation of new interdisciplinary disciplines: clinical radiation physics, radiobiology and radiation protection. Sievert is therefore central to understanding how the official Swedish view of radiation and its risks has developed.

Rolf Sievert was active as a physicist and professional for more than 45 years. This brief biography of his life and work will therefore inevitably leave many questions unanswered. The biography begins with Sievert the researcher and constructor and then proceeds more towards Sievert the organizer and internationally active scientist. In his scientific work, Sievert was in many respects a brilliant combination of constructor and researcher. One of his greatest assets was precisely his ability to merge technical and scientific knowledge into a functioning whole. The biography places some emphasis on Sievert's organizational efforts, chiefly because many of these were of great significance. In part this is also because the available source material is particularly abundant in those areas. One must therefore keep in mind that the volume of source material on Sievert's different activities does not automatically correspond to the distribution of his actual contributions.

All of Sievert's dissertations and articles are usually available in well-stocked libraries and his own habit of generously reproducing his own and others' interesting articles makes the collection of material a relatively simple task. The former Swedish Radiation Protection Institute (SSI) held a rich and easily accessible archive. What is sometimes lacking is access to materials that illuminate the creative work - the influences and discussions that lead to a scientific result. Here the sources often leave a modern reconstructive historian with nothing more than conjecture about what seems reasonable. It is also rare to find the origin of an influence stated when a technical solution is presented. The surrounding framework will, hopefully, all the same provide support to the description and among the larger projects influences are sometimes documented. Covering all the events in which Sievert participated over the course of his life is an enormous undertaking and I therefore ask the reader who wonders why this or that has not been discussed more thoroughly for patience. It is surely the case that many aspects remain to be addressed. My hope is that radiation physics and radiation protection in Sweden may someday be treated in a technological and scientific-historical dissertation.

There is always a certain interpretive dynamism involved in approaching a creative and inventive individual. In this case it has had to occur through surviving documents, letters, articles, dissertations and through the recollections of others. To all the colleagues who helped to sketch a unified yet nuanced portrait of Rolf Sievert, I therefore wish to express my warm thanks. Without their memories and often vivid descriptions of Rolf Sievert, this biography would not have been possible.

I wish to extend a special thank-you to Bo Lindell, Rune Walstam and Sven Löfveberg who answered all my questions with great care. Bo Lindell has given me access to his archive of saved material from Sievert's time and, through numerous factual clarifications, corrected misunderstandings. Sven Löfveberg and Rune Walstam have, in the final stage of the work, responded quickly to sudden questions. Without their help, this biography would hardly have been possible. C-G Junback has patiently followed the work's development and has always been helpful when practical problems had to be solved. Astrid Sievert also deserves special mention.

The following persons have, through interviews or in other ways, contributed valuable information: Hannes Alfvén, Axel Berggren, Sigvard Eklund, Jerzy Einhorn, Sten von Friesen, Svea Forss, Bengt Grabe, Torborg Hammarberg, Arne Hedgran, Matts Helde, Nicolai Herlofson, Bengt Hultqvist, Bengt Håkansson, Karl-Erik Larsson, Lars-Eric Larsson and Eija Väissinen. The staff at the Centre for the History of Science, Royal Academy of Sciences, have cheerfully searched out various documents and Elisabeth Björkman at the Academy has helped me find important minutes.

All those who helped me locate books, articles and archival material at public libraries and authorities I wish to thank for carrying out their work in a friendly and professional manner. I recall especially the anonymous gentleman at the County Administrative Board of Stockholm who patiently and diligently searched out information about Max Sievert. At the Division of History of Science and Technology, librarian Margareta Bond-Fahlberg has been of invaluable assistance.

My advisor, Professor Svante Lindqvist, has patiently supported me with advice and assistance throughout the development of the work and, with a vigilant linguistic eye, ensured that I have not fallen into the worst pitfalls. He has steered the work with a steady hand from idea to reality and has, with his inspiring disposition, always encouraged me. His ability to read and comment on a manuscript with warm irony and humour is something that everyone ought to experience.

It was through Professor Tore Frängsmyr's farsighted mediation that the request for a biography ultimately came to the Division of History of Science and Technology at the Royal Institute of Technology (KTH). Professor Jan Hult has carefully read a late version of the manuscript by return post and Thomas Kaiserfeld and Mats Fridlund have both read the manuscript and given me valuable suggestions.

Lars Sproge read through my manuscript at an early stage and contributed good ideas. Ann Wikström has read and commented on parts of the manuscript. Finally, I wish to thank my fiancée, Susanna Wedefelt, for her encouragement and support and for her hands-on help in the final stages of the manuscript work.

> Every age sees only what it already sees. When previously concealed or obscured facts come to light, the overall picture changes. Anyone who writes a biography is permeated by the thought that everything he writes would fall apart if the dead were to rise from the grave and read over his shoulder.
>
> *Olof Lagercrantz, On the Art of Reading and Writing, 1985*

1. The Development of Radiology 1895–1920

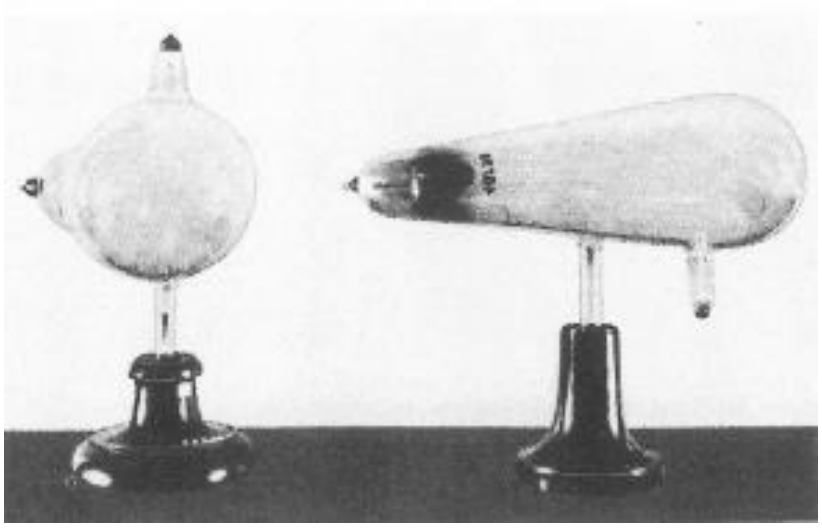
Röntgen, Becquerel, Curie and the First Radiation Injuries

Wilhelm Röntgen, professor at the Physical Institute at the University of Würzburg in Bavaria, discovered in 1895 a type of new rays. Röntgen made his revolutionary discovery by chance while experimenting with discharges in an evacuated Hittorf–Crookes cathode tube.[1] He soon gave the unidentified rays the working name X-rays, a designation that has remained in English-language literature ever since. During a few hectic months following the November discovery, Röntgen documented the properties of the new rays: among other things, they were invisible and not appreciably absorbed by air and unlike previously known rays could therefore travel long distances.[2]

Röntgen tried various materials to measure absorption. He experimented with thin lead plates placed in front of photographic plates and because he held the lead plates in his hand, the developed plates showed the bones in his hand. In the first report that Röntgen published after the discovery, there is also a photograph from an X-ray image of a hand - in one of the fingers a pair of rings can be seen as two thick black lines.[3]

At the end of 1895, Röntgen sent advance copies of his first paper on X-rays to colleagues in Europe and enclosed some photographs as illustrations.[4] One of those who read Röntgen's paper was the French mathematician Henri Poincaré, a member of the French Academy of Sciences. Poincaré reported the new discovery at one of the academy's meetings and physicist Henri Becquerel, who had devoted himself to fluorescence, showed interest. Becquerel suspected a physical connection between fluorescence (a phenomenon in which the atom receives an energy input from radiation and then emits a proportional amount of energy some time later) and X-rays.[5]

Becquerel began a series of experiments to investigate whether radiation from fluorescent materials might also emit X-rays. The first experiments gave negative results and only when he examined a uranium salt was he able to detect radiation.[6] A photographic plate wrapped in paper was placed under the illuminated uranium salt and upon development a clear effect on the plate was visible. He prepared additional samples to confirm his discovery, but in the following days the weather in Paris offered no sunlight. He therefore placed a prepared sample in a desk drawer to await sunshine. The sunshine was delayed and Becquerel, likely impatient,



Röntgen´s original X-ray device in Deutsches Museum in Munich.

developed the plate after a few days. To his great astonishment he saw the same blackening of the plate as after solar exposure.[7]

Becquerel concluded that there must exist something that could be called spontaneous radioactivity, in contrast to Röntgen's technologically produced electromagnetic rays.[8] Becquerel had also discovered that his rays not only blackened photographic plates but also ionized gases - knowledge that made it relatively simple to measure the activity of a radioactive sample.[9]

At the suggestion of her French husband, Pierre Curie, Marie Curie began a doctoral dissertation to study the new phenomenon that Henri Becquerel had discovered.[10] Marie Curie verified through her experiments the radioactive properties of uranium: the radiation was proportional to the amount of uranium, but the intensity did not depend on the chemical state of the uranium. She decided to investigate ores and minerals as well. In her studies she could measure the radioactivity of uranium and thorium, but she also obtained values indicating significantly higher activity than expected from uranium or thorium alone. She concluded that the samples must contain another, much more radioactive element and in July 1898 the Curies announced the discovery of radium and polonium. Marie Curie proposed the name radioactivity for the new phenomenon.[11]

Very early it was understood that radium affected biological tissues. Among the first to discover radium's injurious radiation was Becquerel, who after a visit to the Curies had carried a radium sample in his vest pocket and developed burns.[12] The Curies themselves also suffered radiation injuries. Marie Curie was plagued throughout her life by difficult-to-diagnose illnesses which, as we now understand, originated in the large radiation doses she received while extracting radioactive elements from minerals. She died from leukaemia. The greatest radiation doses she received, however, came during World War I, when she worked as an X-ray instructor for the French army.

The very first Nobel Prize in Physics, in 1901, was awarded to Röntgen for his epoch-making discovery.[13] Two years later, in 1903, the Curies and Henri Becquerel shared the Nobel Prize.[14] The discoveries of 1895 and 1896 would be the starting signal for a new branch of medicine and it was above all with X-rays that physicians would first try new treatment methods.

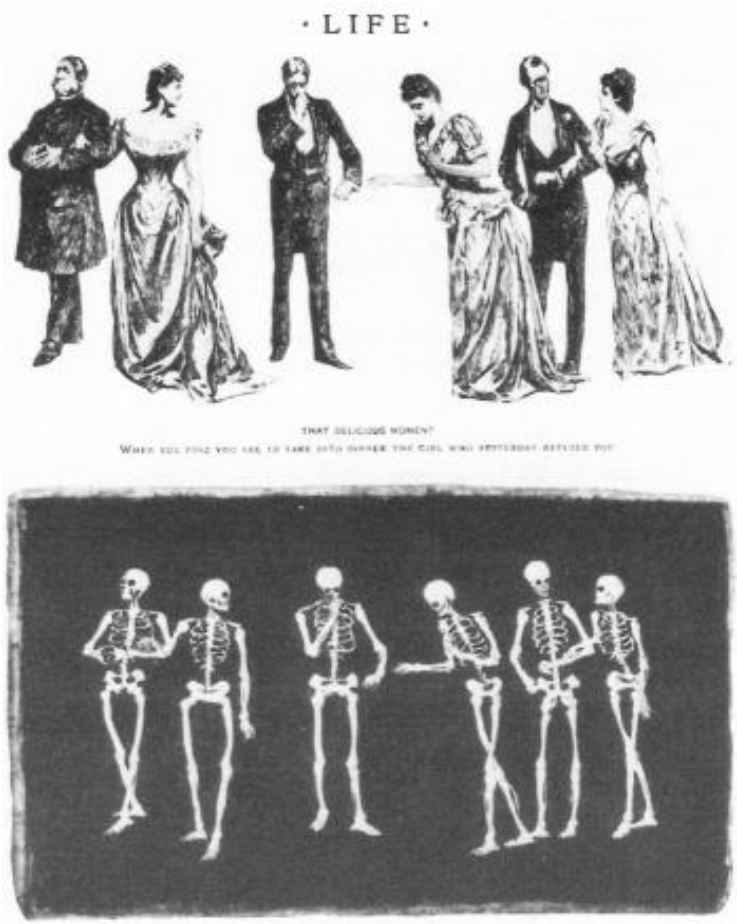


An X-ray image of Mrs. Röntgen's hand, taken on December 22 1895. Her rings are visible on the third finger from the left - the ring finger. When images like this one spread across the world, it became clear to doctors what immense use they could make of X-rays for diagnostics.

Radiation Therapy Abroad and in Sweden 1895–1918

At the turn of the century, there was widespread despair within the medical sciences concerning whether the methods - especially surgical - used in treating cancer actually provided any real improvement for patients. Cancer treatment was, if not hopeless, then at least very uncertain. The results of surgical interventions were often poor and medicine seemed to stagnate while developments in the adjacent natural sciences accelerated rapidly.[15] The intense activity among physicians to adopt X-ray technology after 1895 can be more easily understood against this background. In a broader perspective, the entire scientific world was characterized by a strong belief in progress. Entrepreneurship was admired and the step from invention to commercialization was often short.

The idea of using X-rays for diagnostic purposes emerged almost immediately once news of Röntgen's discovery and the hand radiographs spread across the world. Although it is not entirely accurate to claim that Röntgen himself awakened physicians' interest in X-ray diagnostics, one must remember that he published his findings in a medical journal rather than in a physics journal. The diagnostic potential of X-ray rays was soon described in the professional press. In January 1896, E. Haschek and O. T. Lindenthal succeeded in taking the first X-ray contrast image of a hand.[16] In May, the first X-ray images of teeth were made and



The attention surrounding Röntgen's discovery was immense. Cartoonists were quick to seize upon the rays' remarkable properties. "That delicious moment when you find you are to take into dinner the girl who yesterday refused you." And the whole thing seen through Röntgen's eyes. "For those of our readers who like to get at the inside facts of a case." Originally published in the magazine Life 27, on April 6th 1896.

that same month the first X-ray journal, the English *Archives of Clinical Skiagraphy*, began publication.[17]

Parallel to the scientific triumph of X-rays around the world were reports of radiation injuries from experimental physicists and from physicians using X-rays diagnostically.[18] Already in April 1896—barely half a year after Röntgen's discovery—many laboratories reported skin injuries resembling severe sunburn.[19] The connection between such injuries and ionizing radiation was understood very early, perhaps largely because X-rays were used clinically, allowing physicians to directly observe patient conditions.[20] In an article in the *Journal of the American Medical Association*, the author expressed hope that X-rays could soon be useful for therapeutic purposes as well.[21]

The first radiation injury described in the scientific literature occurred in January 1896. It was the American Emil Grubbe in Chicago who reported how he had injured his hands after experiments with a discharge tube.[22] In March that year, the American inventor Edison wrote that both he and his assistant had suffered severe eye irritation after temporary X-ray exposure.[23] Acting on a colleague's idea, Grubbe tried to determine whether X-rays could affect superficial tumors. On 29 January 1896, Grubbe carried out his first treatment on a patient with advanced breast cancer.[24] The treatment was unsuccessful and Grubbe's failed pioneering attempt resulted in considerable skepticism among his medical colleagues.

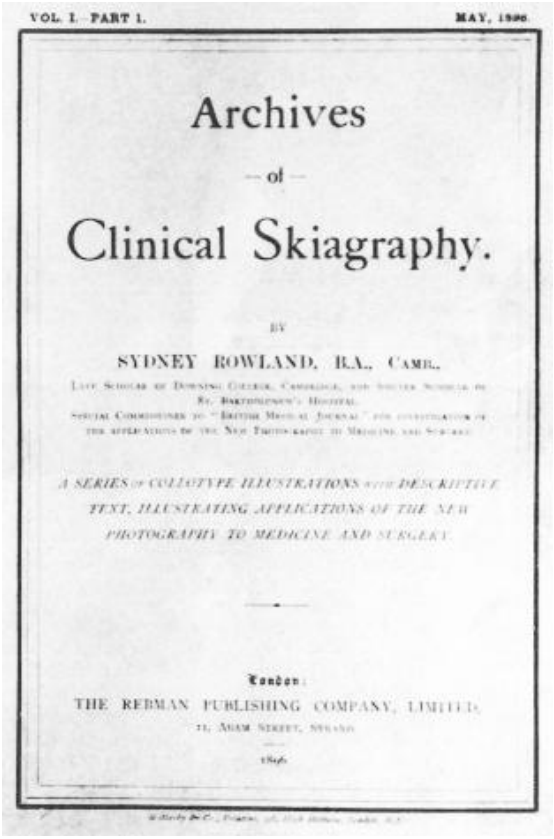


The first X-ray contrast image of a hand, prepared and photographed by E. Haschek and O.T. Lindenthal. A mixture of mineral oil, cinnabar and chalk was used as the contrast agent, absorbing the X-rays.

The Austrian newspaper *Neue Freie Presse* told the story of the radiologist Freund in Vienna, who through repeated X-ray exposures had cured a young girl suffering from a large hairy birthmark.[25]

There were at the time many theories about what caused the skin injuries. Explanations ranged from tiny particles striking the skin, to ozone generation, to high-frequency electrical induction - the latter proposed by the American inventor Tesla. In a well-known experiment in 1901, however, Boston dentist and radiation-protection pioneer William Rollins determined that X-rayed guinea pigs placed inside double Faraday cages (and thus shielded from high-frequency radiation) still suffered injury.[26] Rollins also showed that X-ray injuries were not limited to the skin - the visible proof of exposure - but also occurred deep in biological tissues.[27] In an article in the *Boston Medical and Surgical Journal*, he asked whether the deep effect of X-rays might be valuable in treating inoperable tumors.[28] A year later he reported that certain experiments caused blindness and cataracts in irradiated animals.[29]

Lead is, as is well known, an excellent absorber of X-rays. Röntgen himself was the first to discover its protective properties. He carried out all his experiments with the discharge tube in a zinc container lined with a thin layer of lead.[30] The primary purpose of Röntgen's arrangement was to protect photographic plates in the laboratory from undesired exposure, not to protect himself. Further research showed that lead was the unmatched material for biological radiation protection as well. This was important because the need to protect patients and staff existed from the very beginning. The first X-ray apparatuses operated at low voltages, which required long exposure times.[31] Even though it was known early on that X-rays spread in various


VOL. I. PART 1. MAY, 1896.

Archives

— of —

Clinical Skiagraphy.

BY

SYDNEY ROWLAND, B.A., CANTAB.

A SERIES OF COLLOTYPE ILLUSTRATIONS WITH DESCRIPTIVE TEXT, ILLUSTRATING APPLICATIONS OF THE NEW PHOTOGRAPHY TO MEDICINE AND SURGERY.

London:

THE REBMAN PUBLISHING COMPANY, LIMITED,

11, ADAM STREET, STRAND.

1896.

The cover of the first X-ray journal, Archives of Clinical Skiagraphy, published in London in May 1896 by Sydney Rowland.

directions, it was only in 1903 that Rollins, in his book *Notes on X-light*, emphasized their potentially harmful effects and the importance of preventing unnecessary radiation:

> As X-light spreads its spherical wave, filling a room with an actinic mist which radiated X-light in every direction… it was essential to prevent the escape of every ray not needed to make the photograph or to illuminate the screen.[32]

Gradually, protective equipment—of varying usefulness—began to appear on the market for medical personnel, but it was not until the 1910s that shielding was built into the apparatuses themselves.[33] The early period of X-ray therapy was characterized by an arbitrary approach to radiation protection. Whenever a severe accident occurred due to exposure, new and somewhat stricter rules were introduced, but there was no underlying philosophy for protecting people. The central problem was the lack of quantitative measurement of radiation. Radiologists strove to define the maximum dose the human body could tolerate during continuous irradiation. One of the first attempts was by Rollins in 1902, proposing that if a photographic plate did not blacken after seven minutes of exposure, the dose was essentially harmless.[34]

The Austrian Guido Holzknecht constructed the first dosimeter for X-ray therapy in the same year. It relied on a photochemical process in which a mixture of potassium chloride and sodium carbonate became discoloured under X-ray exposure.[35] After Holzknecht presented his dosimeter, several additional types based on photochemical processes appeared. From today's perspective these dosimeters were not sufficiently sensitive for use in radiation therapy and their readings depended heavily on the purity of the chemicals.[36]



Gösta Forssell (1876–1950). Founder of Radiumhemmet and Professor of medical radiology at the Karolinska Institute.

Gösta Forssell and the Foundations of Swedish Radiology

The scientific and medical activity that followed the discoveries of 1895 and 1896 extended to Sweden as well. One of the first medical institutes was Dr. Thor Stenbeck's private institute for X-ray treatment on Mäster Samuelsgatan in Stockholm.[37] Half a year before the turn of the century, Stenbeck succeeded in performing the first successful cancer treatment in Sweden.[38] Small X-ray units were established at Swedish hospitals, usually attached to surgical departments.

The person who must be considered the founder of Swedish medical radiology is Gösta Forssell (1876–1950). He began his studies at the Karolinska Institute in the autumn of 1895. During his training he became interested in radiation therapy and served for a little over a year as an assistant at Stenbeck's private institute.[39] The early development of radiology in Sweden was relatively limited in scope and became closely associated with Forssell and with the then director of Serafimer Hospital, the surgeon John Berg (1851–1931).[40] It is therefore of interest to describe Forssell's path to Radiumhemmet in Stockholm - an institution that came to symbolize Swedish radiotherapeutic practice.

John Berg was the first established physician in Sweden to take a serious interest in X-ray therapy. Through his position he initiated and facilitated radiology's development. To determine the need for therapy, Berg initiated a cancer survey carried out by the Swedish Medical Board during the three months spanning 1905–1906. The report, covering almost all Swedish treatment centres for cancer patients, was published in 1909.[41] Berg's interest in combatting cancer led to the founding of the Swedish Cancer Society in May 1910.[42] The association came to play a crucial role in the development of radiology and medical physics in Sweden.

Already in 1905 Berg had started an X-ray institute connected to the surgical department at Serafimer Hospital. The small space - 45 m² - was divided into five rooms to allow efficient work. Three people worked in these cramped quarters: a director, an assistant and an attendant.[43] Forssell graduated as a medical candidate in 1902 and served that spring as an extra assistant at Professor Lennander's surgical X-ray laboratory at Uppsala Academic Hospital.[44] On 1 July 1906, Forssell was hired by Professor Berg as director of the Surgical Clinic's X-ray institute at Serafimer Hospital - a position that later expanded into the directorship of the entire institute.[45]

Radiology from its inception was characterized by a broad international network. Forssell devoted much time to visiting prominent foreign institutes: Heinrich Albers-Schönberg in Hamburg, Rudolf Grashey and Hermann Rieder in Munich, Guido Holzknecht and Robert Kienböck in Vienna. He also visited the radiotherapist Keating-Hart in Marseille in 1908 and the Institut du Radium under Dominici and Wickham in Paris in 1909.[46]

Various treatment methods had been developed and Forssell was able to study their advantages and disadvantages. Keating-Hart's method—the so-called spark method—involved post-surgical treatment with high-frequency high-voltage sparks. The method proved harmful and was abandoned after trials in Sweden.[47] At the Institut du Radium, a successful method for treating malignant tumors with radium had been developed. Forssell and Berg purchased a small amount of radium and introduced the method at Serafimer Hospital.[48] The treatment, however, involved risk to personnel, who fastened the radium with skin tape or—in difficult cases—had to hold the preparation by hand.

The Swedish Cancer Society was from the outset a member of the International Association for Cancer Research. Berg, Forssell and Gunnar Nyström (1877–1964), professor of surgery at Uppsala University, attended a congress in Paris on cancer research in October 1910 and lectured on the Swedish Cancer Society's work. Upon his return, Nyström reported to the Swedish Medical Association in a lecture titled: "On Organized Cancer Research and the Fight Against Cancer."[49] The vibrant international environment of early radiology proved a fruitful foundation for later international cooperation in radiation protection. Much of the work that Rolf Sievert (1896–1966) would later undertake had its cultural roots in this milieu.

The need for expanded X-ray services prompted Berg and Forssell to establish, with private donations, a clinic for cancer treatment on Kungsholmen in Stockholm. They rented two floors at Scheelegatan 10 and furnished eight rooms with sixteen beds, X-ray equipment and radium preparations.[50] The clinic opened on 1 August 1910 and was named Radiumhemmet. The same year, responsibility for the clinic was transferred to the Swedish Cancer Society. The interior was deliberately home-like: curtains, paintings, lamps and tiled stoves were part of the décor—according to the principle that patients should feel cared for and respected. Two additional physicians were hired: the oncologist Elis Berven (1885–1966) and the gynecologist James Heyman (1882–1956).[51] These would later become part of the quintet of men who brought Radiumhemmet world renown in the 1930s and 40s. The other two members were the pathologist Olle Reuterwall (1888–1956) and the physicist Rolf Sievert.[52]



A deliberate policy at Radiumhemmet was that patients should not feel anxiety about an unfamiliar environment. Consequently, the rooms were furnished with curtains and some standard furniture. The very choice of the name Radiumhemmet (*radium home*) was intended to evoke associations with a calm, home-like setting. The daily coffee break in the garden by Fjällgatan during the summer months was brightened by music. Robert Thoræus at the crank-operated gramophone.

Radiological diagnostics also expanded and in 1911 Serafimer Hospital opened a central institute for X-rays, planned by Forssell.[53]

Forssell's main goal was to ensure the quality of the work and he argued for centralizing radiotherapy to a few large, well-equipped specialist clinics with well-trained staff who could provide effective treatment.[54] This centralization of radium and X-ray therapy into a few large units became characteristic for Swedish radiological development and it strongly influenced the evolution of medical physics.

Radiology's economic position strengthened over time. Grants from state and municipal funds and private donations enabled long-term expansion. In 1913 Radiumhemmet received 500,000 Swedish crowns from Stockholm's Forsgren Fund and another 500,000 Swedish crowns from a private fundraiser initiated by Queen Victoria. Reports of promising treatments appeared in journals such as *Hygiea*, the Swedish Medical Society's publication and in 1914 the *Nordic Encyclopedia* published an article on radium therapy written at a popular-scientific level.[55] Forssell defended his doctoral dissertation *Über die Beziehung der Röntgenbilder des menschlichen Magens zu seinem anatomischen Bau* in 1913 and was promoted to Doctor of Medicine at the Karolinska Institute that May.[56]

Radiumhemmet's operations expanded and in 1916 it moved to Fjällgatan 23 on Södermalm in Stockholm. The premises, previously belonging to Schartau's Commercial Institute, were renovated at the expense of the city and consisted of two buildings—one for ambulatory patients and radium treatment, the other for X-ray treatment and staff. World War I made the



An image of a stained-glass window at Radiumhemmet, created by artist Harald Lindberg for Elis Berven's 60th birthday. In the foreground, Marie Curie and Wilhelm Röntgen present the gifts of science to the people. Marie Curie holds the radiant radium in her hands and Röntgen carries his X-ray tube. In the background stands the quintet that would lead Radiumhemmet until the mid-20th century: Elis Berven stands above Marie Curie, with Gösta Forssell to his right in the image. Diagonally to the right, slightly above Berven, stands James Heyman and diagonally to the left, above Heyman, the young Rolf Sievert. Beside Sievert to the right is Olle Reuterwall. The inscription reads lux vitae genetrix, which roughly translates to light is the mother of life.

acquisition of radium increasingly difficult and costly. After prolonged negotiations, Parliament granted 20,000 Swedish crowns in extra funds in 1917.[57] That same year a personal professorship in medical radiology was established for Forssell at the Karolinska Institute.

X-ray therapy for skin cancer was an early example of a successful radiological treatment - almost 100 percent of treated patients were cured. The first treatments used low doses and long exposure times. As early as 1909, Forssell had tested a new method involving large doses over two days, followed fourteen days later by a 37-minute irradiation. The dosing was empirically determined and Forssell emphasized the need for better measurement techniques.[58]

The most common method for calibrating X-ray machines and radium preparations was for a physician to irradiate skin for a defined time and then note the redness after a week. The treatment dose was thus measured in Skin Erythema Dose (SED) and depended on skin pigmentation and radiation quality.

Radiation protection for personnel gradually acquired firmer rules. The first documented international protection regulations appeared in Germany in the 1913 *Merkblatt der Deutschen Röntgengesellschaft über Schutzmassregeln gegen Röntgenstrahlen*.[59] The leaflet warned of radiation risks and listed recommended protective measures: lead-lined walls, lead glass and shielding of the X-ray tube itself. Remarkably, it proposed appointing a radiation-protection

officer responsible for the apparatus and safety measures and emphasized workers' right to refuse work if protection was inadequate. The British Roentgen Society adopted similar regulations in 1915.[60] Confidence in such measures was strong and Dr. S. Russ in England expressed his hopes at a London meeting:

> In the future I imagine that before radiologists begin their work the atmosphere will be examined (for radiation effects) just as scrupulously as is the water one drinks.[61]

To create a discussion forum for radiologists in the Nordic countries, the journal Acta Radiologica was founded in 1921 at Forssell's initiative.[62] Eventually Switzerland and the Netherlands also contributed articles. The journal developed into a leading radiological publication and came to play a major role as a forum for Rolf Sievert and the Radiation Physics Institute.

2. Childhood and Student Years

Rolf Sievert's family on his father's side came from Saxony in Germany. His grandfather, Heinrich Theodor Sievert, was born in Quedlinburg, a small German town located about 50 km southwest of Magdeburg.[1] During the first half of the 1880s he moved to Zittau in Saxony, situated just southeast of Dresden near the Czech border. There he established himself as a confectioner and eventually became a member of the city council (Stadtrath). With his wife Agnes Therese (née Thiemer) he had three sons: Max, Georg and Ernst. Rolf Sievert's father Max was the eldest son and was born on 24 August 1849 in Zittau. Thirteen years passed before Max's first sibling was born: Georg in 1861. Two years later came Ernst.[2]

After completing his schooling, Max Sievert devoted himself to agency work in the machine industry. He represented, among others, Zentkers Maschinenfabrik in Berlin and undertook, on their behalf, travels to Russia and the Scandinavian countries. Max Sievert soon recognized the business opportunities available to a merchant dealing in machinery who possessed good German contacts in Sweden and in 1881 he opened a wholesale business in Stockholm: Max Sievert's Machine Company.[3]

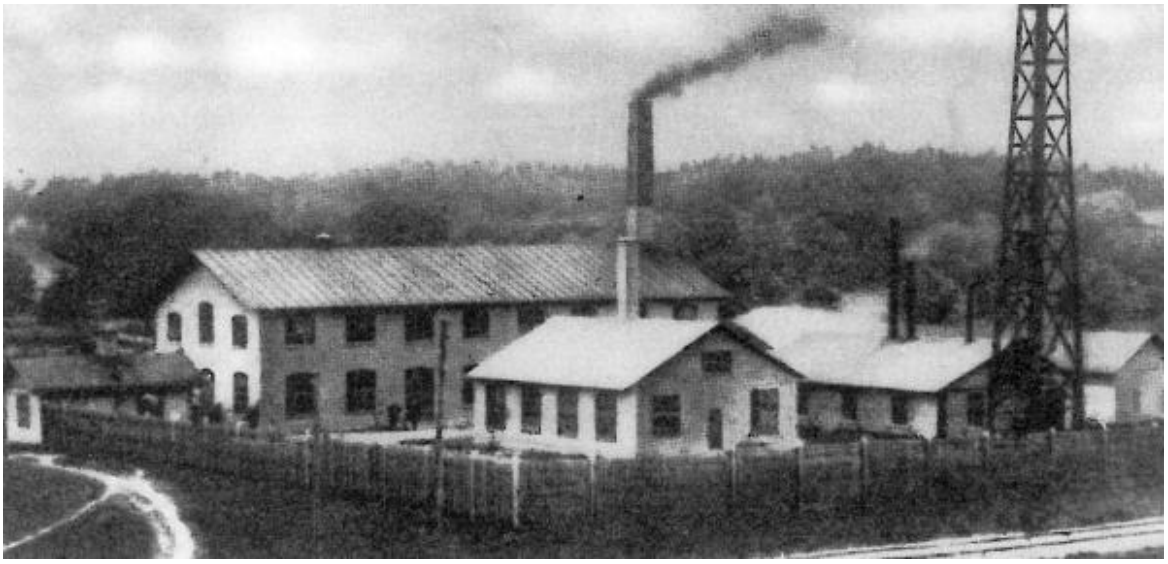
The firm, which initially imported only German tools and machines, was very profitable and generated a financial surplus that made it possible to realize several business ideas. Gradually the product line broadened and Max Sievert increasingly purchased goods from Swedish manufacturers. In the preface to his 1888 catalogue he wrote:

> ... I have succeeded in transferring the manufacture of not a few things - among them quite substantial ones - from abroad to Swedish workshops [...].[4]

Lars Magnus Ericsson, who had begun manufacturing telephones in Sweden, imported telephone cable through Max Sievert's Machine Company.[5] Ericsson's company struggled with costly imports and he asked Sievert whether he might consider beginning wire production in Sweden. In this way Ericsson could avoid the high Swedish protective tariffs and secure a continuous supply.

While discussions about wire production were underway, Max Sievert in 1888 founded the company Alpha in Sundbyberg for the manufacture of horseshoe nails. After accepting Ericsson's proposal, he started experimental wire production that same year in a room belonging to Alpha, but registered the wireworks as a separate company. The business expanded rapidly during its first years and soon received the name Sievert's Cable Works (Sieverts Kabelverk). The largest customers were L. M. Ericsson and the Swedish Telegraph Administration (Telegrafverket), both of whom remained loyal purchasers of nearly everything Sievert could produce. In 1888, L. M. Ericsson bought silk-wrapped copper wire for 15,872 Swedish crowns; in 1894 the figure was 76,664 Swedish crowns. Sales thus increased on average by 30 percent per year. In 1895, Max Sievert reorganized the company as a joint-stock corporation under the name Max Sieverts Fabriks Aktiebolag.[6]

The two younger brothers soon followed Max Sievert to Sweden, where they were taken under their elder brother's protection and began working for him in his various enterprises. Ernst immigrated to Sweden in 1887 and Georg followed later. Ernst eventually became technical



The wire factory in Solna, later Sieverts Cable Works, 1890.

director of the wireworks and Georg assumed part of the responsibility for the agency business at Brunkebergstorg 2, where the firm was located. Max Sievert became a Swedish citizen in 1885. Nine years later he married Sofia Carolina Pancheen, originally from Härnösand.[7] Their daughter Lisa was born in 1895, followed a year later by their son Rolf. Only sparse information survives concerning Rolf Sievert's childhood. It appears, however, to have been a relatively carefree time for Rolf and his sister Lisa. The mother, according to reports, had little aptitude for dealing with children but was culturally inclined. The siblings were close and had a good relationship.[8] The family owned the manor Höstsol in Vallentuna, where the children spent their summers. Rolf enjoyed sailing - a lifelong interest.[9] During the rest of the year the family lived at Riddargatan 45 in Stockholm.

Thus, Rolf Sievert was the only son of a German immigrant who, through business acumen and foresight, had built a considerable fortune in his new homeland. The father figure that Sievert carried with him into life was that of a frequently absent and hard-working industrialist. They were not particularly close.[10]

Initially, the plan was for Rolf to follow in his father's footsteps. When he was old enough, his father placed him as an apprentice in one of his factories. The apprenticeship, however, ended abruptly when a worker threw a metal object at the head of the "director's son."[11] The father was forced to reassign him to a quieter workshop.

The father died in 1913, when Sievert was only 17 years old. This must have affected Rolf significantly and perhaps his grief can be read in his poor examination grades and his indecision about his future. Upon his father's death, Rolf became the heir to a very large fortune. The interest income alone was sufficient to provide him a worry-free existence for the rest of his life.

In 1914 Rolf Sievert completed his high school graduation exam (studentexamen) at Nya Elementarskolan, an experimental school for innovative pedagogical methods. He endured his school years without much enthusiasm and found the studies rather meaningless. In the autumn of the same year, Sievert began medical studies at the Karolinska Institute, but evidently did



A photograph of Max Sievert emanating confidence and authority.

not enjoy them and soon quit. Probably quite unsure of what he wanted to do, he decided to apply to the Royal Institute of Technology (KTH). However, his grades from the Nya Elementarskolan were so poor that in the spring of 1915 he had to undergo supplementary examinations in mathematics, physics and chemistry. This time the results were much better and in chemistry Sievert earned the grade excellent (berömlig).

In the autumn of 1915 he enrolled at KTH, in the School of Electrical Engineering, but this attempt also ended after a few months, as he found the pace too demanding.[12] In the end Sievert found what he was searching for in Uppsala, where he began studies toward a Bachelor of Science (filosofie kandidatexamen) sometime between 1915 and 1917. In 1919 he earned the degree in astronomy, meteorology, mathematics and mechanics.[13]

Around the turn of the century, Swedish physics was dominated by an experimental tradition, in which precision measurements and principles of instrumentation formed the basis for physical understanding.[14] At the time of Sievert's studies, however, theoretical physics began to penetrate this experimental tradition. During the 1910s the dominance of the experimentalists in Swedish physics was softening. In Uppsala, Carl Wilhelm Oseen in particular advocated for the importance of theoretical physics compared with what he regarded as narrower specialties such as meteorology.[15] Oseen became Sievert's teacher in mechanics and Sievert spent almost an entire year studying this subject under him.[16] Oseen pursued a determined campaign on behalf of theoretically and mathematically oriented physics. Around the turn of the century cracks had formed in the conceptual foundations of physics and several mutually incompatible theories coexisted as explanations for fundamental physical phenomena. Oseen was a mathematical physicist with a deep understanding of Maxwell's electromagnetic theories and a strong interest in the solutions of partial differential equations.[17]



Interior view of the cable factory's largest cabling machine for large-gauge, phase-sheathed high-voltage cables. Rolf Sievert's practical experience in the factories familiarized him with the technology as well as its constraints and possibilities. He retained this insight throughout his life. The cable factory also contributed many products to Rolf Sievert's experiments and experimental apparatus in the field of radiation physics.

During the 1920s Oseen became one of Einstein's warmest supporters in Sweden and already in 1919 organized a summer course on the theory of relativity.[18]

The scientific currents that characterized Swedish physics at the time of Sievert's studies were represented mainly at Uppsala University. Whether he was influenced by these trends is impossible to determine but much suggests that he absorbed at least some of the prevailing ideas. Sievert's first independent works - for example, on the intensity distribution around radium sources - also bear a theoretical character.[19] Over time, however, experimental work and, above all, an interest in instrumentation came to dominate.

After completing his studies in Uppsala, Sievert returned to Stockholm. In the basement of the house in Lärkstaden where he lived, he had access to a private laboratory, although its precise use is unclear.[20] That same year he began studies toward the Licentiate of Philosophy degree (*filosofie licentiate*) in physics at Stockholm University College. He completed the degree in 1924 - the year he formally began working for Radiumhemmet and Gösta Forssell.[21]

During the time of his licenciate studies, Rolf Sievert also began participating in the management of Sieverts Kabelverk, where Max's brother Ernst had assumed responsibility.[22] In 1919, Rolf became a deputy member of the board of Sieverts Kabelverk, but he remained only until 1922 and much suggests that his interest was lukewarm. The company showed large losses during 1920-21 and Sievert perhaps saw no future in it. After a two-year break, he was elected to the board in 1926. He held this position until 1928, when he, together with his mother and sister, sold all their shares in the company to the rest of the family.

A commemorative publication, issued when the company turned fifty, states:

Before the 1928 annual shareholders' meeting, the Max Sievert branch of the family sold its shares to the other shareholders. A total of 1,000 shares changed hands; Ernst Sievert acquired 760 and Georg Sievert 197; the remainder was divided among the younger family members of the two brothers. As a result, at the shareholders' meeting Ernst Sievert controlled a very significant majority, holding 1,824 of the 2,400 shares. When later that year the Telefonaktiebolaget L. M. Ericsson appeared as a buyer for the entire stock, Ernst Sievert was the decisive party.[23]

After the sale of the shares, Rolf Sievert purchased the manor Tvartorps herrgård near Rejmyre in Östergötland, which he kept for the rest of his life. He had also inherited a substantial number of shareholdings in various other companies from his father and he retained these as savings and reserve capital.

Although Sievert had some interest in his father's company, he preferred physics and science over business and finance. Much later he could still build bridges between these two worlds, writing in the Teknisk Tidskrift journal:

The scientist's work to achieve personal satisfaction or others' recognition and the engineer's or businessman's desire to achieve a practical or economic result, are merely different expressions of the same human striving.[24]

3. The Physics Laboratory 1920–1938

Study Trip to the United States

After completing his studies at Uppsala University in the spring of 1919, Sievert returned to Stockholm. There he served as assistant at the Nobel Institute of the Royal Swedish Academy of Sciences under Tycho Auren (lecturer at the State Higher Seminary for Women Teachers), who was engaged in experimental work concerning X-ray absorption.[1] At the same time, Professor Gösta Forssell at Radiumhemmet had realized the need for more accurate radiation dosimetry and therefore wished to appoint a physicist who could devote himself to dose calculations. Dr. Gunnar Lundgren, who worked at Radiumhemmet, happened by chance to hear of the newly graduated physicist Rolf Sievert and his work and mentioned his name to Gösta Forssell. Forssell sent Lundgren to speak with Sievert at the Nobel Institute. Lundgren gained a favourable impression of Sievert and asked him to contact Forssell.[2]

Sievert described these first contacts as the origin of his interest in medical radiology. It is possible that he had been inspired by the book *Physikalische und biologische Grundlagen der Strahlenterapie*, published in 1918 by the Germans Bernhard Krönig and Walter Friedrich (Sievert spoke of the book in appreciative terms in a historical overview in 1950).[3]

Before beginning work at Radiumhemmet, Sievert undertook in 1920 a study trip to the United States to examine the latest advances in radiation physics. The journey was probably initiated and financed by Sievert himself. He was impressed by the possibilities that existed for development within radiation physics. At the same time, Gösta Forssell was in the United States in order to study medical radiology and by chance Sievert and Forssell met in Schenectady, New York, which was a centre of radiological research. The place of their meeting and Lundgren's visit to the Nobel Institute caused their conversation to turn immediately to radiology and radiation physics. Forssell later wrote of the discussion in the hotel room:

> There, in a hotel room high up among the stars, we sat throughout an entire night and compared our observations and our plans and there were laid the foundations of a friendship and a companionship in the service of radiology which has lasted ever since.[4]

A direct result of this meeting was that Forssell and Sievert continued their travel together across the United States to study equipment for the production of radium emanation preparations and radiotherapeutic installations. Among other places, they visited Dr. Gioacchino Failla at Memorial Hospital in New York to study a radium emanation apparatus (radium emanation is the term in radiotherapy for radon), which had been designed by William Duane at Harvard University. During their journey, the young Sievert emphasized to Forssell that it was "absolutely necessary to have cooperation between medical doctors and physicists".[5] He later described his attitude at that time as "incredibly cheeky," since he was only a "young greenhorn" and actually lacked experience in radiation for medical use.[6] Yet this boldness seems to have been successful with Forssell, for upon their return to Sweden Sievert was more closely associated with Radiumhemmet and carried out a number of fundamental works on its behalf.



Photograph of a young Rolf Sievert, likely taken around the time of the trip to the USA.

On 2 October 1920, Sievert gave a lecture to the Association for Medical Radiology at its meeting at Lund Hospital. The lecture addressed the preparation of radioactive materials for medical purposes by concentrating radium emanation.[7] Sievert stated that he found the use of radium emanation superior to radium salts, both economically and in terms of volume and he referred to experiences gained in the USA and England. He also stressed the necessity of radiation protection and limited exposure for personnel and the need for staff to rotate work duties continuously.

Sievert made his most important contributions to the clinical development of radiation physics during the period 1920 to 1940. After some initial research at Radiumhemmet over several years, the true radio physical operations began in 1924.[8] The period up to the outbreak of the Second World War was filled with intense creativity, resulting, among other things, in the practical condenser chamber method and in the theoretical Sievert integral. After the war, Sievert increasingly turned his attention to the international arena and his interests shifted ever more from research toward radiation-protection problems and overarching organizational issues, even though in the 1950s he constructed the so-called double chamber together with Rune Walstam.



Sievert around 1923 on Fjällgatan, behind an experimental table in the small partitioned area at Radiumhemmet.

Sievert's Laboratory Work

Sievert began his activities with very limited resources. The central, overarching problem was to quantitatively determine the intensity of radiation for consistent dosing and for better protection of personnel at therapeutic clinics. Work at the physical laboratory at Radiumhemmet thus followed three main developmental lines during the period 1920–1938. These were strongly interconnected and all had the overarching goal of producing methods for radiation measurement.

(1) The first line of development concerned establishing methods for radiation treatment using X-ray apparatus and radium preparations. This involved determining and documenting all X-ray machines and radium sources at Radiumhemmet and constructing so-called radium cannons. This clinical work required the creation of new measurement methods and enabled continuous routine quality control of both patient doses and radiation protection for staff, in cooperation with Radiumhemmet's treatment departments.

(2) The second line of development was applied research aimed at achieving better theoretical understanding of the quantitative nature of radiation in order to develop improved measurement instruments. Studies of the biological effects of radiation were also an important part of this effort.

(3) The third line of development resembled the first but concerned external work at hospitals and private clinics throughout the country. The mobile measurement unit was resource-intensive and soon acquired a separate organizational status in order to be handled properly.

There can be no doubt that it was in the second area that Sievert demonstrated his greatness as a physicist and innovator. But, thanks to his organizational talent and being the head of the laboratory, he also played a central role in the development of the other activities. It nearly goes without saying that the various branches of the work influenced each other. Nevertheless, it is appropriate to distinguish them in order to give Sievert's own contributions as administrator and constructor a sharper profile. Naturally, Sievert drew experience from all

three areas, transferring ideas from one area to another. The construction of a measurement device could thus be directly influenced by an event at Radiumhemmet or in the mobile measurement service. Similarly, a problem at a therapeutic clinic somewhere in the country could lead to action at Radiumhemmet.

A major influence on Sievert's work was the international development of the field, which served as a continuous source of information affecting all three areas. For example, Sievert devoted considerable effort and money to acquiring all literature - primarily journals - that might be of interest. Most of the journals and thus the institution's library, were owned personally by Sievert until his death.[9] It is also evident that some of the measures and investigations Sievert initiated in Sweden had their origins in foreign practices.

Clinical Work

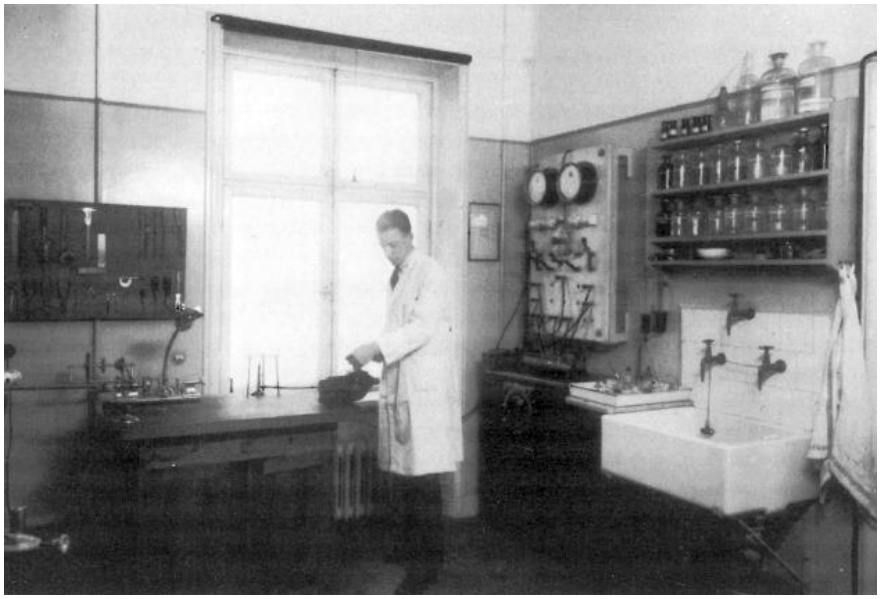
Sievert began his work at Radiumhemmet with scant resources. A small 5 m² partitioned-off area was arranged in 1922 for performing small experiments and constructions. In the Cancer Society's annual report from 1923 one can read that Radiumhemmet made use of "the benefit of voluntary and unpaid collaboration with a radiophysicist."[10] The unpaid radiophysicist was Sievert, who assisted Radiumhemmet with controls of X-ray doses and radium preparations. Sievert had "for this purpose constructed extremely valuable devices and at the clinic also carried out scientific work on the dosing problem."[11]

An early photograph shows Sievert behind the sturdy stone laboratory table with an electroscope before him. He wears the obligatory white hospital coat, unbuttoned, revealing the equally obligatory vest, tie and starched collar. The 5 m² space was naturally far too small to conduct any rational work in a true sense and was intended primarily for simple research experiments involving X-ray tubes and radium preparations. Already in 1923, however, Sievert's first assistant, Paul Haglund, was hired at Radiumhemmet to help the fully occupied but still unpaid physicist.

In 1923 the Cancer Society in Stockholm decided that Radiumhemmet should receive resources to expand its premises. Along with a tumour pathology department, a library and a museum, a radiophysical laboratory was built.[12] Radiumhemmet's physical laboratory officially began operations on 5 July 1924 with Sievert as director, salaried by the Cancer Society. The department, about 40 m², was divided into a high-voltage room, a laboratory, an office and a small 2 m² darkroom.[13] Sievert "conjured up anonymous donors," who donated 30,000 Swedish crowns to the new department. According to the deed of gift, presented to Gösta Forssell in January 1924, this amount was to be:

> used solely for equipment and operation of an X-ray/radium/physical laboratory at Radiumhemmet in Stockholm […].[14]

The deed also stipulated that the Cancer Society should provide an additional 45,000 Swedish crowns for completing the department's equipment. The Cancer Society was furthermore to guarantee the laboratory's maintenance and upkeep for at least five years.[15] The anonymous donor was almost certainly Sievert himself, particularly since the deed ended with:



Sievert's assistant Paul Hag in 1926 in the laboratory section at the Physics Laboratory on Fjällgatan. The image captures much of the scope of the work in radiation physics. On the left of the image is a precision lathe, on the right storage bottles for chemical liquids.

As the donors are personally acquainted with Professor Gösta Forssell, any discussion concerning the matter can take place through him [Forssell].[16]

During the first months the focus was on equipping the laboratory and constructing measurement devices for studying radiation through protective walls.[17] A number of instruments were purchased, mainly precision instruments for electrical measurements, a Zeeman X-ray spectrograph and some smaller devices.[18] As measurement techniques evolved, ever more precise instruments were acquired or developed. New X-ray apparatus, spectroscopes, microscopes - in short, more instruments for an expanding operation - were added. In the first annual report for the physical laboratory (1924), Sievert wrote:

The following instruments […] have been constructed and examined at the laboratory:

(1) An electroscope device for determining very small amounts of radiation.
(2) An instrument for measuring the intensity of X-rays using a galvanometer, to which a self-recording device can be attached.
(3) An instrument for rapid depth-dose measurements with X-rays.
(4) A temperature-measuring instrument consisting of thermoelement, thermostat and galvanometer for rapid temperature measurements in tissues.[19]

From the outset there was extensive daily work aimed at better determining the radiation environment at Radiumhemmet for personnel, developing more precise dose methods for patient treatments and determining variations between different preparations.

Control measurements of Radiumhemmet's radium preparations were carried out and a certificate register for all preparations was established.[20] One of the tubes was compared with the national radium standard to serve as a secondary standard at Radiumhemmet and a few years later this national standard was transferred to the physical laboratory for permanent storage.[21] Sievert drove a conscious expansion of resources in the measurement area. In the 1929 annual report, he stated that the laboratory was now "fully on par with the foremost laboratories in the world in regard to the examination of radium preparations submitted for testing in medical radiology".[22] All X-ray apparatuses at Radiumhemmet were checked and measurement statistics were kept in order to determine deviations. Radiation intensity was



Radium was a costly product that was difficult to extract and the arrival of new radium at the department was a major event. Radium was delivered in lead containers, the kind standing on the floor in front of the group. The shipments were heavy and arduous to transport. Pictured: Sievert in the centre, flanked by Sven Benner (standing) and Elis Berven in white coats, as well as Torsten Magnusson (standing) and Arne Forssberg.

checked three to four times per week with a simplified galvanometer device. A special workspace with surrounding lead walls was constructed for X-ray examinations.

By late 1927, operations at Radiumhemmet had expanded so much that Sievert's access to X-ray machines had become severely reduced. Thanks to his academic contacts, however, Sievert was able to carry out examinations on an X-ray tube at the Nobel Institute of Physical Chemistry.[23]

The expansion led Sievert to develop proposals for a larger laboratory which he presented to the Cancer Society. The proposal, which involved an expansion to 200 m², was accepted and by the end of 1929 Sievert could move into new premises located at Fjällgatan 20A on Södermalm in Stockholm. A smaller basement laboratory was used for the mobile measurement unit. The main laboratory consisted of two rooms for radium work, two X-ray laboratories, a workshop and some smaller spaces. A permanent device for calibration of X-ray apparatuses was installed and in a dedicated laboratory an instrument was set up for quantitative determination of radioactive substances using the gamma-radiation method.[24]

Prior to the decision to undertake this reconstruction, Sievert demonstrated what would become characteristic: his interest in architecture, drawings and buildings, something that later became well known. Sievert employed a clear strategy of preparing his proposals as meticulously as possible, since he believed that the chances of getting a proposal accepted increased when no competing concrete proposal existed. This strategy seems to have been tested during this reconstruction. The analysis and cost calculations had to be ready and - as Sievert expressed it - "preferably the contractor's bid as well."[25]

In late 1929, Sievert carried out a first change in staff work hours to reduce exposure times during radium handling.[26] The measure must be seen in light of the International X-ray and Radium Protection Committee formed in Stockholm in 1928 and its adopted recommendations for work with X-rays and radium.

Once the condenser chamber method had been fully developed, much of the measurement work shifted to this method for both radium and X-ray measurements. Many patient treatments included, as a routine measure, a measurement with condenser chamber and staff carried small condenser chambers to determine their own received dose. A series of measurements on the intensity distribution during intrauterine radium applications was carried out. Throughout the period up to the Second World War, there was a continuous development of instruments at Radiumhemmet, all of which bore Sievert's imprint. Sievert continued even after the war to design measurement instruments, but the growing use of American apparatuses made his own inventions less dominant. Unsatisfactory risks and high radiation levels often led to new devices - for example, the new radium cannon which was developed after measurements had shown too much leakage from the old one yielding an unacceptably high risk to personnel.[27]

The Mobile Measurement Unit

In the autumn of 1925, Sievert travelled to the Physikalisch-Technische Reichsanstalt in Charlottenburg (Berlin) to calibrate his instruments in the established X-ray unit (the "R-unit"). "As of 1 January 1926," he wrote in the annual report for 1925, "dosage of X-rays at Radiumhemmet will be in R-units, defined as a physically definable skin dose."[28] The calibration was important because it allowed comparison of conditions in Swedish hospitals with those abroad. That same autumn Sievert visted all Swedish hospitals conducting radiation therapy in order to compile statistics in R-units on the skin erythema doses (SED) used.[29] The idea for the collection of statistics Sievert had obtained from similar studies in Germany and France, published in journals such as The American Journal of Roentgenology.[30] The results showed that for a given radiation quality, the SED could vary by as much as a factor of four between hospitals.[31] Sievert, therefore, immediately introduced a physical average dose at Radiumhemmet and he and Forssell began discussing improved standardization. These discussions led to planning of a mobile measurement unit whose task would be to make regular visits to all radiotherapy clinics for checking their apparatus and for standardizing X-ray dosage. The unit was organized to be administratively and financially independent from the physical laboratory but was allowed to use all its instruments. Sievert, who had a fondness for elegant instruments and pleasing design, donated money so that the portable instruments could be stored in suitable cases.

Sievert began the first year of operation, which commenced on 1 May 1926, by visiting nine different hospitals in Sweden. He soon observed that "the interest which the mobile unit has attracted indicates that it meets an existing need."[32] However, he quickly grew tired of the travelling and in early 1927 hired the civil engineer Robert Thoræus (1895–1970) to take over the responsibility for the unit.[33]

By 1929 the mobile unit had grown and Thoræus visited 27 departments.[34] The inspection of X-ray apparatus and dosing meant that Sievert soon had built up a detailed overview of all



The mobile measurement unit's instruments for measuring X-ray therapy equipment. To the left, a control console, a recorder and a measuring device for current, voltage, or resistance. On the table directly ahead, likely an electrometer (1930).

Swedish X-ray operations. Everything of interest was now documented - types of equipment, local operating conditions - and available at the physical laboratory where hospitals could access the accumulated experience. For the same purpose, Sievert attempted to maintain as complete a library as possible of foreign radiological journals.

During visits, the mobile unit measured high voltage, tube current and dose rate and provided assistance with any problems encountered. Sometimes detective work was needed to determine the cause of incorrect dosing - Thoræus reported reversed components and mis-marked X-ray machines. The mobile unit recommended operating conditions that took into account not only radiation protection but also economic factors such as expected lifespan of the apparatus. The interval between visits varied but most institutions were visited approximately every six months. Each X-ray tube was equipped with a control card to be filled in each month by the staff where operating time and number of treatments were recorded for statistical purposes. The overwhelming majority of X-ray tubes were of AEG *(Allgemeine Elektrizitäts-Gesellschaft*) manufacture.

Since the mobile unit was to be financially independent, it charged a fee set by the Cancer Society: 200 Swedish crowns per visit for the first treatment room and 100 Swedish crowns for each additional room.

With the expansion of the physical laboratory in 1929, the mobile unit also received larger premises. Sievert had borrowed an X-ray tube from the Nobel Institute that could be used by the unit for its tests. The unit was also called upon whenever hospitals expanded or modernized their radiological facilities and carried out a number of investigations for various hospitals.

During the early years of the mobile unit, the only major technical change in Swedish hospitals was the transition from direct current to alternating current operation. Thoræus wrote:

> From a technical standpoint, alternating current is preferable since both the apparatus and its operation thereby become somewhat simplified.[35]

Already in Stockholm in 1928, the International X-ray and Radium Protection Committee had recommended a new dosage unit.[36] Sievert, as a member of the committee, worked for its rapid introduction in Sweden as well. From 1 January 1936 the Swedish Association for Medical Radiology decided that all dosage should be given in this international "r-unit," which had a definition different from that of the R-unit. Prior to this decision the mobile unit conducted numerous investigations and prepared and printed conversion tables from SED to the r-unit. Yet, Sievert regarded even this r-unit as a blunt instrument and in 1937 he wrote in *Acta Radiologica*:

> the r-unit is a correct dosage unit only if the biological effect of radiation is proportional to the ionization in air and independent of the quality of the radiation.[37]

At the same time, external measurements of quantities of radium for hospitals and clinics throughout the Nordic countries were carried out at the physical laboratory. Determination of radium quantities, however, was never incorporated into the mobile measurement work which remained dedicated solely to X-ray apparatus. It was only after the reorganization of Sievert's activities in connection with the Radiation Protection Act of 1941 that the radioactivity measurements became extensive enough to require a dedicated department.

Researcher and Constructor

The core of Sievert's work as researcher and constructor lay, as already noted, primarily in the period before the Second World War. Even though he continued after the war to be engaged in research and construction, organizational and international matters demanded increasing time and attention.

Around late 1920 and early 1921, Sievert published a study on the intensity of gamma radiation near non-point-like radium sources and provided a mathematical expression for the distribution. In radiotherapy, radium preparations were introduced into various body cavities and to give proper treatment preparations were applied in various geometrical forms. It was therefore essential to know the radiation distribution around the preparation. Prior to Sievert's work, knowledge of this distribution was poor.

Through Gösta Forssell's mediation, Radiumhemmet provided radium for the work. The experimental work was carried out at the Nobel Institute for Physical Chemistry under the supervision of Professor Svante Arrhenius.[38] *Acta Radiologica* published Sievert's paper in 1921: "Die Intensitätsverteilung der primären γ-Strahlung in der Nähe medizinischer Radiumpräparate."[39] In the paper, he emphasized the link between, on the one hand, insufficient knowledge of the physical dose and, on the other hand, the contradictory results in medical research regarding the biological effects of radiation. This early work laid the foundation for calculating radiation distributions and contained a tabulated integral, which was later expanded in several publications. In the English-language literature this integral became known as Sievert's integral.

One conclusion Sievert drew was that the German radiophysicists Walter Friedrich and Otto Glasser - who had worked on the same problem - must have arrived at incorrect results. His publication was followed by an exchange of letters between Glasser and Sievert regarding the intensity distribution. Friedrich was an authority on the subject and a well-known physicist

who had begun work with deep-therapy at the University of Freiburg during the First World War.[40] Sievert argued with scientific clarity when Glasser accused him of using formulas Glasser had previously derived and published in his 1919 dissertation. Sievert replied in *Acta Radiologica* that he had been unable to find this dissertation in the normally well-stocked Swedish libraries, but added: "A comparison of the results would certainly have been interesting."[41] In the summary of his article "Zur Frage der Intensitätsverteilung der γ-Strahlen in der Nähe medizinischer Radiumpräparate," Sievert wrote unequivocally:

> The […] article shows that most of the assertions given in this Journal […] by O. Glasser regarding the distribution of γ-ray-intensity at short distances from medical preparations are quite untenable. Further, it is pointed out that mistakes will easily be made in the use of the word 'isodoses' as the name for lines or planes of equal intensity.[42]

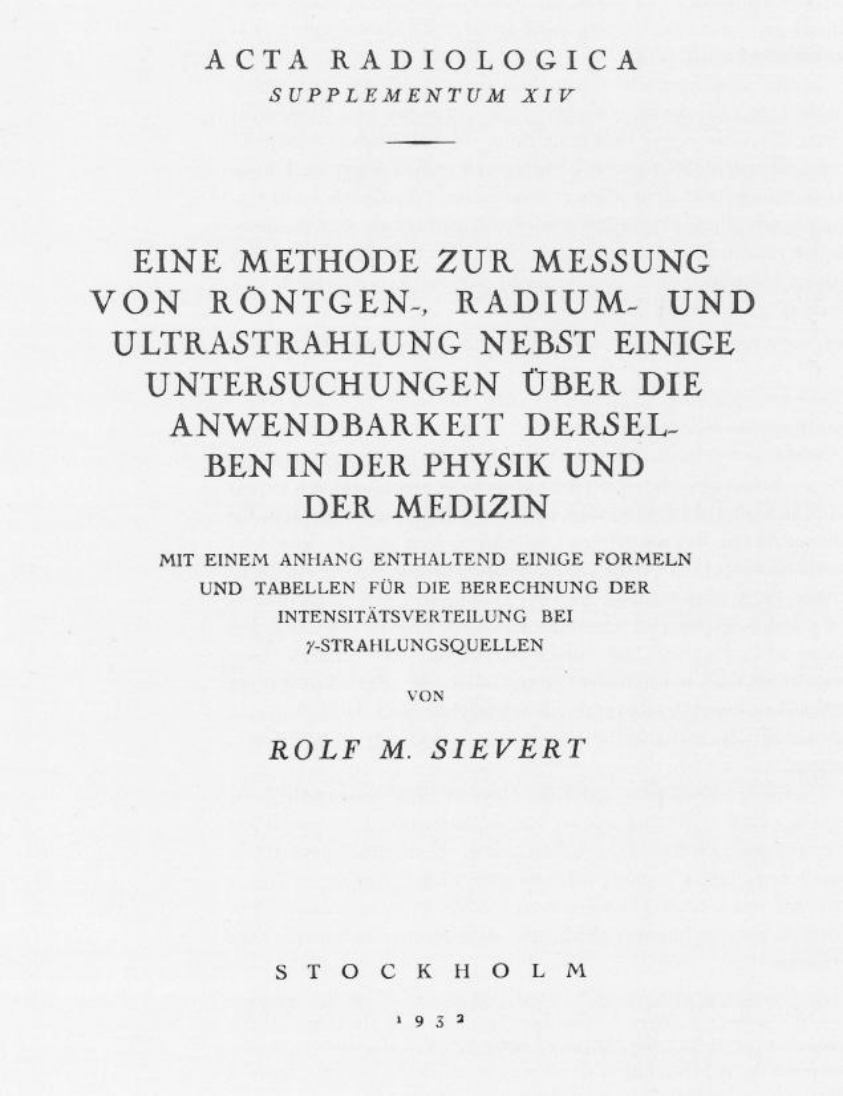
In the matter of isodose curves, Sievert also opposed Glasser's proposal in the major German journal *Zeitschrift für Physik*.[43] After these two articles by Sievert, no reply from Glasser is documented and it appears therefore that Sievert had the final word in this scientific controversy - something that must have strengthened his self-confidence.[44]

Ten years later Sievert completed a major work on determining the intensity distribution around radium preparations. This was a continuation of his 1920 work but contained a more detailed theoretical investigation. In this publication Sievert tabulated the Sievert integral extensively for calculating radiation distributions in different source geometries.

In mid-1923, Sievert published a paper in *Acta Radiologica* dealing with secondary radiation in radiotherapy.[45] The problem was of considerable interest, since primary radiation gives rise to secondary radiation. Both beta and gamma rays are scattered from irradiated tissues due to changes in the direction and energy of incoming rays as atoms scatter them. The irradiated tissue then becomes a source of secondary radiation. Surrounding tissue not intended for irradiation can thus receive a dose. Although this is an inevitable physical phenomenon, it was of great interest to determine the energy and intensity of secondary radiation in various directions. Sievert presented in the paper three theorems of principal relevance for calculating secondary radiation at a given point. These could be applied when interpreting measurements from ionization chambers. He discussed the requirements for chamber material and thickness to achieve correct measurements.[46]

This paper rested heavily on Sievert's construction earlier in 1923 of the first measurement instrument for gamma and beta intensity. The instrument's advantage was its speed, since the measurement method was based on comparisons between the unknown intensity and a known standard. Its disadvantage was that the device was bulky with a long tube that became difficult to handle. In 1923 Sievert also investigated the secondary radiation produced by radium preparations by measuring intensity behind the protective shields at Radiumhemmet. He sketched some simple rules of thumb to avoid personnel overexposure and initiated experiments on radiation absorption in biological tissues.

The problem of exposed personnel drew increasing interest and in 1924 Sievert began an investigation at Radiumhemmet to determine radiation levels behind the protective shields used in daily therapy. He proposed several Radiumhemmet-specific protection measures. The apparatus prepared for the measurements was constructed with the help of Professor Gustaf



ACTA RADIOLOGICA
SUPPLEMENTUM XIV

EINE METHODE ZUR MESSUNG VON RÖNTGEN-, RADIUM- UND ULTRASTRAHLUNG NEBST EINIGE UNTERSUCHUNGEN ÜBER DIE ANWENDBARKEIT DERSELBEN IN DER PHYSIK UND DER MEDIZIN

MIT EINEM ANHANG ENTHALTEND EINIGE FORMELN UND TABELLEN FÜR DIE BERECHNUNG DER INTENSITÄTSVERTEILUNG BEI γ-STRAHLUNGSQUELLEN

VON

ROLF M. SIEVERT

STOCKHOLM

1932

The title page of Sievert's doctoral thesis, presented at Uppsala University within the Faculty of Mathematics and Natural Sciences on May 26, 1932.

Ising at Stockholm University College (since 1960: Stockholm University), who had earlier assisted Sievert.

The same year as this investigation, Sievert constructed a portable instrument for X-ray intensity measurement. It quickly became part of Radiumhemmet's routine and each X-ray tube was checked twice per month. This periodicity was later recommended by the mobile measurement unit in its guidelines. The knowledge gained at Radiumhemmet resulted in recommendations for other X-ray clinics in Sweden. The interaction between external and internal experience, established early on, proved vital for the laboratory's role as a centre of expertise and for Sievert's increasingly clear position as the leader of Swedish radiation physics.

Soon Sievert also began studies to determine radiation transmission through building materials. He used the so-called "lead equivalence" for comparative studies - that is the thickness of a given material that produced the same absorption as a specified thickness of lead. Work on the optimal wall materials and dimensions was later taken over by laboratory staff, including Robert Thoræus.

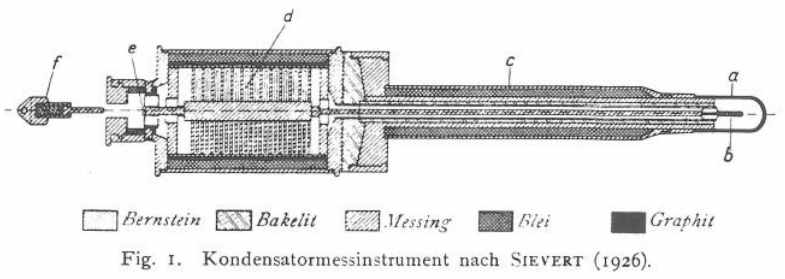


Fig. 1. Kondensatormessinstrument nach SIEVERT (1926).

The first measuring instrument that Sievert designed was based on the ionization chamber principle. Regarding the instrument, Sievert said long afterwards that the design was certainly simple, but by no means reliable.

Already early on, quack doctors were attracted to the idea of selling radium products claiming various healing effects. The company Hälsokällan (meaning source of health), for example, marketed radium emanation devices said to reduce white-blood-cell counts and increase sexual vigor. "Why is Vestersel's strongly radioactive health water so superior?" asked a brochure from the Vestersel Radium Spring in Bjästa.[47] In 1926 Sievert undertook to examine the commercially available "radium cloth" Radiwoll and issued a scathing verdict on its supposed properties - which included curing beard fungus. After measuring the extremely low activity, he concluded: "It would indeed be interesting to see the face of the person who tried to remove his beard fungus with Radiwoll."[48]

The Condenser Chamber Method

What became Sievert's greatest success as a designer was the condenser chamber method. In 1926 Sievert formulated the principle of the condenser chamber, based on radiation-induced ionization of gases. The design came to be Sievert's major contribution to medical radiology. Sievert set four fundamental requirements for the measurement method: (1) The detector had to be electrically isolated from the readout instrument during measurement. (2) The measurement should not be affected by mechanical shocks. (3) The measurement range must include all doses used in therapy. (4) The method had to be applicable for both surface and depth-dose measurements.

Earlier equipment consisted of an ionization chamber, electrometer and a cable between them. The electrometer measured the current arising when air was ionized within the chamber and the apparatus was bulky. Reading the electrometer required the presence of a physicist during the measurement which was demanding in terms of staff. Sievert's innovation was to separate the ionization chamber from the evaluating electrometer. With the new method the physicist did not need to be present during irradiation and the ionization chamber could be sent to him afterwards for evaluation. The design also solved the problem of high staff exposure during high-intensity measurements - no one had to be present in the irradiated area to read the result. This seemingly simple solution met all criteria for a brilliant idea.[49]

The method was presented in *Acta Radiologica* in 1926 in the article "Eine einfache, zuverlässige Vorrichtung zum Messen von Tiefendosen" (A simple, reliable device for depth-dose measurement). The principle was simple: a capacitor with a connected gas volume was charged to a known potential. X-ray or radium radiation ionized the gas in the chamber, causing the charge to be transported and the capacitor discharged proportionally to the dose received. The capacitor walls were usually insulated with amber. The reduced voltage was later read and, knowing the irradiation time, the intensity could be calculated.[50]



Group photo from the laboratory on Fjällgatan. The image is likely one of the last taken before the Physics Laboratory moved to new premises in Solna and simultaneously became a department. The laboratory was set up in almost the same way at the new location. The distinctive protective circular enclosure visible on the left was also present in Solna. Seated from left: Robert Thoræus, Sievert, Sven Benner. Standing from left: Paul Haglund, Vera von Cronsteen, Lilly Wicksen, Bernström, Ulla Gard (married name Forssberg), an unidentified woman and Arne Forssberg.

In 1931 Sievert published preliminary results of further development and wrote: "the author sets great hopes on this method and will publish more detailed and expanded studies later."[51] The most important change was the construction of an alternative ionization chamber that could also function as a capacitor of appropriate capacitance at low dose levels. Thus the method had two main applications: large-capacitance chambers for high patient doses and small-capacitance ionization chambers for the low doses received by personnel.[52] Protection routines could now be simplified and improved.

The condenser chamber method required significant development work and Sievert later noted that although the method was simple at first, it was certainly not reliable.[53] A problem was that the chamber sometimes fully discharged during measurement. However, together with the instrument maker Ragnar Scheer in Stockholm, Sievert improved the designs making the chambers less sensitive to disturbances and cheaper to manufacture. Special chambers were built for measurements in water phantoms and many shapes were constructed to measure doses inside and outside the body.

The extensive research presented in Sievert's doctoral dissertation (1932) showed that the method "could not be considered less accurate than other methods" using larger stationary equipment. The smallest chamber, only 14 mm in diameter, could even be mailed and chambers were sent between Stockholm and New York for measurements at an American hospital.



A large part of the staff at Radiumhemmet around 1935. Sievert is seated fourth from the right in the front row, flanked by Elis Berven on the left and Robert Thoræus on the right.

The method was soon introduced into daily routines at Radiumhemmet. The modest size of the chamber made it easy to attach to various body parts and cavities, improving control over dose delivery. Personnel protection could also be extended and monitored at reasonable cost. The condenser chamber had been developed primarily to meet the physicians' need for better depth-dose measurement during treatment and to reduce staff exposure but the experience gained allowed Sievert to develop a general method for radiation-protection measurements.
The chambers soon spread internationally. Manufactured in many designs, they were usually called "Bg-chambers," referring to the basic materials: **b**ernstein (amber) and **g**raphite. Internationally they were called "Sievert chambers." Precision and cleanliness in assembly reduced electrical leakage to negligible levels, making them very useful and practical detectors in medicine.

Biological Effects of Radiation

One area to which Sievert devoted much time and energy was the biological effects caused by radiation, especially the role of time in irradiation. This work began in 1929 when he hired the biologist Arne Forssberg (1904–1975) part-time as assistant. In 1931, Sievert and Forssberg conducted experiments on the eggs of the fruit fly (*Drosophila melangoster*) by irradiating eggs for different durations and with different dose intensities, comparing their development with that of unirradiated eggs. Their initial experiments revealed no statistically significant effects and they concluded – correctly - that a large sample size would be required to reach reliable results.[54]
In the early 1940s Sievert, together with Sven Benner (1900–1986), studied how pressure in an ionization chamber affected air ionization. He discussed ionization in very small air volumes

and in an article in *Acta Radiologica* he questioned whether ionization measurements could meaningfully be related to biological and medical effects:

> I wish to emphasize that our lack of knowledge, not only of the ionization near the surface of different substances, but also - and not least - of the mechanism of the biological effects of radiation, gives us reason to question the suitability and reliability of the present ionisation methods as a means of measuring radiation for biological and medical purposes.[55]

The biological work reached a kind of theoretical peak in 1941 when Sievert presented a mathematical description of the interaction processes between different materials in irradiated tissue. He assumed that some vital substance in a cell is affected during irradiation. The cell then attempts to compensate for the change, like a physical system seeking equilibrium. By studying the cell's reaction time and biochemical processes, it was thought possible to obtain a theoretical description of the sequence of events. The theory consisted of differential equations that could only be solved graphically which limited its usefulness. The time-consuming calculations required discouraged practical application. Later, however, researchers in other countries took up the theoretical model and were partially able to verify Sievert's theory.

The biological problem remained unresolved throughout Sievert's life. Repeated attempts in the 1940s and 1950s never led to a satisfactory solution. A long-term experiment in which fruit fly eggs developed in a radiation-reduced environment was conducted in the mid-40s but did not result in any fundamental understanding of radiation's biological mechanisms. Arne Forssberg nonetheless published a paper about the experiments.[56]

Units

In parallel with this research, Sievert was deeply engaged in discussions on radiation units. Already in the early 1930s (before the Third International Radiology Congress) he proposed the introduction of a new unit for intensity called "Intensity Roentgen" (Ir), which would simplify therapeutic dosing.[57] In 1928 the committee on units at the Radiology Congress in Stockholm had determined that the X-ray dose "1 r" should be defined as the radiation that releases a specified amount of charge in air under given conditions. Sievert wished to complement this definition with a time factor, proposing that 1 r be generated during one minute, giving a measure of intensity rather than dose. His argument for the new unit was:

> When using rays of constant quality, the X-ray dosage will be equal to a constant intensity radiation time. As we do not yet know for certain whether the same doses, if given at different times, will have the same therapeutic effects, it is of greatest importance that the time of radiation is always stated when assigning the dose.[58]

Similarly, as early as 1921, Sievert proposed a unit for gamma-ray intensity called "Intensity Curie" (Ic), defined as the intensity at 1 cm from 1 gram of radium in equilibrium with its daughters and encapsulated in 1/2 mm of platinum.[59]

Many physicists argued that gamma radiation should also be measured by its ionizing capacity so that as few units as possible would be needed. Sievert, however, pointed out that such a unit had no practical application in daily radiotherapy. This argument, he believed, outweighed the advantages of fewer units.



Workshop manager Axel Berggren in a white coat in front of the entrance to the Department of Radio Physics in 1942. He is flanked by the two instrument makers Törnqvist and Arvid Matsson.

Bridging the gap between theoretical science and practical applications

The core of Sievert's work lay in a field that may be described as "bridging the gap between theoretical science and practical applications." His work was always concrete and based on specific problems, drawing daily nourishment from the experiences at Radiumhemmet. A fitting description of Sievert is that he moved along the boundary between applied scientific research and non-scientific construction and innovation.[60]

The distinction matters only if one defines both applied scientific research and non-scientific construction and innovation. The aim of scientific basic research is to increase knowledge within a field usually documented in a dissertation or article. Applied scientific research creates something specific to reach a predetermined goal - in this case better dosimetry methods. Non-scientific construction and innovation occur under conditions similar to those in industry: incremental improvement or refinement of existing products or methods.

Sievert moved between these fields. He did not study new phenomena but deepened knowledge of radiation and dose distribution where it had direct practical relevance for Radiumhemmet. While improving measurement methods, he made use of long-established principles such as air ionization and constructed numerous variations of his condenser chamber.

It is impossible to know whether Sievert would have accepted such definitions. But this constant interplay must have suited him well. His academic, theoretically oriented disposition worked alongside his marked personal traits - decisiveness, impulsiveness and a practical, constructive talent.



The new workshop at the Department of Radio Physics. It was here that Berggren, Håkansson and others designed and manufactured measuring instruments based on Sievert's ideas. Sievert would order overtime if he considered a particular design urgent. On such occasions, he would often bring down a tray with sandwiches and beer—partly so the work could continue and partly so he could see for himself how it was progressing.

Gustaf V's Jubilee Clinic

With the founding of the physical laboratory in 1924, the work that would become the Radiation Physics Institute began. Yet, if one looks back to the founding of Radiumhemmet itself, one notices similarities in how both organizations developed. This is noteworthy because Sievert was an enthusiastic organizer. He loved drawing organizational charts and proposing new improvements.[61] A study of organizational development reveals a strong centralist tendency in Sievert. He was a rationalist and the structure he sought - large units under a small but powerful central authority - was characteristic of the era and shaped Swedish society profoundly. This tendency later led to some conflicts within the Radiation Physics Institute when a revised radiation protection law was developed in the 1950s.

Both Radiumhemmet and the Radiation Physics Institute experienced an initial period of separation and identity-building followed by a period marked by centralizing ambitions to rationalize operations. Both succeeded and became internationally leading institutions: Radiumhemmet in the 1930s and the Radiation Physics Institute in the 1950s. Their developments were parallel but time-shifted by about twenty years, with Radiumhemmet leading the way.

The decisive development for Radiumhemmet occurred when it moved to Norrbacka in Solna and became part of the Karolinska Hospital under the name Gustaf V's Jubilee Clinic. At the same time, the Radiation Physics Institute was established as an independent unit largely due to Sievert's energetic efforts.[62]

Already in 1926 the government had appointed a commission to investigate a new hospital in Stockholm and new premises for the Karolinska Institute.[63] The next year the Swedish parliament reserved land in Solna for this purpose.[64] The financial basis for new premises for Radiumhemmet was created in 1928 when King Gustaf V donated the gift he had received from the Swedish people on his 70th birthday to cancer research in Sweden. The gift amounted to over 5 million Swedish crowns and the Gustaf V Jubilee Fund was established with Gösta Forssell as chairman, to administer the funds.[65] The Cancer Society's board and the hospital commission approached the Jubilee Fund and they agreed on a program for establishing a radiotherapeutic clinic at Karolinska Hospital.

According to the first plans, Radiumhemmet would consist of four departments located under one roof in a large building complex. X-ray diagnostics and radiotherapy were to be located in the central building while radiopathology and radiation physics would be placed in a smaller building connected via a corridor. Sievert opposed this arrangement. He wanted a freestanding building for radiation physics and argued two reasons. First, Radiumhemmet handled preparations that occasionally leaked radon making sensitive measurements impossible if there were a physical connection through which radon could spread.[66] Second - and most important - such a connection would hinder future expansion of radiation physics, if it were too closely tied to Radiumhemmet.[67]

Sievert - thus in conflict with the appointed building committee - developed a separate proposal with the architect Malm, which he submitted to the Cancer Society's board. The proposal was accepted and the Radiation Physics Institute could move into its own new building located about 100 meters north of the Jubilee Clinic. The building consisted of three floors totalling 850 m². On the top floor Sievert had a service apartment of five rooms and kitchen, his home in Stockholm until his retirement in 1965.

A reason for why the building could not be completed until ten years after the royal donation was the question of the organizational affiliation of the Radiation Pathology Department.[68] Radiation pathology belonged administratively to Radiumhemmet but should, by nature of its tumour-diagnostic and teaching functions, belong to the Karolinska Institute. After lengthy investigation, in 1934, an agreement was reached on a proposal from the university chancellor. The proposal established a governing board consisting of a representative from the Jubilee Fund as chair, the head of Radiumhemmet, the two department heads of radiopathology and radiation physics and a representative from the Karolinska Institute's faculty. This ensured faculty influence over pathological diagnosis and research at Radiumhemmet.[69]

One year after the inauguration of the Jubilee Clinic in 1938, the department heads of radiation pathology and radiation physics issued a proposal that resulted in both becoming separate institutions in 1941. They belonged to the Karolinska Institute but also functioned as independent units within the Jubilee Clinic.[70] The reorganization was intimately related to Sweden's first Radiation Protection Act, adopted the same year.[71]

The freestanding building of the Radiation Physics Institute symbolized the increasingly independent radiophysical operations. The fundamental basis for this independence was the mobile measurement unit which meant that the Institute served the entire country. Although formal permissions were granted by the National Medical Board, the Radiation Physics Institute effectively handled all relevant applications. As a consequence, the Institute addressed nearly all major radiophysical and technical problems at Radiumhemmet. This model later became the template for hospitals throughout Sweden. At the Jubilee Clinic, Sievert was responsible for medical physics until his retirement.

4. International Engagement

The Radiology Congress in Stockholm 1928

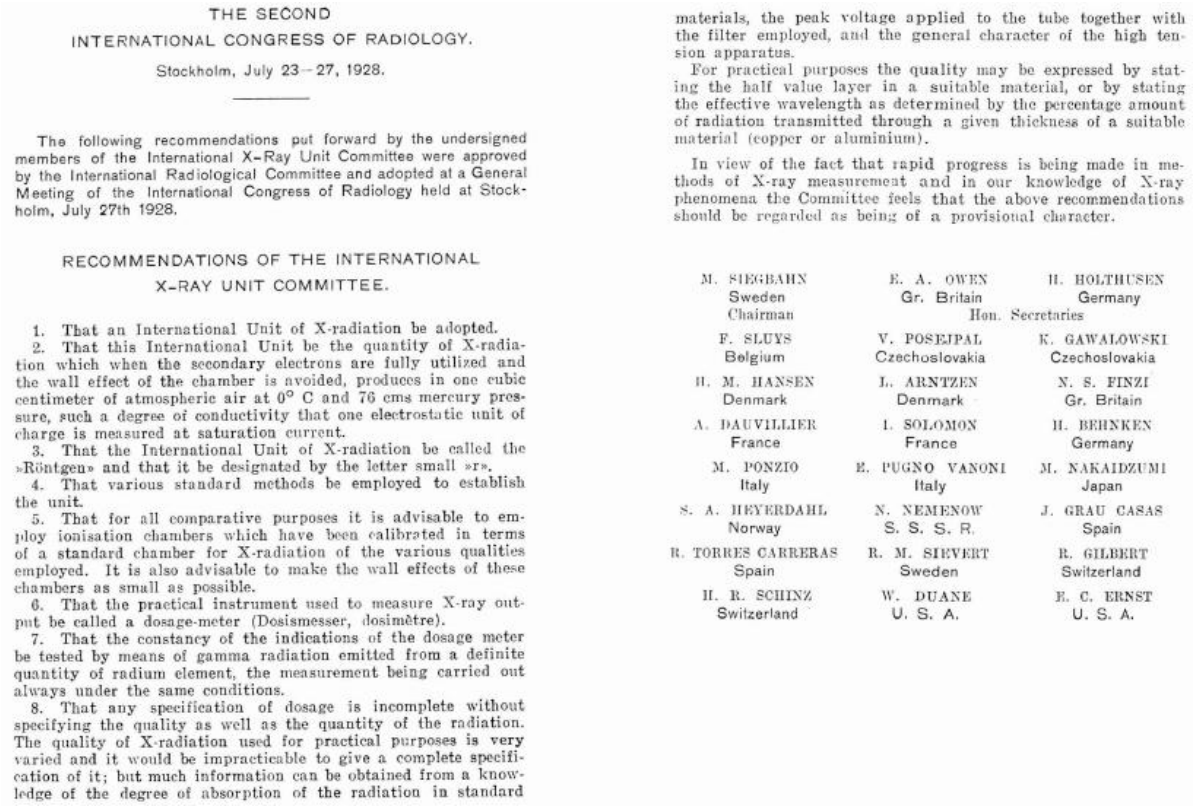
In the early 1920s, the use of the hot-cathode X-ray tube invented in 1913 by William David Coolidge, became increasingly widespread.[1] The hot-cathode X-ray tube could deliver radiation with significantly higher energy than the early gas X-ray tubes and could therefore also cause more serious and deeper-seated radiation injuries. During and after the First World War, the use of X-rays increased dramatically. Over time, an elevated number of cases of aplastic anaemia (anaemia due to radiation damage to the bone marrow) was observed among those who had worked with X-rays in military medical services. The hazards of radiation attracted publicity and the newspapers drove the development of radiation-protection measures.[2]

In the mid-1920s, researchers attempted to determine the harmful effects of radiation on humans. Early on, they sought analogies with toxicology (the science of poisons), where one of the most important aspects is to identify the threshold dose at which a toxin begins to act and they assumed that the same type of reasoning could be applied to radiation. For therapeutic applications, establishing a tolerance dose for healthy tissue was crucial. It was known that tissue exposed to a harmful dose of radiation did not tolerate repeated irradiation even if the damage had healed. The skin seemed to have the ability to "remember" previous irradiation. The only dose that could be guaranteed harmless was the dose that in no way affected the body. The fundamental problem was that one could not prove how far this line of reasoning held, since it was based partly on experience and partly on assumptions.[3]

It became clear early that some of the radiation energy was absorbed by cells. In X-ray irradiation of materials such as lead, researchers could observe fluorescence. If a cell receives a sufficiently large amount of energy - it dies. Hence, an innocuous dose was defined as a dose insufficient to kill or damage the cell. More commonly, however, an innocuous dose was said to be a dose after which no change in biological function could be detected.[4] In 1927, the geneticist Hermann Muller discovered that X-ray radiation could induce stable mutations of the same character as spontaneously occurring mutations. Chromosomes (that, as we now know are composed of the DNA chain) could break and rejoin in a variety of ways in consequence of intense irradiation. In 1946 Muller received the Nobel Prize for this discovery.[5]

Great efforts were made to establish a dose that could be accepted for radiological work. From observations it was known that a given dose, spread over a long time, was less dangerous than the same dose delivered over a short time. In the USA, the American Roentgen Ray Society formed a radiation protection committee in 1920, followed by a British counterpart a year later.[6] Work on defining a tolerance dose led, in 1925, to the American Arthur Mutscheller numerically deriving the first tolerance dose, which he set at one-hundredth of a skin erythema dose (SED) per month.[7]

At the first International Radiology Congress in London in 1925, convened at British initiative, detailed discussions were held on the need for radiation-protection recommendations and the



THE SECOND
INTERNATIONAL CONGRESS OF RADIOLOGY.
Stockholm, July 23 – 27, 1928.

The following recommendations put forward by the undersigned members of the International X-Ray Unit Committee were approved by the International Radiological Committee and adopted at a General Meeting of the International Congress of Radiology held at Stockholm, July 27th 1928.

RECOMMENDATIONS OF THE INTERNATIONAL X-RAY UNIT COMMITTEE.

1. That an International Unit of X-radiation be adopted.
2. That this International Unit be the quantity of X-radiation which when the secondary electrons are fully utilized and the wall effect of the chamber is avoided, produces in one cubic centimeter of atmospheric air at 0° C and 76 cms mercury pressure, such a degree of conductivity that one electrostatic unit of charge is measured at saturation current.
3. That the International Unit of X-radiation be called the »Röntgen» and that it be designated by the letter small »r».
4. That various standard methods be employed to establish the unit.
5. That for all comparative purposes it is advisable to employ ionisation chambers which have been calibrated in terms of a standard chamber for X-radiation of the various qualities employed. It is also advisable to make the wall effects of these chambers as small as possible.
6. That the practical instrument used to measure X-ray output be called a dosage-meter (Dosismesser, dosimètre).
7. That the constancy of the indications of the dosage meter be tested by means of gamma radiation emitted from a definite quantity of radium element, the measurement being carried out always under the same conditions.
8. That any specification of dosage is incomplete without specifying the quality as well as the quantity of the radiation. The quality of X-radiation used for practical purposes is very varied and it would be impracticable to give a complete specification of it; but much information can be obtained from a knowledge of the degree of absorption of the radiation in standard materials, the peak voltage applied to the tube together with the filter employed, and the general character of the high tension apparatus.

For practical purposes the quality may be expressed by stating the half value layer in a suitable material, or by stating the effective wavelength as determined by the percentage amount of radiation transmitted through a given thickness of a suitable material (copper or aluminium).

In view of the fact that rapid progress is being made in methods of X-ray measurement and in our knowledge of X-ray phenomena the Committee feels that the above recommendations should be regarded as being of a provisional character.

M. SIEGBAHN Sweden Chairman	E. A. OWEN Gr. Britain Hon. Secretaries	H. HOLTHUSEN Germany
F. SLUYS Belgium	V. POSEJPAL Czechoslovakia	K. GAWALOWSKI Czechoslovakia
H. M. HANSEN Denmark	L. ARNTZEN Denmark	N. S. FINZI Gr. Britain
A. DAUVILLIER France	I. SOLOMON France	H. BEHNKEN Germany
M. PONZIO Italy	E. PUGNO VANONI Italy	M. NAKAIDZUMI Japan
S. A. HEYERDAHL Norway	N. NEMENOW S. S. S. R.	J. GRAU CASAS Spain
R. TORRES CARRERAS Spain	R. M. SIEVERT Sweden	R. GILBERT Switzerland
H. R. SCHINZ Switzerland	W. DUANE U. S. A.	E. C. ERNST U. S. A.

The Commission on Radiation Units drafted guidelines for how to define an r-unit. It was decided to recommend that this unit be measured using an ionization chamber to facilitate comparisons, that the term "dosimeter" be used and that any specification regarding the radiation be considered incomplete unless the radiation quality was stated alongside the quantity. Representatives from no fewer than 14 countries signed these recommendations.

establishment of universal units. A result of these discussions was the formation of an unofficial group to study the question of units. The group was tasked with reporting at the next radiology congress in Stockholm three years later. Since the issue of radiation protection was deferred to the Stockholm meeting, this led to intense efforts in various countries to develop proposals for a radiation-protection philosophy and recommendations. An informal group, in which Sievert took part, was formed at the London meeting to reflect on these questions. In a history of radiation physics published in 1960, Sievert wrote:

"During 1927-28, a large part of the work at Radiumhemmet's physics laboratory was devoted to preparations for the 2nd International Radiology Congress in Stockholm 1928. The preparations included, among other things, drafting - together with a number of radiologists - of an initial proposal for protective regulations for work with X-rays and radioactive preparations."[8]

The second International Radiology Congress took place from 23 to 27 July 1928 in the Parliament House (Riksdagshuset) in Stockholm, with 964 delegates from 40 countries. Gösta Forssell who had invested considerable organizational effort, served as president of the congress. Åke Åkerlund later described the meeting, in his biographical sketch of Forssell, as an "organizational triumph."[9] A special exhibition of equipment and instruments for medical radiology was arranged at Liljevalch´s Art Gallery (Liljevalchs konsthall).[10]

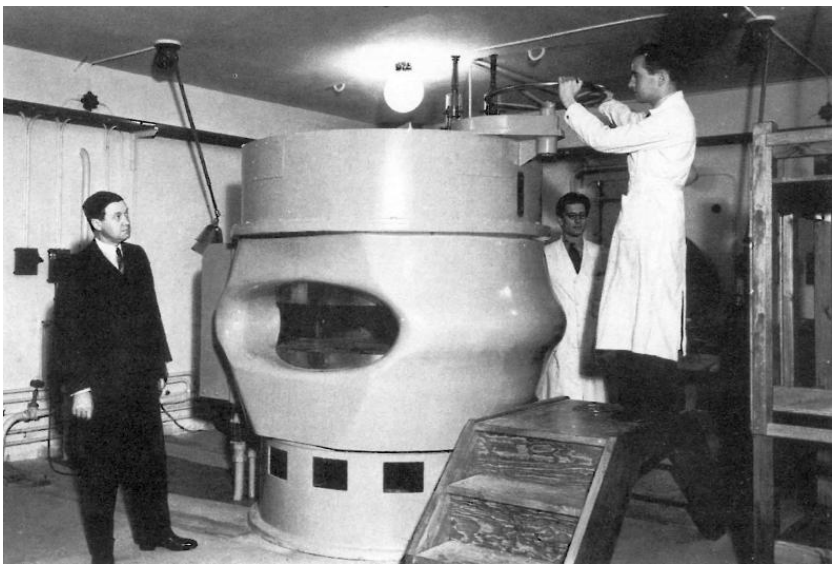
During the congress, a small discussion group on radiation-protection questions formed with the Englishman Dr G. W. C. Kaye at its head. This informal working group decided during the congress to endorse the British radiation protection recommendations drawn up before the meeting. The group drafted an organizational plan for a committee for radiation protection, which was presented at the closing session on 27 July. The congress decided to establish a radiation protection committee. Sievert was one of those who together with the American Lauriston Taylor and others joined this committee: the International X-ray and Radium Protection Committee which was later reorganized into the International Commission on Radiological Protection (ICRP). Sievert was elected chairman, Lauriston Taylor a member along with G. Grossmann of Berlin and I. Solomon of Paris. Two Englishmen were elected as secretaries: G. W. C. Kaye and Stanley Melville. The geographical spread was thus relatively broad.[11]

On the basis of new experience from its sister committee dealing with units (the International Commission on Radiation Units – ICRU), the protection committee decided to limit its membership to people actively working with radiation protection issues.[12]

The most concrete step was the introduction of a table giving the necessary lead thickness for protection at a given X-ray voltage or amount of radium. One notes that neither dose rate nor distance between the source and the operator were specified. The specification was based on the criterion that the dark-adapted eye should not be able to perceive fluorescence from a screen placed at the operator's position. Considering that a relatively high intensity is required to produce fluorescence in such screens, the actual radiation doses could in fact have been very high.[13] From the documentation it is clear that the issue of radiation protection divided radiologists and physicists and it can be seen as a success that the congress nevertheless agreed on recommendations. The protection question was, however, clearly subordinate to the question of units for ionizing radiation which attracted much greater attention.[14]

The driving force in the ICRP before the war - despite Sievert's role as chairman - was the Englishman Kaye.[15] The committee met in Paris in 1931, Zurich in 1934 and Chicago in 1937 in connection with the International Radiology Congresses. At the Zurich meeting, the committee for the first time set a dose limit. The aim was to avoid non-stochastic radiation injuries and the dose was specified in the new unit, the roentgen.[16] At the same congress, Sievert gave an overview lecture on natural gamma radiation in which he summarized investigations showing higher radiation levels indoors and he reviewed discussions on the biological effects of radiation on growth in animals as well as the contradictory discussion concerning mutations.[17]

The international debate on radiation doses and the obvious lack of quantitative physical measurement methods naturally influenced Sievert's work. This parallel track in his activities is very evident - a cross-fertilization of national and international problems. The early development shows that international issues gave Sievert impulses to his work on dose distribution and to the construction of the condenser chamber method. This development was natural: influenced above all by Forssell, the newly appointed physicist worked on numerous practical and theoretical problems. Gradually, his knowledge reached such an extent that he stood at what we today would call the research front. Sievert gained much of his new knowledge by drawing on information from abroad. Studies carried out elsewhere found their



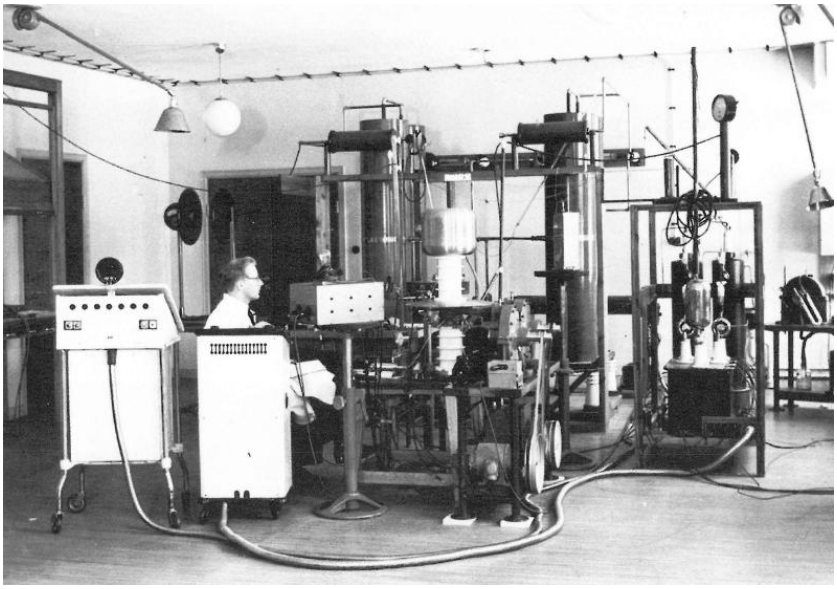
Manne Siegbahn at the Academy of Sciences' Institute for Experimental Physics in 1938, in front of Sweden's first cyclotron, the so-called "little cyclotron." The text on the back of the photograph reads: The magnet has arrived. Siegbahn was awarded the Nobel Prize in Physics in 1925. His influence as a teacher and mentor to many of our foremost physicists was profound.

counterpart in Sweden - for example the documentation of SED variations between Swedish hospitals. Over time, the flow of influence shifted, with Swedish experiences making an impact on the international arena. This occurred as Sievert gained an increasingly comprehensive overview of the field and established a growing reputation as a highly skilled theorist and a distinguished constructor.

Research Colleagues at Home and Abroad

One of Sievert's more prominent friends was the Nobel laureate Manne Siegbahn who in 1937 moved from Uppsala to a newly established professorship at the reconstituted physics institute of the Royal Swedish Academy of Sciences in Stockholm.[18] One of the main advocates for re-establishing the institute was Gösta Forssell who within the Academy pressed for funds for buildings and equipment.[19] Siegbahn later became Sievert's ally in organizing the military physics research initiated in 1939. Exactly how Sievert and Siegbahn came into contact is unclear. It is evident that most professors and leading researchers in the relatively small community working with radiation physics knew each other. Thus it is likely that they had ample opportunity to get acquainted. A mediating link, besides Forssell, was Robert Thoræus who in the 1920s had worked under Siegbahn and, in his technical development work on X-ray spectrographs, had succeeded in extending the wavelength range to 20 Å.[20] In 1927, Thoræus began working for Sievert at Radiumhemmet and his experience from Uppsala allowed him already in 1928 to present his combined X-ray filter for deep therapy. This filter later formed the basis for Thoræus's doctoral dissertation in 1932.[21]

Siegbahn's view of instruments as tools of research and his technical interest distinguished him from the prevailing Uppsala tradition.[22] He was primarily engaged in the leadership of research and shared Sievert's aversion to teaching. Siegbahn was a leading figure in the institutional expansion that Swedish science experienced from the turn of the century to after the Second World War and his life is a good example of the transformation of science from "closet



One of Siegbahn's students was Sigvard Eklund who later became responsible for the construction of Sweden's first nuclear reactor, the so-called R1. Eklund also served as Director General of the IAEA in Vienna for many years. The photograph dates from 1941 and shows Eklund at a 400 keV neutron generator at the Academy of Sciences' Institute for Experimental Physics.

existence" to research industry. He shared the expansive and rational approach with Sievert, as well as the technical interest in the laboratory.

Siegbahn trained and influenced many researchers who later also encountered Sievert: Hannes Alfvén, Erik Ingelstam, Torsten Magnusson, Sten von Friesen, Sigvard Eklund and Arne Hedgran, among others.[23]

One of Siegbahn's students who became important to Sievert was Sven Benner. He began in 1930 as Sievert's assistant, while holding a lectureship (*docentship*) in physics at Stockholm University College between 1932 and 1943.[24] Thoroughness and detailed analysis were Benner's hallmarks. He served as the physics laboratory's unofficial mathematician and his extensive language skills made him almost indispensable to his colleagues.[25] In 1937, Benner took charge of the department responsible for the supervision of radioactive substances and their use, a post he held until 1952 when he moved to Gothenburg as head of the newly established radiation physics institute at the University of Gothenburg.[26]

In his work, Sievert, like Siegbahn, travelled frequently. Unfortunately, there is no comprehensive record of all his journeys but there is every reason to believe that they were numerous and fruitful. Most of the foreign colleagues whom Sievert met during his travels later corresponded with him and he left behind a large number of letters. The intervals between letters varied greatly. At times there were pauses of ten years or more while in other periods letters were exchanged weekly.[27] A considerable portion of this correspondence consisted of letters of introduction for people expected to visit. The dialogues themselves are usually rather brief, undoubtedly because in-depth discussions took place when they met at conferences.

Following the Second International Congress of Radiology in Stockholm in 1928, where Sievert came into contact with researchers working on the same problems, there was an opportunity for contacts and visits on a personal level. Two of the friendships Sievert particularly valued were with the British physicists Frederick W. Spiers and Harald Gray. The latter had early in his career published fundamental work on the quantitative measurement of absorption of radiation. Gray gradually turned to the use of radiation in cancer therapy and in 1934 took up a post as physicist at Mount Vernon Hospital in Northwood. His main duties were



Gray and Sievert side by side (at the back, in front of the pillar; Gray is to the left of Sievert in the photo). The image is a detail from a group photo taken at a radiobiology conference in Stockholm in 1952. The full is reproduced in chapter 7.

to measure the ionization produced by radiation and to study the role of neutrons in radiation biology.

In 1938, Harald Gray visited Sweden and the Radiation Physics Institute where Sievert was working on the condenser chamber method and its applications. After the visit, Gray and Sievert corresponded about the method. Sievert arranged for Hemlin's Mechanical Workshop in Stockholm to send drawings of a radium cannon he had designed and some of these cannons were later exported.

Early in 1939, Gray received funds to equip a laboratory at Mount Vernon Hospital and wrote to Sievert about this. Sievert congratulated him on the stimulating work ahead and offered advice if Gray should need it. During the Second World War, the contact between them ceased and afterwards it was limited to the exchange of interesting articles and some more personal matters although Gray did visit Sweden again after the war.

Another foreign contact was the radiation physicist Gioacchino Failla in New York. As early as 1920, during their study trip, Forssell and Sievert had visited the hospital where Failla worked. Up until the war, their contact consisted of occasional letters. After the war, however, the correspondence became livelier in connection with various radiation-protection organizations. Sievert came into contact with a large number of English and especially American researchers and a great many letters between Sievert and these colleagues survived. Among them, besides Spiers and Failla, were W. V. Mayneord and Lauriston Taylor, who after the war became Sievert's close collaborators in the ICRP and ICRU. Many regarded Sweden as one of the leading countries in radiation protection and researchers from other countries often came to Sweden for training before organizing radiation protection in their own countries.

5. During the Second World War

The Radiation Protection Act of 1941

"The Radiation Physics Institute at Karolinska Hospital has emerged from the need for expertise in physics and biophysics in the use of X-rays and radioactive substances for medical purposes, particularly within radiotherapy. Since the institute was nationalized in 1941, it now constitutes the Department of Radiation physics of the Karolinska Institute as well as the radiation physics research division of King Gustaf V's Jubilee Clinic at Karolinska Hospital, in which capacity it is also at the disposal of the Jubilee Fund for work falling within the Fund's program. [...] In addition, the institute exercises, under the oversight and direction of the National Medical Board, supervision of radiological work and the storage of radioactive preparations according to the Act of 6 June 1941 concerning supervision of radiological work, etc."[1]

This quotation from the Swedish Government Official Reports (*Statens Offentliga Utredningar*) 1956:38 gives a brief description of the establishment of Sweden's first radiation protection law. From an international perspective, Sweden was among the earliest countries to regulate radiation protection. In the same year that Sweden adopted its first radiation protection act (1941), both France and Germany issued laws regarding X-ray work and associated protective measures.[2]

However, the increased use of X-rays during the 1910s and 1920s had already led to committees and professional societies drafting guidelines and recommendations for the use of X-rays. These guidelines naturally became the foundation of the various national laws, since the societies represented the limited expertise that existed. Although one cannot speak of continuity in a strict legislative sense, most countries had a tradition of protective thinking since the medical use of radiation had accelerated around the turn of the century.

Differences between countries' ability to regulate radiation protection depended partly on whether a centralized institution for radiation therapy existed and partly on the absence of strong international organizations to rely upon. Despite this, at the international level there is a relatively good correspondence between different nations and their legislation.

The first country to enact a law protecting both patients and staff already in 1925 was Italy. The Italian law was the first in the world to also regulate protection of third parties by establishing protective measures for those living near therapy facilities.[3] The same year, the People's Commissariat in the Soviet Union issued a decree regulating protective measures, working hours and health examinations.[4] Among the Nordic countries, Denmark adopted on 15 April 1930 the law *"Brugen af Røntgenstråler m.v."* - which was revised and expanded in 1938 - placing the *Sundhedsstyrelsen* (equivalent to the Swedish National Medical Board) as supervisory authority. Norway followed in 1938 with the law *"Lov om bruk av røntgenstråler og radium m.v."*, similar in most respects to the Danish law.[5] Sweden was likewise inspired by the Danish law, which served as a model for the Swedish version, particularly regarding fees.

The work to create a Swedish radiation protection law can be traced back to 1928, when Sievert, in connection with the second International Radiology Congress in Stockholm, submitted a proposal for Swedish regulations - unsuccessfully. The mobile measurement unit, established in 1925, had during its visits across the country answered many practical questions and acted as a consulting institution, thereby creating a type of knowledge bank within the physical

laboratory.[6] At the same time, Sievert devoted significant time to assisting Nordic and Swedish hospitals with radium handling and measurements - work which also provided a good overview of how handling was conducted and of its potential shortcomings.[7] All stakeholders agreed that overarching regulation was necessary.

In 1932, the National Medical Board developed a second legislative proposal, submitted to the Crown (*Kunglige Majestät*), but after six years of consideration, the Minister for Social Affairs rejected it. However, he simultaneously instructed the Medical Board to complete radiation protection guidelines.[8]

When the proposal for a radiation protection law was submitted to the government at the end of 1939, the question of organization within the newly established Karolinska Hospital played a major role. Under the 1934 agreement, the Jubilee Fund appointed the heads of the research departments while the staff working at Radiumhemmet were state employees. This organizational hybrid created significant economic disadvantages. In a memorandum to the Jubilee Fund, the supervisory board for the research departments declared that the departments ought to become state institutions because:

> "they so well serve the interests of the state that transforming the research departments into state institutions appears fully justified."[9]

The Jubilee Fund submitted a plan to the Crown that included both proposals for organizational reforms and a draft of a new radiation protection law.

When Sievert in 1938 saw the 1932 bill rejected, he realized that the matter could soon be resubmitted to the government. Together with Court of Appeal assessor Martin Wahlbäck and administrative secretary Erik Björkqvist, he formulated a law divided into 16 paragraphs and with the help of Robert Thoraeus and Sven Benner at the department, he prepared a proposal for a new organizational structure.[10] Sievert's first legislative proposal had failed primarily because of the cost the state would incur for supervising the law.[11] This time - following the Danish model - Sievert instead designed the supervisory activity so that it was financed through fees which markedly increased the chances of approval.

The law regulated the handling and possession of radioactive materials and X-ray equipment. The National Medical Board became the supervisory authority and issued permits. In practice, however, it was the Radiation Physics Institute that performed investigations and measurements and that issued opinions on applications—thereby effectively making the decisions.

All X-ray apparatus over 5,000 volts and all radioactive substances (primarily radium) weighing more than 0.1 milligram could only be used with a permit from the Medical Board.[12] The license application was required to include a description of premises and equipment, as well as information on the qualifications of the person responsible for supervision. The operator was also required to report any changes without delay. The evaluation of applications fell to the Radiation Physics Institute, which issued recommendations for formal decisions by the Medical Board. The institute became the supervisory body and was required to conduct inspections at regular intervals. The law also regulated mandatory reporting of injuries and mandated health examinations for radiological personnel. Costs associated with enforcement of the law were to be covered by annual fees paid to the state.[13]

The law also gave significantly greater academic weight to the Radiation Physics Institute. In an instruction accompanying the act, it was stipulated that the institute was to conduct scientific research in radiation physics and biophysics within areas that might be relevant to the law's application.[14] The instruction divided the institute's supervisory activity into three divisions:

"…one division for control of X-ray installations for diagnostics and for technical and scientific purposes; one division for control of X-ray therapy installations; and one division for control of protective devices for radioactive preparations and for examination and assembly of such preparations […]."[15]

Sievert designated these divisions A, B and C and the instruction also required the institute to maintain a biochemical and biological laboratory. It also mandated teaching - something Sievert likely found burdensome. According to colleagues, he was not particularly fond of lecturing and gladly delegated teaching duties to more willing radiation physicists.[16]
The war, together with Sievert's engagement in military physics, delayed the law's implementation or, as he phrased it, *"*affected it unfavourably*."* Although numerous notifications came in during the first year - after a backlog of unlicensed X-ray users - the subsequent war years saw a relatively slow growth in new applications.[17]

The Military Physics Institute (MFI)

The outbreak of the Second World War created a new sense of unity in Sweden. The war made the country's small size and vulnerable position strikingly apparent. National consensus became necessary and a pragmatic foreign policy shaped Sweden's relationship with the outside world. The ultimate symbol of national unity was the establishment of the coalition government (*samlingsregeringen*).
Across Europe, the war acted as a powerful technological engine and technological innovations, rather than military strategy, proved decisive.[18] The warring nations' enormous investment in military technology was followed with considerable - and worried - interest in Sweden.
Despite the Prime Minister's assurances, Sweden's military readiness soon proved inadequate. National mobilization demanded contributions from all citizens and sectors of society. Politicians, researchers, industrialists and civil servants together created numerous commissions, committees and boards to promote Sweden's technical development. Expanded basic research and applied research were essential if Sweden were to maintain an economic and technological level comparable to that of other nations.[19]
Government funds flowed to academies, universities and colleges, research institutes and associations. Leaders of these organizations faced concrete problems on many fronts and felt a need for interdisciplinary and inter-organizational coordination. Energy supply became crucial and studies of various combustion alternatives were undertaken.
Swedish military-technological research had already received governmental and parliamentary sanction in 1928 when the Royal Swedish Academy of Engineering Sciences (IVA) established the Technical Preparedness Committee, with members from the Academy and representatives from the military defence authorities. Collaboration between military and industry, however, was far older. From the late 19th century, the military and Swedish industry had maintained



In 1938, Sir J. J. Thomson wrote a book about the work of the English Board of Invention and Research (BIR) which greatly influenced Swedish physicists. He described how English physicists had worked on submarine detection using microphones during the First World War and he also recounted unsuccessful attempts to use seals to locate the submarines. A major part of the BIR's work involved evaluating submitted inventions. Thomson cites a figure of 100,000 proposals - a number that stands in stark contrast to the handful (around twenty) from the Military Physics Institute (MFI) era that are preserved in the War Archives in Stockholm.

steady and functional relations in a network that endured for a long time and still forms an important part of Sweden's defence.[20] Together with the existing defence organization and established doctrine, this network constituted the *"*military structure*"* at the beginning of the war.[21]

The initiating factor for Swedish military-scientific research was the use of chemical warfare agents in the First World War. Chemist Gustaf Ljunggren began research in this field in Lund in 1926 and in 1937 the Defence Chemical Institute (FKA) was established at Ursvik, northwest of Stockholm.[22] Before the Second World War, there was no corresponding activity among physicists.

When tensions rose in Europe and war drew closer, the National Commission for Economic Defence Preparedness requested that IVA, through Rolf Sievert:

"with the greatest possible speed conduct an inventory of the country's resources with regard to physical and chemical laboratories."[23]

Persons who could be of use for scientific work of military relevance were to be listed by institutional heads for exemption from military service. Sievert, together with the other physicists, was willing to place his expertise at the disposal of the state - but not under the influence of IVA or the defence industries. Throughout the 1930s, Sweden had debated how research should best be directed to yield valuable, socially beneficial results. A strong "public service" ethos existed among scientists long before the outbreak of war and the general mobilization.[24] Physicists could refer to foreign examples of scientific participation in the First World War but were unwilling to abandon the independence they enjoyed at universities and colleges.

IVA's requested investigation must have appeared to physicists as an attempt to subordinate scientists to industrial control. Sievert, however, was ready to initiate a more profound integration of physics into the defence sector.[25] As an advocate of the direct innovation chain -



A V-2 rocket crash-landed outside Kalmar on June 13th 1943. There was no advanced guidance equipment in the rocket.

technology is applied science - it was natural for Sievert to begin with research. Or, as he himself put it:

"Physics together with chemistry constitutes the foundation upon which technology and technical research are built. [...] Therefore [...] there is always a considerable fund of experience and knowledge within physics that has not yet found technical application and thus has not yet been used to meet the many different needs of practical life."[26]

Just a few days after the outbreak of war on 1 September 1939, Sievert approached Manne Siegbahn at the Nobel Institute and proposed that physicists should be organized in order to apply "their special expertise to the handling of military-technical problems."[27] At a meeting on 6 September:

"several of the heads of the country's physical institutions convened under the chairmanship of Professor Siegbahn."[28]

An organization was created consisting of the five physical institutions in Stockholm, Uppsala, Lund and Gothenburg, as well as the Physics Department and the Photographic Institute at the Royal Institute of Technology, the High-Voltage Research Institute at Uppsala University, the Geophysical Laboratory in Djursholm, the Academy of Sciences' research institute in physics and the Radiation Physics Institute at the Karolinska Institute.[29] The institutions were to:

"seek contact with the military authorities in order to obtain problems of a physical nature."[30]

After contacts with the Minister of Defence during the autumn, the Physicists' Preparedness Committee was established, with one physicist from each institution. The committee was instructed to:

"seek direct contact and cooperation with military experts."[31]

After two months the organization was placed under the Swedish National Committee for Physics. During the winter of 1939–40, the physicists worked to identify problems where they could assist the military. Some were tasked with completing collimator installations for the adjustment of optical instruments, others experimented with radio-based remote detonation of



Gustaf Ising, professor of physics at Stockholm University.

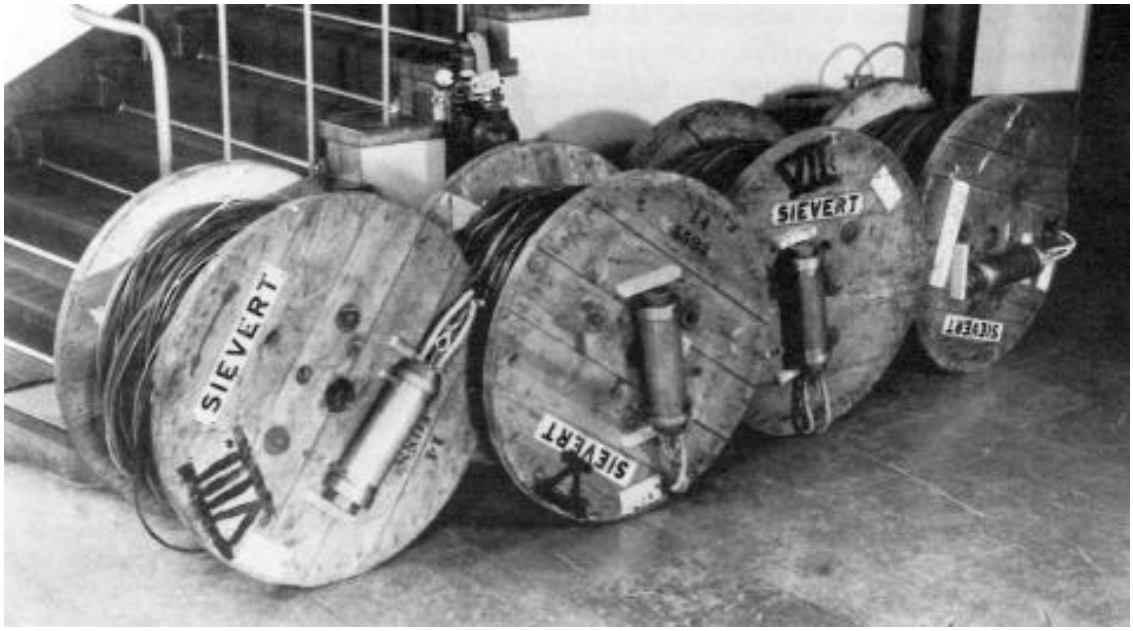
explosives. In summer 1940, a demonstration of the physicists' work was held for relevant government ministers. In September the group received an appropriation which in November was expanded to include the establishment of a provisional Military Physics Institute (MFI) with an associated test station.[32]

In April 1941, Olof Arrhenius (son of Svante Arrhenius) donated a 130-hectare estate at Grindsjön, south of Stockholm, to the Crown for establishing the test station.[33] The building was erected during the autumn and Torsten Magnusson - later Director-General of the Swedish Defence Research Agency (FOA) - was hired as administrative chief. The physicist Bengt Grabe became head of the station. Several talented young physicists were recruited, among them Sten von Friesen, Matts Helde, Erik Ingelstam, Nils Ryde and Gösta Stenvinkel. They sought to create a relaxed and non-bureaucratic environment to foster creativity.[34] Secrecy was essential and the station's activities were to be kept as hidden from the public as possible.

The National Committee for Physics appointed a board for military physics research with Sievert elected as executive member.[35] As a result, much military-technical activity was located at the Radiation Physics Institute:

"A large part of its premises served as offices and laboratories for this work and the institute's workshop worked practically entirely for the defence."[36]

The work was innovative and later proved to be well aligned with developments among the major powers. As early as 1940, tests were conducted with rocket weapons of long and short burn times, including types intended for anti-tank use or as infantry cannons.[37] It was not until 1944 that Sweden confirmed that Germany was using such weapons, when a V-2 rocket crash-landed in Sweden after a test firing.[38] In 1942 MFI worked on shaped charges for anti-armor use and attempted to combine these with rocket propulsion. In 1941 experiments were conducted on acoustic bombs, based on the proposals of Hannes Alfvén and Sten von Friesen. Vibration-triggered detonators were developed and Gustaf Ising invented a heating apparatus for submarines based on physical principles.[39] Erik Ingelstam developed an infrared barrier



In April 1943, the submarine “Ulven” disappeared off the coast of Gothenburg. The drama became a national event and physicists from MFI led by Sievert designed probes to measure anomalies in a generated magnetic field. Four of these magnetic probes, along with their associated cables and cable reels from Sievert’s cable works, are visible in the picture. The young researcher Karl Gustav Friskopp from MFI took part in the search and reported to the Naval Administration: "At 14:30, the device from unit 352 was taken aboard a small boat to the “Belos” after which we used the device to sweep around a bottom-skimming grapple dispatched by the minesweeper M16. Slight readings from the grapple were obtained. The sweeping operation ended at 15:45. Divers went down and confirmed that a large boulder was lying on the seabed." On May 5, divers from the “Belos” found the “Ulven” and the search was called off.

capable of detecting aircraft at up to 5 km distance. Docent Nils Ryde in Lund worked on infrared telephony, though it appears not to have been applied.[40]

Research produced ideas and military authorities were consulted to assess practical applicability. Many proposals would have required enormous financial inputs - beyond what a small country like Sweden could manage. Researchers, especially Sievert, encountered lukewarm interest from the military. Sievert also felt resistance from Swedish weapons manufacturers who wished to remain sole suppliers of new technologies to the defence (he complained particularly about Nobelkrut’s slow deliveries). This reluctance to take on large technical projects, together with hesitation to take physicists' work seriously, caused increasing tension between scientists and the military. A factor in the conflict was that physicists became the dominant idea-generating group while the military were pushed into a more passive consumer role that did not align with their responsibility for national defence.

The need for more coherent military-technical research soon became clear. In February 1943, the Defence Research Board (*Försvarets forskningsnämnd*) was established with Manne Siegbahn as chairman. Its task was to stimulate and coordinate military-technical activities and to determine the future organization of defence research. The board consisted of one physicist, one chemist, one representative for technical research and one representative for each branch of the armed forces.[41]



The department operated at a reduced level during the war, but in 1941 Sievert was appointed Professor of Radiation physics at the Karolinska Institute. The inauguration took place in one of the Karolinska Hospital's lecture halls. To the right of Sievert in the picture sits Olle Reuterwall.

Sievert welcomed the board's establishment but divergent views between physicists and military representatives soon arose. It is highly likely that Siegbahn entrusted most of the argumentation to Sievert, who felt that physics was being marginalized. Sievert later recalled:

"The military members acted independently for only a few meetings, but soon found one another and, together with the chemist and the engineer, formed a majority that took no account whatsoever of the opinions of the other members."[42]

Thus, the board's work was marked by conflict from the outset. Sievert's entrepreneurial spirit now met an existing traditional structure, producing an outcome radically different from that of the radiation physics operations.

In December 1943, the Defence Research Board submitted its organizational proposal for creating the Swedish Defence Research Establishment (FOA). Both Siegbahn and Sievert submitted formal objections.[43] The proposal - ten divisions under a scientific director - met with varied criticism rooted in different perspectives. The military-industrial network (represented by the Federation of Swedish Industries and the Army Administration) sought more goal-directed research and argued that basic research should remain the domain of universities. The two physicists wanted to give basic scientific research a more autonomous position and proposed that research be placed under a military administrative chief with scientifically competent division heads responsible for the actual research.

At the heart of the conflict lay fundamental questions about control and use of research for military purposes.[44] The tension between academic freedom and military structure had been latent throughout MFI's existence. Physicists, with Sievert in the lead, had succeeded in generating enthusiasm among politicians and military leaders sufficient to secure funding for largely independent research. When this activity was now to be integrated into a larger organization, they had to defend scientific independence to prevent the MFI concept from dissolving into nothing.

Before the government made a decision on FOA, Sievert sent the Minister of Defence his personal reflections on the military physics operation—containing sharp criticism of both military and industry:

"Experience from the Defence Research Board shows unequivocally that the military experts do not understand research. In case of disagreement among the civilian members, they unite and support the position that from their uninformed standpoint seems best aligned with the military's desire to take control."[45]

His judgment on industry was no kinder:

"One cannot perhaps say that industry has sabotaged MFI's work, but that it has not attempted to promote it is evident. Given the importance that rapid deliveries have for experimental research, this amounts to direct opposition to a state research activity of utmost desirability in the present situation."[46]

FOA was inaugurated on 1 April 1945 and MFI became Division 2 within the new institution. Despite the organizational conflicts, it was recognized that physics played a vital role in new military applications. Many physicists involved in MFI later held prominent positions within FOA. However, Sievert's involvement in military physics decreased sharply after 1944 - a puzzling development in light of Sweden's secret post-war nuclear research. The energy Sievert had invested in founding MFI created fertile ground for disappointment when the outcome did not match his expectations.

In a surviving carbon copy of what appears to have been part of a letter dated 14 November 1944, Sievert wrote:

"Why do the men of technology and industry - and lately even some military men - use every opportunity to cast suspicion upon the person who, without thought for personal gain, initiated and led the military-physics activity?"[47]

Despite his bitter departure, it is clear that Sievert was the driving force that introduced physics as a component of military-technical research. That Sievert - an innovator and advocate of centralist solutions - clashed with others equally committed to centralization is therefore understandable. MFI nevertheless survived the organizational conflicts and became a significant building block of FOA. The pragmatic spirit that had marked the war years persisted; understanding of industry's need for basic research was supported by government ministries and industry cooperated with an expanding public sector.[48]

The Institute on Minimal Resources

Sievert's strong engagement in the Military Physics Institute meant that the Radiation Physics Institute's research activity was limited during 1941-45. A contributing factor was also the new radiation protection law, which required supervision and extensive administrative work. Throughout the war, Sievert's institute suffered from severe staff shortages while the workload increased. The institute's workshop was occupied with military-physics work and Sievert himself spent most of his time organizing MFI, meeting with government ministers and secretaries, visiting the chiefs of different defence branches and conducting negotiations by telephone.

MFI's administrative office was placed in a laboratory at the Radiation Physics Institute, as administrative assistance could be conveniently obtained there. The only research that could continue in a somewhat undisturbed manner was the biophysical work. Arne Forssberg investigated the reaction of the mold *Phycomyces blakesleeanus* under varying irradiation times. In a 1943 article, Forssberg reported that the growth rate of the mold was highly sensitive



Arne Forssberg in the laboratory.

to radiation. Comparison with Sievert's earlier theoretical model - based on differential equations - showed reasonably good agreement in its time course. In 1945, Sievert began experiments in which mice were subjected to very high radiation doses. These experiments were preliminary steps toward the planned experiments in the high-voltage hall - a project initiated immediately after the war.

Sievert later described the war years as a "dark and difficult period."[49] International exchange could not be maintained for obvious reasons. A planned conference in Groningen was postponed indefinitely. Reduced international trade likely made the acquisition of radium more difficult, though no direct evidence shows that the institute experienced serious shortages. Most likely, it was able to continue operations in reasonably normal form.

6. Back to Research 1945–1951

The High-Voltage Hall

From the time Otto Hahn, Lise Meitner and Fritz Strassmann discovered uranium fission in 1938 until the end of the Second World War, nuclear physics underwent an extraordinary transformation, from a small academic specialty into a vast scientific-industrial enterprise.[1]
The very first concrete reaction to the American atomic bomb was that military leaders in other countries immediately demanded funding to build their own bombs. After Hiroshima, the first issue discussed by the Japanese military was whether Japan could hold out long enough to fabricate an atomic bomb of its own.[2] There is no reason to believe that the Swedish military reacted differently from military establishments around the world. It was the Supreme Commander who initiated research on the atomic bomb and tasked the Defence Research Institute (FOA) with reporting on what was known. In Sweden's defence budget for 1946/47, Parliament granted 3.5 million Swedish crowns for the development of new defence material, of which 1.2 million Swedish crowns was allocated for research on atomic energy.[3] In the classified documentation forming the basis for this request, the Supreme Commander emphasized that the atomic bomb was a research subject of urgent importance.[4] The Swedish debate concerning whether Sweden should possess nuclear weapons or not arose much later.
The atomic bomb also triggered an explosive need for knowledge of the effects of large, extremely short radiation doses and suddenly radiation physics found itself at the centre of the military arms race in a way previously unimagined. Simultaneously, peaceful uses of atomic energy were seen as one of the most important questions of the future - a possible solution to all conceivable energy problems. Knowledge was therefore needed both for defence purposes and for radiation protection in the design of future nuclear power facilities.
The government appointed the Atomic Committee (*Atomkommittén*) already in the late autumn of 1945, so as not to fall behind the rest of the world. The committee, chaired by county governor Malte Jacobsson, included among others Professor Hannes Alfvén, Professor Manne Siegbahn and Håkan Sterky, Director-General of the Swedish Telegraph Administration.[5] The following spring, the committee submitted its first report. It requested funding for basic research at universities and colleges. Among those granted funds was radiation physics research concerning biological effects of radiation.
The so-called high-voltage hall (*högspänningshallen*) became Sievert's largest project by far after the Second World War. The scientific questions forming the basis for constructing an entire building with an accompanying high-voltage installation were not new: the question of dose rate had already been raised before the war. Internationally, it had been established that low doses delivered in as little as one one-hundredth of a second did not produce a different biological effect compared with the same dose delivered over a longer time interval.[6] Researchers wanted to investigate how an extremely short radiation dose influenced the body. During the first years of the war, Sievert constructed a machine capable of irradiating objects with a predetermined radiation amount down to one thousandth of a second but he wanted to



The high-voltage hall at the Department of Radiation Physics, photographed from the east. The building had a volume of 2,300 cubic meters - a figure Sievert used when describing the hall. It was constructed under the supervision of the master builder Anders Dunder.

reduce exposure times even further.[7] The purpose of the high-voltage hall was twofold and in a report to the Atomic Committee, Sievert wrote:

"The installation is intended for two distinct purposes for which the required equipment is in most respects the same. The first concerns the biological effects of short-duration, intense X-ray radiation at such doses that death follows shortly after irradiation. […] The second purpose […] is the experimental development of new treatment methods using short-duration, intense X-ray radiation."[8]

To generate a short and intense dose, a cascade generator and large capacitors and batteries were required. Some of the capacitors were up to ten meters tall and the entire installation required immense space. Considering its construction urgent, the Board of Karolinska Hospital had already requested funding for the 1945/46 fiscal year to build a high-voltage hall. The Atomic Committee received the matter for review and, in a statement on 25 January 1946, expressed its support for the hall but noted that funding could first be allocated to the Radiation Physics Institute during the 1946/47 fiscal year.[9]

The hospital board's request originated from a memorandum by Sievert, in which he emphasized the longstanding need for a high-voltage installation. Sievert's reasons were partly scientific, partly related to gaining knowledge about protective measures against atomic attack and about radiation effects from atomic bombs.[10] A third - although less important - reason was the increasingly high voltages used in industrial X-ray applications, which needed to be studied. Thus, the need for some type of high-voltage installation had existed for some time but Sievert had not concretized his plans nor requested funding. The atomic bomb changed the situation radically. Sievert wrote to the Karolinska Hospital Board:

"During the past weeks, however, the matter has acquired an entirely different urgency. In carrying out an investigative assignment concerning the atomic bomb, which was given to me by the Defence Research Institute, I have become convinced that the problems mentioned above are of such importance from a defence standpoint that they should be taken up immediately at the Radiation Physics Institute, since this institution is the only one in the country with the proper prerequisites for doing so."[11]

In the Atomic Committee's report, Sievert's funding request constituted one-quarter of the committee's total cost proposal. The Radiation Physics Institute received 215,000 Swedish crowns from the committee for constructing the high-voltage installation.[12] Master builder



The stacks making up the capacitor bank were interconnected and transferred the charge via a lowering connecting arm to the anode of the X-ray tube, visible at the far right of the image. Below the anode was the treatment table which was separated from the hall itself.

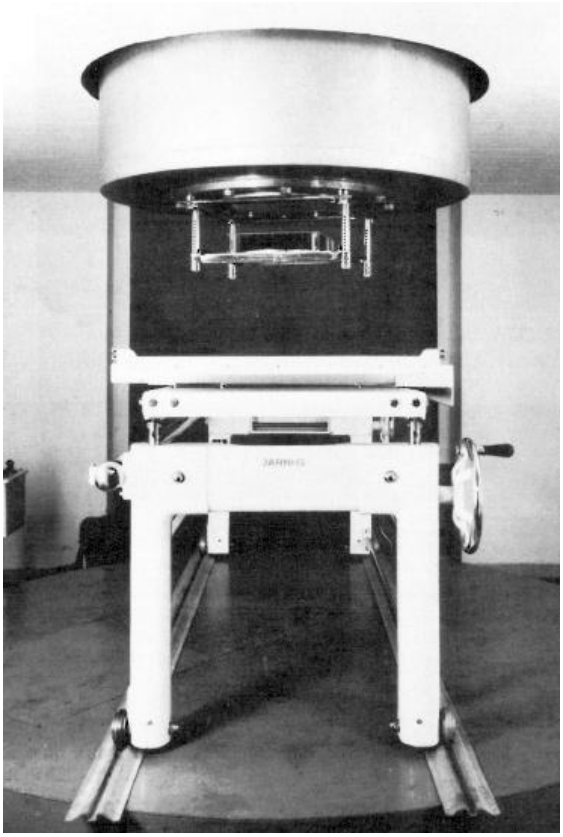
Anders Dunder not only supervised construction but also contributed financially by funding the irradiation room.[13] Work continued during 1946 and 1947.[14]

The hall's floor area covered 209 square meters and housed a Cockcroft–Walton generator, built by Sievert's Cable Works in collaboration with the Academy of Sciences' Research Institute for Physics. The hall also contained a capacitor bank of 40 capacitors donated by Sievert's Cable Works.[15] The generator and the capacitors were enormous structures that rose ten meters toward the ceiling. The X-ray tube consisted of a water-cooled iron cylinder with a conical anode in the centre. Surrounding the anode were initially 48, later 144 tungsten filaments able to handle a maximum discharge current of 20,000 amperes. The filament current of 3,000 amperes came from a 16-volt submarine battery and was regulated by a remotely operated resistance unit constructed at the institute.[16]

During discharge, X-rays were to be generated along the surface of the conical anode, whose tip was removed. The anode was shaped as a truncated cone so that the radiation would focus outside the iron cylinder, in the imagined extension of the cone. Thus, treatment could in principle be delivered so that the patient received intense irradiation only at the narrow focus of the radiation cone. For experiments on mice and rats, the conical anode could be exchanged for a cylindrical one into which the animals could be lowered, enabling the whole animal to be irradiated instantaneously.[17]

Next to the hall, three smaller rooms were built, including a raised control room offering a good overview of the facility. The room was electrostatically shielded for the 1.2 million volts generated by the hall's high-voltage system. A photographic darkroom and a small room for biological work were also constructed adjacent to the control room.[18]

In January 1948 the building was completed. By spring 1949 the interior installation was finished. During the summer the institute carried out about 80 discharges, all below 400



The treatment table beneath the high-voltage hall where the patient was to be positioned. The table was adjustable in all directions. Above the table, one can see the iron cylinder that enclosed the conical anode and the collimator which appears as the horizontal circle in the image above the table. The sector-shaped collimator consisted of a large number of rectangular plates, perpendicular to the table and these divided the circle into small conical sectors so that no radiation would scatter outside the focal area.

kilovolts. From the outset, there were problems with the extremely strong discharge current.[19] Strong magnetic fields caused breakdowns despite the vacuum. The requirement of high vacuum also meant that the iron in the structure had to be "out-gassed" every time the tube was opened. As always in construction work, Sievert was impatient. Hemlin's Mechanical Workshop performed most of the machining and overtime often extended into the early morning hours.[20]

Two of Sievert's closest collaborators in the coming decades were Bo Lindell, MSc in engineering physics and Bengt Håkansson, engineer - both hired during the hall's completion. They later recounted Sievert's eagerness to get the hall running and how he pushed the work forward without regard to costs. The conical anode was specially manufactured from the rare element tantalum, at Sievert's insistence.[21]

The high-voltage hall was inaugurated on Monday, 8 May 1950. At 11:30 a.m., more than 150 invited guests gathered in the new hall, measuring 2,300 cubic meters, accompanied by music from the Kyndel Quartet. After welcome addresses by the chancellor of the Karolinska Institute and the hospital's director, Sievert spoke to the guests after which Crown Prince Gustaf Adolf formally inaugurated the facility. Sievert took the opportunity to showcase the institute's work: no fewer than ten demonstration stations were arranged so that guests could gain insight into various activities. Each department head acted as guide. Bo Lindell, for example, demonstrated the control room above the high-voltage hall, which resembled the bridge of a ship.[22]

However, it soon became clear that it was extremely difficult to make the X-ray tube operate at the discharge voltage needed for the intended radiation doses. In 1952 the tube was therefore redesigned exclusively for biological experiments and the idea of patient treatment was abandoned. Lindell had been sent to the United States in autumn 1951 to seek advice from



Crown Prince Gustaf Adolf arrives at the inauguration of the high-voltage hall. "Without permission, but with sincere admiration, from the neighbouring building [Radiumhemmet]," reads the inscription on the back of the photograph.

high-voltage experts at General Electric and the Massachusetts Institute of Technology but they considered it unlikely that a tube with such large metal surfaces could operate at voltages higher than about 300 kilovolts.[23]

Thus the high-voltage hall never met its ambitious goals. Sievert regarded this as a personal failure, having invested much of his prestige in securing funding from various donors. However, he recovered rather quickly and engaged in other scientific activities. His major concern now became the future projects that might be difficult to finance because of the failure of the high-voltage installation. The hall itself remained largely unused for many years. The immense building, despite its volume, could not be repurposed due to its highly specialized design.

The reasons for the failure are difficult to determine. Unrealistic ambitions or poor management may be cited but neither explanation is particularly convincing. The more plausible explanation is that advances in electronics had outpaced Sievert's technical expertise. In the United States, the transistor had already been introduced. Sievert had designed an installation far beyond the capabilities of older electrical engineering methods.[24] At the very high voltages involved, physical problems began to appear that did not occur at low voltages. It seems Sievert attempted to apply the same technical reasoning used for smaller installations - an approach often leading to the mistaken belief that one can simply scale up a technology linearly.[25]

Parallel to the high-voltage hall, Sievert and physicist Agnar Egmark built a radon laboratory, officially called the emanation laboratory. Sievert received additional funding from the Atomic Committee for this purpose.[26] Unlike the high-voltage hall, the laboratory functioned exactly as intended. The idea was that the Radiation Physics Institute would store larger quantities of radium for Swedish universities and colleges. At the laboratory, radium emanation (radon gas) was to be produced and sealed in small glass capillaries.[27] To prevent radon from spreading to other parts of the institute, the laboratory was built as a freestanding structure.[28] In 1952 Sievert wrote to the Atomic Committee:

"Work at the radon laboratory has proceeded according to program throughout the year and without interruptions due to disturbances."[29]



Coinciding with the inauguration of the high-voltage facility, Sievert showcased the department's other activities. He demonstrated, among other things, to the Crown Prince how the fruit fly experiments were conducted. Experiments were carried out in a reduced-radiation environment to determine whether radiation affected biological development. The circular disc coated with fly glue rotated once every 24 hours, while a jet of air blew out the flies that had hatched from the container. This made it possible to determine when the eggs had hatched and, in theory, any resulting delay. However, in practice, no delay could be detected.

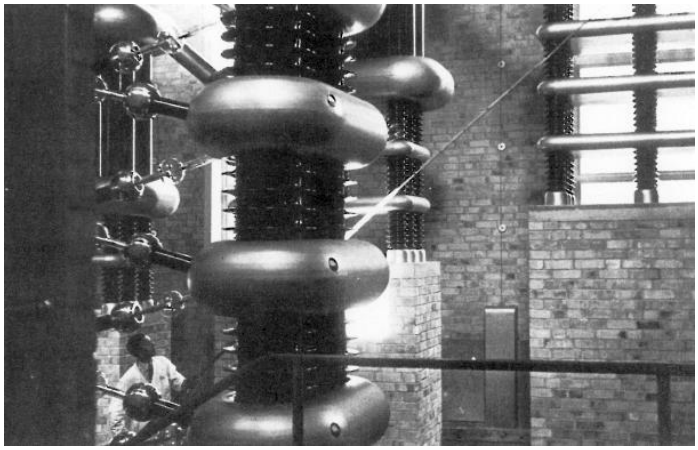
Handling radon was not entirely without risk. The greatest danger was inhaling radon during the process of pumping it into the capillaries. Work shifts sometimes ended with a walk in the park to "ventilate" the radon from one's lungs.[30]

Radiation from the Human Body

At the same time that Sievert built the high-voltage hall, he constructed a small measurement laboratory beneath it. There the institute could measure radiation emitted by the human body using the ionization-chamber method - relying on the principle that radiation ionizes gases.[31] The apparatus consisted of ten elongated high-pressure ionization chambers arranged in a ring. At the centre was a cylindrical space in which a person could be placed for full-body measurement.[32] These measurements were intended primarily for examining individuals who, through their work, might accidentally ingest or inhale harmful quantities of radioactive substances.[33] Of particular interest was determining threshold values relevant for future nuclear power installations - or, as Sievert wrote to the Atomic Committee:

"The investigation of the naturally occurring quantity of gamma-radiating substances in the human body also has value for assessing the maximum amount of radioactive substances that can accumulate in the body without risk. Abroad, great interest is shown in this question, which plays an essential role in determining the protective and purification measures required at atomic-energy facilities."[34]

Because the human body naturally contains small amounts of radium, Sievert wanted to measure this. However, in collaboration with, among others, Spiers, he demonstrated that the dominant source of radiation in the human body was potassium-40 which constitutes 0.012 percent of all potassium in the body.[35]



The day-to-day operation of the facility demanded great effort, especially since the facility never met the ambitious targets set for it. Charges had to be "picked off" using a long, grounded rod. In the foreground to the left is the Cockcroft-Walton generator which was constructed at the Sieverts cable works.

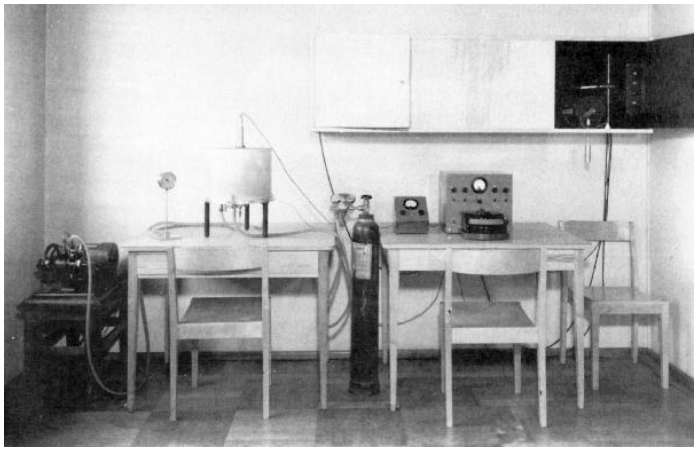
When the laboratory was completed, Sievert wanted to measure radiation in different population groups to see what variations occurred due to geographic factors or biological factors such as body type and diet. He contacted, among others, a school doctor in Solna who provided several volunteer classes.

Over time, however, the laboratory came to be used almost exclusively for routine examinations, limiting opportunities for more research-oriented measurements. The measurements proved significantly more precise than expected but Sievert wanted to conduct measurements in a place shielded from all external radiation. The small laboratory at the institute was insufficient and Sievert began searching for a rock cavern in which measurements could be performed protected from cosmic radiation.[36]

In 1952, a much larger measurement laboratory was completed.[37] It was located deep inside the Henriksdal sewage treatment plant, surrounded by at least 70 meters of granite. Cosmic-ray intensity was reduced by the rock and natural radiation from the rock was reduced by surrounding the laboratory with large water tanks filled with specially low-activity water.[38] As a result, radiation levels could be lowered to one percent of the average radiation in an ordinary stone building.[39]

The specially developed measurement device could measure the human body's potassium-40 content with an accuracy of about ten percent. Test subjects lay for four hours inside a 90-centimeter-diameter drum, with "possibility to read and make telephone calls during the experiment."[40] In addition to examining people, the institute - primarily through the traveling Bengt Håkansson - measured radium and thorium content in drinking water from various parts of Sweden.[41] The institute also developed a method to measure radon in exhaled air which served as an indicator of the body's radium content.[42]

The establishment of the Henriksdal laboratory illustrates almost dramatically Sievert's entrepreneurial spirit and originality when seized by his own enthusiasm. Once he had access to the cavern, he needed to obtain low-activity water for the tanks surrounding the laboratory. According to available information, the water containing the least radioactivity in Europe was in England, where the river Thames flows through highly calcareous soils. No sooner said than done: Sievert contacted Stockholms Rederi AB Svea, which operated shipping routes to London and was able to persuade the company - likely by pointing to the scientific importance - to fill one of their ships' ballast tanks with Thames water. When the vessel arrived at Stadsgården in Stockholm, several trucks from the city's milk distribution service were waiting



The radon laboratory, with its minimal equipment, contrasted with the large hall. Producing concentrated radon gas, however, was no easy procedure. The radon gas had to be passed through two different cold traps to remove first water vapor then oxygen and nitrogen.

to transport the water to Henriksdal. The remaining problem - getting the water down into the rock cavern - was solved with a third telephone call: the Stockholm Fire Brigade came and used their pumps to fill the eight-cubic-meter iron tanks that formed the floor, ceiling and walls of the laboratory.[43] In his characteristic manner, Sievert had managed to reduce the water's radioactivity by a factor of ten and reduce the ambient radiation to about one percent. His method was simple: a telephone call or visit to the highest person in charge at the relevant organization was all that was required. Delays caused by complicated decision processes seem not to have existed in his worldview.

Radon Research - A Pioneering Contribution

Around this time, a line of research began at the Radiation Physics Institute that would become increasingly important over time: radon in homes and soil. Together with the young physicist Bengt Hultqvist and engineer Gunnar Eklund, Sievert investigated the geographic variation of naturally occurring gamma radiation in Sweden.[44] Work on natural radiation led Hultqvist to study variations inside houses. In his 1956 doctoral dissertation, he showed that radiation levels could vary by a factor of ten between houses, depending on the building materials used.[45] The main focus of his study was radon concentration in indoor air and radiation dose to the lungs.
Radon gas is produced when radium decays and, because radon is an intert gas, it diffuses easily through materials. Radon is present in soil, groundwater and in varying amounts in different building materials. Radon itself is unstable and decays through a chain of substances collectively called radon daughters, ending eventually with stable lead. Throughout this decay chain, different types of radiation are emitted. When radon and radon daughters - often attached to aerosols - are inhaled, radioactive decay can occur in the lungs and alpha particles (two protons and two neutrons) irradiate the lung tissue. Alpha radiation has very short range but high energy, making it biologically harmful - the ultimate consequence can be lung cancer.[46] Hultqvist found that unventilated rooms could contain thirteen times more radon than ventilated ones.
His study was the first dissertation on radon in Sweden but Sievert had earlier concluded that the largest radiation exposure came from radon in homes. It would take more than two decades before the growing radon hazard received proper attention in Sweden.



Agnar Egmark, Head of the radon laboratory.

The Double Chamber

In the early 1950s, Sievert and Rune Walstam constructed the so-called double chamber. The Radiation Physics Institute manufactured several hundred double chambers and an automatic reading device enabled extensive studies of radiation-protection conditions at Radiumhemmet. The chamber consisted of three concentric cylinders, dimensioned so that the electrical capacitance between the outer and middle cylinders was equal to that between the middle and inner cylinders. The ionized air volume, however, was ten times larger in the outer chamber than in the inner one. Consequently, the difference in sensitivity was a factor of ten, solving one of the problems associated with the condensation chamber, namely its relatively narrow measurement range.

The Kiruna Geophysical Observatory

The first proposals for a scientific station in northern Sweden date back to the mid-1880s. In 1902 the Stockholm Scientific Society made the idea concrete, reasoning that such a station would provide valuable information in meteorology, geology, physics, zoology and botany. Conditions in the far north were unique and therefore scientifically interesting. In meteorology, one could study winds - especially the *foehn* wind's effects on snow - and the nature of forest-destroying storms. Avalanches and aurora borealis were other phenomena of interest.[47]
With contributions from the foundation Stiftelsen Lars Hiertas Minne, various companies, societies and individuals, the Stockholm Scientific Society purchased a building at Vassijaure, Lapland, which was restored and equipped primarily for seismic observations. Operations began in 1903, with financial support from the Academy of Sciences starting in 1904. The building burned down in 1910, destroying instruments and records. Two years later a new station was built in Abisko, after the Crown granted free use of 46.4 hectares of land. In 1919 operations were divided into two departments: geophysics and biology/geology. Meteorological observations were transferred in 1929 to Riksgränsen, where the Swedish Meteorological and Hydrological Institute (SMHI) had established an observatory. The Stockholm Scientific Society dissolved in 1933 and its assets passed to the Academy of Sciences which took over the station and appointed two inspectors.[48]



A demonstration of the department's first whole-body counter. Bengt Håkansson acts as the test subject and Bo Lindell leans over him. In the background, Sievert and Axel Berggren.

Activity continued at a fairly high level, particularly in biology. From 1903 to 1944, around 160 scientific works were published by Swedish and foreign scientists who visited the station. Routine observations were carried out by young scientists hired for short terms. After the station's director, Professor Filip Åkerblom, died in July 1942, the position remained vacant until 1951 when Gustaf Sandberg from Uppsala assumed the role. Activities at Abisko were therefore largely dormant for nearly a decade, except for provisional routine work carried out by a caretaker for the Academy and SMHI.

The idea of combining the northern research stations into a single unit was proposed in a 1944 report on SMHI's organization, prepared by senior director Gustaf Slettenmark. International comparison had shown that the other Nordic countries organized their observational networks more centrally and efficiently than Sweden. In another report, industrialist and former Minister of Trade Gösta Malm suggested a special investigation to determine whether geophysical, seismological and magnetic observations in Riksgränsen and Abisko could be combined to a meteorological observatory. The Ministry of Communications therefore instructed the Academy of Sciences, SMHI and the Hydrographic Office to conduct such an investigation.

The Academy appointed three inspectors - Axel Gavelin, Robert Fries and Erik Hulthén - as its representatives. SMHI contributed Anders Ångström and Carl Johan Östman and the Hydrographic Office contributed Nils Ambolt and Sven Åslund. Gavelin chaired the committee until August 1945, when he resigned and was replaced by Rolf Sievert. The committee co-opted Professors Hannes Alfvén, Gustaf Ising, Hilding Köhler and Harald Norinder. In June 1946, the chairman and several members visited Abisko and Kiruna and a Scandinavian geophysical conference was held with participants from Norway, Sweden, Finland and Denmark.


AFTONBLADET
Uppl. 3
25 öre
LÖRDAGEN DEN 18 APRIL 1953
ERT BARN
radioaktivt!
Unika mätningar på Söder - Bilder

Sievert wanted to examine radiation levels in different population groups to see what variations existed due to both geographical factors and biological factors, such as body constitution and diet. Following measurements carried out in Henriksdal on school classes from Sofia Elementary School, an "Aftonbladet" newspaper headline proclaimed the then little-known fact that we all (including children) carry significant amounts of radioactive substances.

Sievert became the central figure in the Academy's effort to remedy the inadequate research conditions in northern Sweden. He had a broad interest in auroral research, likely strengthened through contacts with Hannes Alfvén. As an active Academy member, he wanted to contribute his greatest asset - his entrepreneurial ability. Sievert drove the project from its earliest plans to the final architectural drawings, cooperating with politicians both locally and nationally. He succeeded in turning the committee into a functioning group despite diverse backgrounds of the committee members. Meetings were often held at the Radiation Physics Institute or at Sievert's official residence, ending with light meals, beer and schnapps.[49]

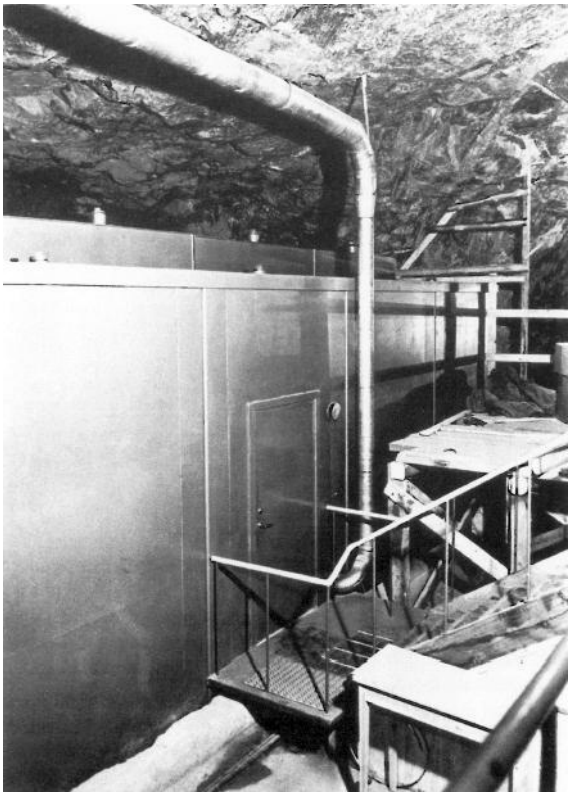
The committee, calling itself the Abisko Committee, submitted its report on 20 December 1946 and on 10 January 1947 delivered the "Report with Proposal for a Geophysical Observatory in Kiruna, etc." to the Ministry of Communications.[50] Two days earlier, Sievert presented the report at an Academy meeting.

The Abisko Committee proposed establishing a geophysical observatory near Kiruna - the Kiruna Geophysical Observatory - and continuing operation of the Abisko natural science station. Smaller outposts, the so-called Hamberger observation huts, were to be retained mainly for meteorological work.[51] The overarching organization was to be called "Upper Norrland's Natural Science Research Stations" with a governing board chaired by the Academy's president. The board would appoint staff and coordinate routine work for SMHI and the Hydrographic Office.

Given Sweden's small size and limited resources, the committee argued that centralization would be beneficial.

"The importance of international research cooperation for a small country like Sweden cannot be overstated, particularly given that, as a result of the war, our country was for a long time cut off from contact with the rapidly evolving scientific activities in the major nations".[52]

The committee emphasized that if Sweden focused on scientific areas where it had uniquely good conditions, it could offer "counter-services" internationally and thereby meet its scientific obligations.[53]



The entrance to the laboratory in Henriksdal. The measurement laboratory - built primarily by Bengt Håkansson - was blasted into a rock cavern and surrounded by water tanks containing water from the river Thames in England which has lower levels of radioactivity than Swedish river water.

Although centralized organization had not been Sievert's original idea, he championed it vigorously. Some observations - such as auroral, meteorological and seismological measurements - were best conducted at geographically separated sites. But economic considerations and communications difficulties argued strongly for centralization. Additionally, a central research station would more easily attract foreign scientists, something the committee deemed vital for postwar Swedish science.[54]

The original plan was to place the observatory in Abisko, but geomagnetic measurements revealed that the railway's power lines created too much interference. Meteorological conditions at Riksgränsen were also too local to be representative. Eventually, a site 8 km east of Kiruna was identified:

"Investigations have shown that neither the railway nor Kiruna's tram system causes measurable disturbances in magnetic recordings. No disturbances of the type observed in Abisko have been detected."[55]

Kiruna was also a representative site for northern Sweden's meteorology and transportation links were excellent:

"Kiruna is Sweden's northernmost rail-served town, with a well-maintained road network. All major roads, including to Kuuravaara, Jukkasjärvi and Kaalasluoppal, are served year-round by buses with several daily departures."[56]

Construction costs - observatory building, radio-sounding buildings, absolute magnetic house and magnetic recording house - were estimated at 1,355,000 Swedish crowns.[57] The station would require nine full-time staff members, led by a geophysicist.[58]

Sievert had already decided that Bengt Hultqvist was the right person to lead the observatory. Letting Hultqvist go was difficult for Sievert, as the Radiation Physics Institute needed to



Bengt Hultqvist photographed as the first opponent at Bo Lindell's doctoral defence.

expand after the war and trained physicists were scarce. But Sievert's stance reflected both the importance he attributed to northern research and his broad view of what benefited Swedish science.

The committee gathered opinions from universities, colleges and industry. All were supportive. Hannes Alfvén wrote:

"Since geophysics is one of the most neglected sciences in our country, establishing a northern geophysical observatory would be highly desirable."[60]

He highlighted the importance of studying rapid changes during magnetic storms and cosmic radiation. The heads of the relevant organizations told the government:

"Because of the great importance for Sweden's position in international scientific cooperation that the proposed observatory may have, we consider it urgent that the issue be presented to the 1947 Parliament."[61]

However, Parliament did not act quickly and it took until 1956 before a contribution of 850,000 Swedish crowns was approved - likely due to the upcoming International Geophysical Year.[62] At an Academy meeting in 1948, Sievert and the Abisko inspectors Hulthen and Florin proposed creating a provisional organization with an interim board of four members, since no government action was expected soon.[63] The board held its first meeting at the Radiation Physics Institute on 11 May 1948, with Sievert as chair.[64]

The committee had scientific reservations about Abisko and had also been approached by Kiruna Municipality, which sought to diversify its mining-dominated economy. Kiruna cooperated eagerly on land issues and other matters. This "push and pull" effect strongly influenced the final location of the observatory. Kiruna capitalized on its geographical asset - its high latitude - and succeeded in its ambition to attract a scientific institution to the town.[65]

Temporary barracks and housing were built in 1948 with municipal support.[66] A panoramic ionosonde was installed by Professor Olof Rydbeck and a magnetic recording house was set up under the Hydrographic Office and Nils Ambolt.[67] The Academy also improved Abisko



The Abisko Committee gathered in 1946 at the conference where the seed of the Kiruna Geophysical Observatory was sown. Seated: the foreign guests; standing, from the left: research fellow Malmfors, Nils Ambolt, Carl Johan Östman, Hannes Alfvén, Hilding Köhler, Rolf Sievert, Harald Norinder, Gustaf Ising, Sven Åslund and research fellow Werner.

station. In 1952 the Ministry of Communications established a board of eleven persons, seven appointed by the Academy.[68] Sievert persuaded former Prime Minister and Foreign Minister Rickard Sandler to become chair of the board for Upper Norrland's scientific stations, thereby strengthening its political support.

The board oversaw the Kiruna Geophysical Observatory, Abisko station, the Sarek natural science facilities and the Tarfala glaciological observatory, with a budget of about 200,000 Swedish crowns. A territory of 2,220 hectares was granted to the Academy.[69] In 1954 the board secured 250,000 Swedish crowns from Kiruna toward the total projected construction cost of 1,550,000 Swedish crowns.

Internationally, the field of geophysics has always been characterized by cooperation - a necessity for gathering the data required for research. International activities had also been taking place for a long time: the years 1882–83 and 1932–33 had served as so-called "polar years" for global measurements and a new solar activity maximum was predicted for twenty-five years after the last polar year. This prompted researchers to proclaim an International Geophysical Year (IGY), running from July 1, 1957, through the end of 1958. Many of the research stations currently located at the poles were established in conjunction with the IGY. The satellite programs of the major powers trace their origins to the IGY, beginning with the Russian Sputnik in 1957. For researchers, the IGY offered an opportunity to forge new international contacts. Hannes Alfvén discussed the IGY at a board meeting in early 1956:

"The planned Arctic conference in Stockholm, 22 - 25 May 1956 forms part of the preparations for IGY. It would be desirable if the board used the opportunity to contact foreign scientists for whom research at the Kiruna observatory during those years would be of interest."[70]

When the government approved construction in 1956, IGY played a decisive role. The observatory could be seen as Sweden's contribution to geophysical research and Sievert used this argument effectively. Parliament allocated 850,000 Swedish crowns and construction began, with Sievert chairing a special building committee.[71]

A main building of red brick, a new ionospheric observatory and a cosmic-ray recording house were inaugurated on 2 July 1957 by county governor Manfred Näslund. At the same time, Sievert received the Academy's Linne Medal (small gold) for his contributions. In the main building's dining hall, the observatory's board presented Sievert with a frieze by Gustavsberg artist Stig Lindberg for his 60th birthday.[72] Later, the Academy commissioned Erik Kinell to paint a portrait of Sievert at age 67, now kept at the Kiruna Geophysical Observatory. The description states:

"At age 67, waist-length, seated at a desk, facing slightly left, gray thick slightly wavy hair, clean-shaven, brown eyes, light gray suit, light blue shirt, brown tie."[73]

He sits leaning back in his chair holding a cigar in his right hand, left hand resting on the desk. The sharp gaze behind horn-rimmed glasses meets the viewer. A replica of this painting hangs in the Swedish Radiation Safety Authority's conference room and an image appears on this book's cover.

Within a year of the observatory's inauguration, it became involved in a major international research project after scientists discovered an unexpected proton emission from the sun. Gradually the observatory expanded, accelerating after 1973 when the state assumed responsibility for its operation.[74] Sievert, who had become chair in 1961 after Sandler, acted largely as a guardian of the observatory's interests. The Kiruna Geophysical Observatory developed into what is today the Swedish Institute of Space Physics and the well-known Esrange. Sievert's efforts testify to his entrepreneurial spirit and organizational talent. He served as chair of the Upper Norrland research stations until his death in 1966, maintaining his interest in northern research throughout his life.

7. Nuclear Energy: A Double-Edged Sword

Fifteen Years of Interaction

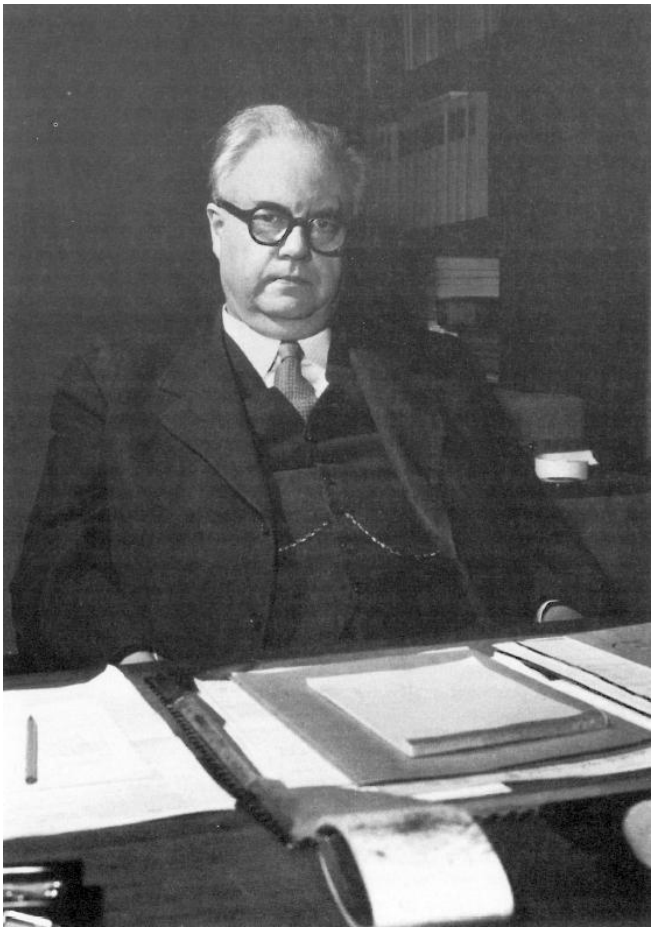
The Henriksdal laboratory marked the beginning of a new epoch in Sievert's life. His interest in radiation emitted by the human body and in radiation injuries would lead him into extensive international engagement and place heavy responsibility on his shoulders in international organizations. At the Henriksdal laboratory, several investigations were carried out on different categories of test subjects - children, elderly people, individuals with a great deal of muscle mass - in order to gain an understanding of how the body's natural quantity of radioactive substances was distributed. At the same time, Sievert equipped a bus that carried out background measurements throughout Sweden. The result was that he could create a quantitative picture of how radiation varied geographically across the country. This nationally based knowledge could then be used in the international work that followed the global fallout from the United States' and the Soviet Union's atmospheric nuclear test explosions in the 1950s and 1960s.

The radiation problem became international and dispersion phenomena attracted attention from researchers all over the world. Mass media interest was immense and the fear of nuclear war was gradually redirected toward concern about radioactive contamination. Under pressure from world public opinion, the UN began to work for deeper knowledge of radiation and radioactive fallout, so that political discussions on nuclear weapons and nuclear weapons testing could be conducted on the basis of scientific consensus.[1] In 1955 the UN therefore formed the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), an expert committee reporting directly to the General Assembly.[2] The organization's purpose was partly to respond to the public's strong anxiety and partly to provide a platform for discussions and informal contact in the Cold War.

Parallel with military developments, practically all countries invested in national, peaceful nuclear energy programmes. Sweden, at an early stage, created the resources needed to construct several reactors. The first Swedish reactor was built in 1954 and located on Drottning Kristinas väg on the premises of the Royal Institute of Technology (KTH) in Stockholm.

Since 1941 the Radiation Physics Institute had been the supervisory authority for all activities connected with radioactivity and radiation. Sievert realised early that supervisory tasks would increase sharply and in the mid-1950s the radiation protection law was revised to suit the strong increase in artificial radiation sources. A Nuclear Energy Act (*atomenergilag*) was added in 1956 and from 1963 a separate act regulated compensation for accidents caused by nuclear-powered ships.[3] The increased need for supervision was not at all unique to Sweden but applied to the whole industrialised world.

Sievert became chairman of the ICRP in 1956 and, two years later, of UNSCEAR. These positions gave him a platform for his ambition to create a large, overarching and above all economically independent organization for radiation-protection issues. That organization never came into being, but Sievert strengthened the financial position of the existing organizations and made it possible for the ICRP to continue with increased resources and independence.

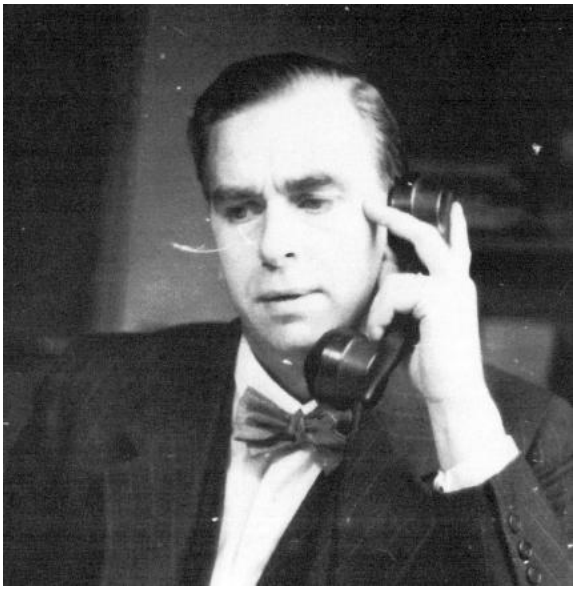


Sievert, as many remember him, behind the desk in his study.

The poor state of knowledge regarding harmful effects of small radiation doses made Sievert a cautious general and the stricter limits that he advocated were gradually accepted, also internationally through the ICRP. His cautious stance proved clear-sighted and far-seeing and is evidence of his scientific competence in a field that is very difficult to master. Radiation protection was, at an early stage, an area that was strictly regulated. Compared with many other risks, one may say that the risks of radiation are not only well documented but also framed by an explicit protection philosophy, with balances between benefit and risk. Quantitative risk assessments, however, lay outside the strictly scientific field; such value judgments could only be made by politicians. Nevertheless, the ICRP decided - rather boldly - to propose limit values for entire populations.

The well-documented risks at high radiation doses also meant that all activities associated with radiation could be subjected to criticism and indeed they were - more or less seriously. Critics primarily argued that long-term effects had been underestimated when radiation-protection recommendations were developed. The discussion has continued over the past decades and lay partly behind the 1980 referendum in Sweden on the future of nuclear power.

The Windscale accident in England occurred in 1957 and a radioactive dust cloud followed the winds down over Europe and then turned toward Scandinavia. The accident attracted great publicity and directed attention to the risks of nuclear reactors. As a consequence of the Windscale accident and several other smaller accidents and incidents, Sievert contributed to the creation in Sweden of the Expert Committee for Advice in Nuclear Accidents (*Expertkommittén för rådgivning vid atomolyckor*, KRA). The committee was to function as a



One of Sievert's colleagues, Matts Helde (Licentiate of Philosophy), voiced criticism in a public inquiry regarding Sievert's way of organizing the Department of Radiobiology and the radiation protection work. Alongside his role as head of X-ray supervision, Helde studied changes in the blood counts of irradiated individuals.

group of experts who would assist authorities at the accident site. The work with KRA began in the early 1960s.

In the latter part of his life, Sievert devoted considerable interest to Nordic cooperation in radiation protection. This cooperation was a consequence of the state of readiness in the Nordic region when the Soviet Union conducted nuclear tests at Novaya Zemlya. Under unfavourable wind conditions, Scandinavia might have received dangerous levels of radioactive fallout. That never happened.

Between about 1950 and 1965 Sievert was heavily engaged in international work. The experience he had accumulated during the Henriksdal investigations in the early 1950s gave him substantial opportunity to influence international developments. In the same way, Sievert gained influence over international radiation-protection recommendations, since the Radiation Physics Institute in Sweden held a very strong international position in radiation protection.

Some people viewed the international emphasis in Sievert's work as a neglect of Swedish activities. Internal criticism from Matts Helde, head of Division A at the Radiation Physics Institute, led Helde to write a separate dissenting statement in the so-called radiation-protection inquiry (*strålskyddsutredningen*).

Renewed International Work

The Second World War had interrupted all international cooperation in the area and it would be ten years before new contacts could be established between countries. Work on radiation protection had, however, continued during the war. In Sweden and England it had been found that even very low radiation doses could cause changes in blood formation.[4] At the Radiation Physics Institute, Helde, as division head, had demonstrated blood-picture changes at radiation exposures down to 0.5 roentgen per week.[5] The German-American geneticist Hermann Muller had already in 1927 discovered that X-rays could cause an increased mutation frequency, but it was not until the late 1930s that his discovery led to investigations within radiation physics.[6] The entry into the atomic age caused Sievert to adopt a cautious attitude toward low radiation doses. In 1947 he held a lecture in London in which he advocated a maximum weekly dose of

0.1 roentgen for personnel engaged in radiological work - one tenth of the weekly dose that had been adopted in 1934 in Zurich at the Third International Radiology Congress.[7] Sievert's main motive was caution in the face of the increasing use of ionizing radiation that he anticipated.[8] The use of nuclear energy would also mean that substantial segments of the population might be exposed to radiation in their work or in the event of an accident. However, he did not consider that lowering the weekly dose would entail "any serious technical or economic consequences".[9]

At the Sixth International Radiology Congress in London in 1950, the International X-ray and Radium Protection Committee changed its name to the International Commission on Radiological Protection (ICRP).[10] With this, the Commission wished to underline its expanded area of work, reflecting the rapid development in nuclear physics. At the meeting, the dose limit was adjusted to 0.3 roentgen per week.[11] Recommendations were also issued concerning the maximum permissible amounts in the body of the most common radioactive substances.[12] To work effectively, the Commission set up five committees dealing with different aspects of radiation protection.[13] For a long time, Sievert applied lower limits in Sweden than those recommended by the ICRP but in 1956 the ICRP lowered the dose limit to 0.1 roentgen per week, i.e. the value Sievert had already proposed in London in 1947.[14]

Hermann Muller received the Nobel Prize in Physiology or Medicine in 1947 for his research showing that X-rays produce mutations.[15] Muller was worried that a large part of the population was being exposed to radiation in diagnostic and therapeutic radiology that could affect the hereditary material.[16] A gene mutation generally represents a change for the worse. If an individual carries such a hereditary gene mutation, or allele, it can be transmitted to the child in recessive form. If both parents carry the same allele, it can be passed on in homozygous form, which means that the allele is manifested as an undesirable trait. The probability that a population will be harmed by recessive gene mutations thus depends on how many people carry the same allele. If the inherited trait severely deforms the child or leads to sterility, the child will not be able to have children and the trait is eliminated from the population. If the allele is less harmful, it can be propagated over several generations but will, due to selection pressure or by chance, eventually be eliminated. Muller termed this "genetic death".[17] According to Muller, a single quantum of radiation could be sufficient to damage a cell's chromosomes and therefore no threshold exists below which radiation is harmless. He worried that the use of X-rays might lead to an increased amount of genetic death.[18]

When Sievert in 1952 took the initiative for a joint meeting in Stockholm of the ICRP, the ICRU and UNESCO's body for radiobiology, to discuss the biological effects of radiation, Muller was invited to propose measures to prevent genetic damage.[19] Together with Muller, a number of other recognized biologists were also invited. No consensus was reached on what recommendations would be appropriate. Sievert later wrote:

> "Due to the lack of agreement between the geneticists and to the meagre information available at that time, no specific recommendations were prepared. It was, however, recognized that genetic effects must be taken into consideration."[20]

Muller proposed that the radiation dose should amount to a maximum of 0.67 rad per year, based on the principle that the natural mutation rate in a population must not be increased by



Group photo from the radiobiology conference in Stockholm in 1952. The American geneticist Hermann Muller stands second from the right in the front row. At the conference, the biological effects of radiation and potential recommendations were discussed. Muller received the Nobel Prize in Medicine in 1947 for his research in this field.

more than 25 percent through man-made radiation. A few years later the ICRP recommended dose limits that agreed fairly well with Muller's proposal.[21]

At the ICRP meeting in Copenhagen in 1953, the Commission for the first time produced a more extensive report, which was completed and published the following year.[22] The report contained sections in which blood tests of personnel and processing of the test data were discussed. "Permissible dose" was defined as the dose of ionizing radiation that does not injure a person during any period of his lifetime.[23]

Reactor 1 at Drottning Kristinas väg

Sweden's first reactor, named R1, "went critical" at nineteen minutes past six in the evening on 13 July 1954 at Drottning Kristinas väg in Stockholm. The power of the reactor was measured at 0.3 W, which must be characterized as a very cautious first test run.[24]

The person who came to lead the work of building Sweden's first nuclear reactor was Sigvard Eklund, who during the war had worked at the Nobel Institute, among other places and had been partly involved in the military physics work at MFI.[25] Eklund published an article on nuclear fission in *Kosmos* in 1941, when he was working at the Nobel Institute under Manne Siegbahn.[26] When FOA was created, Eklund in 1946 became head of the nuclear-physics section within FOA's physics division. Later he transferred to AB Atomenergi, together with a number of other physicists, during a reorganisation intended to rationalise research in preparation for reactor construction.[27] The work was located at IVA's experimental station at Drottning Kristinas väg 47–49, where Atomenergi had premises and the reason given for this location was proximity to the scientific and technical research at KTH.[28]

The official decision to build a Swedish "zero-power" reactor was taken at the end of 1949.[29] Research, however, essentially began already in 1945, when the Supreme Commander



Rune Walstam in 1953, en route to the radiology congress in Copenhagen. Walstam would go on to succeed Sievert as professor at the Department of Radiobiology. Sievert paved the way for Walstam's academic career; prior to joining Sievert, Walstam had studied mechanics at the Stockholm Technical Institute and worked in industry for seven years. Before his employment with Sievert, Walstam had also studied electronics in evening classes at the Technical College in Stockholm.

requested a report on the atomic bomb from FOA. In August 1945 the United States published a report, prepared by Professor Henry Smyth, containing a surprisingly detailed description of the work behind the atomic bomb. The first contact Swedish physicists had with the so-called Smyth Report was a photocopy that Manne Siegbahn received from the American ambassador in Sweden.[30] In the autumn of 1945 the report was regarded as something like the atom physicist's bible and formed the main basis for FOA's own report.[31] At this very early stage, no distinction was made between military and civil uses of atomic energy.

During the build-up phase, international contacts were indispensable and Eklund early created many such connections abroad. In the radiological field, it was Sievert who provided Eklund with the necessary introductions. One of these was to Lauriston Taylor, who had connections to the National Bureau of Standards, one of the most important sources of information when it came to building a nuclear reactor.[32]

At IVA's experimental station, Eklund planned a Van de Graaff machine enclosed in a pressure vessel in order to reduce the risk of electrical breakdown and thereby reach higher voltages. The Van de Graaff machine was necessary to produce neutrons for nuclear fission.[33] In a letter of 9 July 1948, Eklund wrote to Sievert and thanked him for the introductions he had received to the English researchers Mayneord and Gray, who were working with precisely such machines.[34]

To obtain a permit to construct a nuclear facility, FOA and Atomenergi had to receive approval from the National Medical Board (*Medicinalstyrelsen*), whose evaluation in turn was carried out by the Radiation Physics Institute.[35] The siting of the reactor so close to Stockholm was highly sensitive and required that safety be good. Sigvard Eklund had English specialists examine the site and provided them with access to the plans.[36] At an early stage, a decision was made to measure the radiation in the area so that values before and during reactor operation



Sigvard Eklund beneath the IAEA symbol: the laurel wreath and the atom - mankind's triumph over atomic power. Eklund became Director General of the IAEA in 1961.

could be compared. Measurements and evaluation, undertaken by AB Atomenergi, were carried out in close cooperation with Sievert's colleague Sven Benner.[37]

In autumn 1948 the Radiation Physics Institute submitted a document to the National Medical Board which (probably) contained an application to build the reactor at IVA's experimental station. In a note to Eklund, Sievert reported that he had sent the Board a letter after "first having conferred with them by telephone".[38] Sievert's position on the test reactor was very positive. He advocated construction of a reactor in order to clarify the problems surrounding nuclear-power use. According to Eklund, Sievert was very keen to create the necessary conditions and acted in a highly un-bureaucratic way. Sievert shared the common view that emissions from the reactor could be limited and controlled. Compared with other chemical industries, nuclear power was tightly controlled early on, because from the outset there were good possibilities to measure radiation.[39]

It was Sven Benner who organised radiological supervision at R1.[40] From the late 1940s, regular blood-picture examinations were carried out on Atomenergi staff, especially those who in their work came into contact with radioactive substances.[41] No alarming changes in blood pictures were ever noted, although it did happen that someone had to be granted so-called radiological leave when he or she had received too much radiation dose.[42]

In 1950, an Atomic-Energy Research Radiation-Protection Council was created at the Radiation Physics Institute - an informal body to discuss issues concerning nuclear energy. In the institute's annual report, Sievert wrote:

"The council consists of representatives of the Atomic Committee, AB Atomenergi, the Civil Defence Board, the Defence Research Establishment, the Defence Medical Administration, the Defence Staff, the National Medical Board and the Radiation Physics Institute, as well as the member of the Medical



To address scientific problems related to atomic energy research, the Swedish National Committee for Physics convened a conference in early 1946. Beneath the bust in the foreground is Manne Siegbahn, to his left in the picture is Erik Hulthén and to his right are Sievert and Gustaf Ising.

Board's Scientific Council in radiotherapy, the head of the division at the Radiation Physics Institute responsible for the control of protective devices for radioactive preparations, the laboratory head in radiation biology who is also chemist at the Radiation Physics Institute, an expert in nuclear physics and atomic energy appointed by the council from among its other members and such additional persons as the council may unanimously appoint."[43]

This substantial council was to support the development of radiation protection in the use of atomic energy. The four organizations with military connections show the degree of interest the Swedish defence establishment took in the development of nuclear energy. It is important to note that at that time no linguistic distinction was made between the peaceful and the military uses of atomic energy.

Whether the council discussed radiation-protection issues connected with a possible Swedish atomic-bomb programme is unclear but at the Radiation Physics Institute the genetic risks of a possible nuclear war were investigated in 1951. It should be stressed that nowhere can one see that Sievert himself was engaged in work on Swedish nuclear weapons.[44] With great discretion, people such as Torsten Magnusson and Sigvard Eklund carried out studies on Swedish nuclear weapons and the production of the necessary plutonium. There is hardly any doubt that Sievert knew of these studies and the discussions around them.[45] It is clear that the pros and cons of Swedish nuclear weapons were openly debated in the latter half of the 1950s. In 1955, Eklund argued in *Dagens Nyheter* for the possibility of allowing planned nuclear power plants to produce plutonium for weapons purposes and thereby subsidise civil nuclear power.[46]

Nuclear power was one of the factors that caused the supervisory work of the Radiation Physics Institute to increase in scope during the 1950s. As mentioned earlier, in 1951 the then Minister of the Interior Gunnar Hedlund appointed a radiation protection committee (*strålskyddskommittén*) to develop a new law and to investigate how research and supervision should be organised.[47] Sigvard Eklund of AB Atomenergi served on the committee. Hedlund wrote in a statement at the time of appointment:

"With regard to radiation-protection control in nuclear-energy research, there should be consultation with the Atomic Committee and AB Atomenergi, with the latter in order to determine to what extent



The specially equipped survey vehicle, a Volvo Duett. Bengt Håkansson travelled along Swedish roads in both summer and winter. On one occasion, Sievert was waiting for him in Gothenburg and as he approached the city, two police officers pulled up behind the survey vehicle. Sievert had asked the police to "escort" Håkansson to the hotel so that he wouldn't stop for a cup of coffee but would instead show the impatient Sievert the measurement results without delay. Sometimes Sievert would place a radium sample along the road to see if the equipment registered a reading.

the Radiation Physics Institute can be expected to be called upon for protective control at the facilities which the company is planning."[48]

At that time no commercial reactor was yet in operation and the committee had no foreign model to work from. The intention was therefore to keep the provisions as general as possible. In the report submitted in 1956, the committee wrote that a location far from densely populated centres was preferable in the case of a nuclear-power accident with plutonium release but that economic considerations might argue against such a solution.[49]

The risks that were particularly relevant in the case of R1 concerned the danger to the working personnel, since the reactor was primarily intended for scientific investigations. That this work also entailed risk was demonstrated in October 1958 when an accident occurred in the former Yugoslavia during experiments with a zero-power reactor. The reactor was subcritical while shielding was being removed. By mistake it became critical and six staff members were exposed to neutron and gamma radiation. One of them died four weeks later from the radiation injuries.[50] The technical design of radiation protection and the granting of permits to handle radioactive substances were considered satisfactory in Sweden even under the 1941 radiation-protection law.

"Because of the complicated technical equipment, the granting of permits must in much higher degree than in other radiological work be based on close cooperation between the supervisory authority and the owner of the facility regarding its planning and the provision of protective devices."[51]

The committee further stated that supervision through frequent and thorough inspections must ensure that no accidents occur. The protection philosophy was that radiation protection should be designed so that it was geared to the highest conceivable radiation from the facility and the "maximum radiation risks associated with reactor operation".[52]

However, the committee was more doubtful about the fact that the government granted permits to build and operate a nuclear facility, while the National Medical Board granted permits to conduct radiological work. The committee wrote that in practice the Medical Board could hardly refuse a permit if the government had already granted one for construction and



Sid. 4: SJ-loken apelsinfärgas mot krockrisken

Grundades år 1830 av LARS JOHAN HIERTA

AFTONBLADET

KVÄLLSUPPLAGA

Pris 10 öre På tåg och båtar 15 öre

TELEFONER Lokala nummer 22 62 00 Riksnummer 22 62 40 TELEXNYTT 22 91 40

Nr 179 **** Torsdagen den 7 juli 1955 XXX

RADIUM I SVENSKA DRICKS- VATTNET

efter atomsmällarna - professor lugnar

ATOMBOMBFÄLLNINGARNA i Ryssland och USA påverkar det svenska dricksvattnet. Detta har framkommit i en undersökning som radiofysiska institutionen vid Karolinska institutet gjort av dricksvattnet i ett 20-tal städer.

Rapport har lämnats till atomkommittén.

VILKA STADER som har extremt radiumhaltigt vatten vill inte institutionen avslöja förrän undersökningarna slutförts. Vid sidan av dessa har gammastrålningen hos 900 barn, medelålders personer och gamlingar i Stockholm undersökts, liksom 300 anställda vid Atomenergi. De var inte onormalt påverkade av strålningen.

— INGEN SOM HELST anledning till oro föreligger med anledning av radiumhalten i dricksvattnet, framhåller institutionens chef, professor Rolf Sievert till Aftonbladet.

NÄR UNDERSÖKNINGARNA är slutförda läggs resultatet fram för allmänheten. Sidan 4

Concern about the fallout was also reflected in the Swedish newspapers.

operation.[53] The committee therefore proposed a special reactor-safety committee composed of experts in all areas relevant to such a special concession procedure as a nuclear power plant entails.[54] The Radiation Physics Institute would have representation on this committee in order to oversee radiation-protection issues in particular.

Fallout and More Fallout

Sievert's interest in the natural radioactivity of the human body ran parallel to his interest in natural background radiation. From 1950 he constructed instruments for continuous measurement of gamma radiation in the environment.[55] Four instruments were in operation from 1950 and a further two were added in 1956.[56] Three years later, Sievert had managed to reduce the pressure-ionization chamber to a volume of four litres with an overpressure of 20 atmospheres. At the same time, he obtained funds to create a network of measuring stations across Sweden. The network was built in the same year by Sievert's all-round colleague Bengt Håkansson.[57]

Sievert found that background radiation varied with the seasons, in that the snow cover played a decisive role by absorbing gamma radiation.[58] Radiation also varied between different environments. A marked increase in radiation could be observed in cities compared with the countryside.[59] Håkansson and Sievert undertook many trips to measure levels along Swedish roads. Sievert would sometimes travel ahead to their destination and place a radium preparation somewhere along the road to see whether the instrumentation registered it at the right place. In his 1956 dissertation, Bengt Hultqvist showed that "the natural dose rate" could double from one room to another within the same dwelling.[60]

Another well-known fact was that background radiation varies geographically. In India, among other places, there are monazite deserts containing large amounts of radioactive substances. Sievert had advanced plans - approved by the Indian embassy - for an expedition in which elephants, equipped with pressure-ionization chambers, would measure the radiation but for unknown reasons he never carried out the project.[61] Arne Hedgran was hired in 1951 as

successor to Sven Benner and at the same time questions concerning nuclear weapons and their effects came to the fore.[62]

The Radiation Physics Institute first registered increased background radiation in 1953, after the Soviet Union exploded its first hydrogen bomb in mid-August. In an article in *Arkiv för fysik*, Sievert wrote:

"The first indication of a higher level was found in August 1953 after the thermonuclear weapon test over the northern hemisphere [...]."[63]

Since the article was written as late as 1959, it is unclear whether he already in 1953 interpreted these elevated values as a consequence of the nuclear tests.

On 1 March 1954 the United States exploded a powerful hydrogen bomb at the Bikini Atoll.[64] To obtain as powerful an explosion as possible, the hydrogen bomb was surrounded by a uranium casing that, through the neutrons produced in fusion, could be made to undergo fission. The inhabitants of the Rongelap Atoll were in an area that, due to an unexpected wind shift, was affected by fallout and during the 44 hours that passed before evacuation they received a radiation dose exceeding 100 roentgen.[65] The event created great publicity and debate about nuclear weapons. In Sweden the Radiation Physics Institute did not register any elevated radiation values compared with the previous year but it is likely that Sievert began to think about dispersion phenomena.[66] The only known case of global spread of particulate matter was when the volcano Krakatoa exploded in 1883 and spread fine dust across the entire world. Sievert acquired a book about the eruption and dispersion phenomena and dispersion paths became important subjects of study at the institute.[67]

After nuclear tests in July 1955, fallout increased in southern Sweden and the average gamma radiation rose by ten percent.[68] This level stabilised in 1956–57, but the truly significant increase would come in 1958. In the article in *Arkiv för fysik*, Sievert wrote:

"In the last part of the relatively rainy summer of 1958 the radiation rose to values of the order of 20% higher than the natural radiation and the tests over the northern hemisphere in September-October 1958 brought such quantities of fallout that in May-June 1959 there were still a 10-15% higher radiation level than there had been before 1953."[69]

Since Sievert had been measuring natural radiation in the body for ten years and had by then ascertained that people working with radioactive preparations showed elevated levels of gamma-emitting substances, he suspected that fallout might accumulate in humans. In 1951 he wrote:

"Already after a few years some persons working with radium or thorium show a marked increase in their gamma-radiation."[70]

From 1952 onward, Sievert had collected various foodstuffs and stored them to examine their radioactivity. In a study published in 1956 he summed up:

"In every case a significant increase has been observed which seems to originate from fallout from atomic bomb tests."[71]

The elevated values that Sievert obtained in his measurements only revealed increased intensity - they did not indicate what the fallout consisted of. This mystery was solved only in 1955/56, when the Chicago researchers C. E. Miller and L. D. Marinelli succeeded in identifying cesium-137 and some other radioactive substances. They stated that the results of their investigations



The display panel showed the equipment of the bus specially prepared for the Geneva Conference. The bus was a converted Volkswagen van. The idea behind the bus was that, in emergency situations, it could rapidly measure radiation levels in large numbers of people and large quantities of food. For instance, it was equipped with 16 ionization chambers for measuring water and air.

corresponded well to the fission products expected from atomic-bomb explosions. In an article in *Science* in 1956, they drew the following conclusion:

"Moreover, they [the results of 1955/56] suggest that Cs^{137} might be gaining access into the human body by its continual deposition on grazing lands and following thereafter much the same pathways described in the case of Sr^{90}."[72]

This explains Sievert's conclusion in 1956. Miller and Marinelli had used a new instrument for their investigation and soon all the major institutions in Sweden that worked with radioactivity were equipped with scintillation spectrometers, among them AB Atomenergi and the Defence Research Establishment.[73]

Around 1955, Sievert bought a Volkswagen bus and fitted it out as a mobile measuring station and laboratory. Among other things, the bus was used to map background radiation along Swedish roads. In this way, Sievert soon obtained a complete radiation map of Sweden. He also had mosses examined and specially equipped aircraft to measure radioactivity in areas of particular interest.[74]

In August 1955 the UN organized a conference in Geneva on the peaceful uses of atomic energy.[75] In his lecture there, however, Sievert did not mention the elevated background radiation - probably because it was still too early to draw conclusions from the limited available material. Instead, he concentrated on presenting the results from the Henriksdal laboratory and the differences in body radiation found between men and women, urban and rural populations.[76]

Sievert brought to the conference the newly equipped measuring bus, which was intended for use in a catastrophic situation. The bus contained equipment to detect radiation sources and to measure radiation in people's bodies. Its capacity was to examine about one hundred persons per hour.[77] At the conference Sievert also met UN Secretary General Dag Hammarskjöld for



At the 1955 Geneva Conference, UN Secretary-General Dag Hammarskjöld inspected the Swedish bus (which is not visible in the picture, except for one of its side mirrors on the left). Hammarskjöld is standing just behind the edge of the camera lens. Bengt Håkansson stands at the far left.

the first time and had the opportunity to demonstrate for him the equipment that the measuring bus carried.

In 1959, Bengt Håkansson and Rolf Sievert travelled to the United States in connection with a UN gathering on radiation protection. Sievert, who did not particularly enjoy travelling - especially not by air - set out by ship. To measure background radiation during the voyage, he had, after negotiations with the shipping company, an instrument mounted on the bridge. Today we know that background radiation varies with the Earth's magnetic field. To calibrate the instrument, Sievert brought along a radium preparation. Before arriving in Sweden, the ship had loaded hides in Riga and was therefore inspected by the American Coast Guard on arrival in Portland. One of the customs officers carried a Geiger-Müller counter which registered activity under Håkansson's cabin where Sievert, as a joke, had hidden the radium. After some commotion, the customs officers found the preparation and Sievert expressed his great gratitude at recovering his "lost" radium and promised to pass on praise to the officers' superiors.[78] Such practical jokes were something of a Sievert hallmark.

The content of cesium in the human body reached its first peak around 1960 with an activity of 11 nCi. This was, however, nothing compared with what was to come. After a few years of decline, levels rose again in the early 1960s, reaching a maximum in 1964 of 32 nCi.[79] The fallout naturally caused concern among experts, because radioactive substances were being concentrated in the food chain. Milk was a particularly sensitive foodstuff, partly because substances that are easily taken up by the body occur in milk and partly because it is a staple consumed in large quantities. Already during the first increase, experts from Sweden (among them Sievert and Lindell), Denmark and Norway gathered to discuss possible measures. However, levels were never high enough for the experts to recommend that public-health authorities implement protective action.

Sievert found this problem highly engaging. After the 24 measuring stations had been set up, he could spend entire nights telephoning around and recording values whenever indications suggested an increase was to be expected.

When the two Chicago researchers Miller and Marinelli showed that radioactivity from nuclear tests in the Pacific could be detected in the bodies of people on the other side of the globe, it attracted great attention and stirred anxiety in the media worldwide.[80] This anxiety led the UN,

in mid-1955, to decide to appoint a committee consisting of fifteen countries, each represented by a scientist with a deputy and advisers.[81] In *Nordisk Medicin*, Sievert wrote that the cause of UNSCEAR's creation was primarily "the increase in radioactivity over the whole world due to nuclear weapons tests [...]".[82] The growing use of ionizing radiation in medicine and elsewhere - for example, nuclear power - was also cited as a reason for setting up UNSCEAR. The committee's mandate was threefold and consisted mainly in compiling:

(1) Observed radiation levels and radioactivities. (2) Scientific findings concerning the effects on humans and their environment of ionizing radiation. (3) Recommendations on sampling methods and equipment for radiation measurements.[83]

A Reserved Attitude

At home, criticism of Sievert and his strong position within radiation physics was growing. The reason was an inherent tension between supervision and research. After the Radiation Physics Institute became supervisory authority in 1941, the number of cases for its three supervisory divisions increased rapidly. With limited staff, the medical-physics work at Radiumhemmet and, not least, research soon suffered.[84] As early as 1948 Sievert requested reinforcement of personnel but the request was rejected.[85] While the institute's workload increased, new tasks arose in connection with artificial radiation sources and the utilisation of nuclear energy. To manage the growing activity, Sievert then requested the appointment of an inquiry to regulate the institute's exercise of authority in a more orderly fashion.[86] The result was the Radiation Protection Committee of 1951, commissioned by the Minister of the Interior, Gunnar Hedlund, to undertake "a comprehensive review of both organizational conditions and existing legislative provisions".[87] The committee had five members and, from the Radiation Physics Institute, Sievert and Matts Helde were included. The chair was county governor Malte Jacobsson. For nuclear-energy matters, Sigvard Eklund was a member and Sven Benner of the Radiation Physics Institute was called as an expert in the same area, having been responsible for supervision at R1 in Stockholm.[88]

Sievert's hopes for the committee's outcome were somewhat contradictory. On the one hand, he wanted relief from his own workload and from routine supervision while on the other hand he wanted to retain control over all divisions of the institute.

The committee's work covered two parts. One was to draft a new law - the Radiation Protection Act (*strålskyddslagen*) - to regulate the steadily increasing and more diverse use of radiation sources. The other was to develop a new organization for implementing the law.

The committee's draft law, later adopted by the Parliament, was an expanded version of the 1941 act on radiological work. It was based on the same type of supervision as the old law, but it emphatically stated that the law was to "provide protection for every object of radiation" - in other words, also regulate protection of third parties.[89] The 1941 law specified in its text a lower technical limit for X-ray-tube voltage and for the quantity of radioactive substance and only values above those limits were subject to the law. These limits were abolished in the new act, allowing the Radiation Physics Institute to assess risks and adjust the volume of supervision according to its own judgment.[90]

The long interval between the committee's appointment and its report hints that the work did not proceed without disagreements. In February 1954 Sievert wrote to an American colleague

that he could not come to the USA because: "*We have so many current organization problems which require my presence in Stockholm*."[91] These organizational problems were likely expressions of conflicts within the inquiry. Sievert was relatively alone in his efforts to keep the different parts of the Radiation Physics Institute's activities entirely under his own influence.[92] The committee summarized the conflict in its report:

"Both the strength and the weakness of the Radiation Physics Institute's present organization lie, in the committee's view, in the fact that no clear boundary exists between the qualified staff's tasks in research and those in more routine activities. The strength of such an organization lies in the fact that research tasks can be taken up and developed within the institute and later gradually transferred for application in supervisory or medical work. The weakness of the same system has been that ongoing supervisory tasks have in reality taken precedence so that insufficient time has remained for research."[93]

This fundamental conflict played a decisive role on several levels. The institute faced the threat of being split into several separate organizations, something contrary to Sievert's desire to keep his creation under one roof. At the same time, internationally, he was working to create a new central radiation-protection organization, uniting the many bodies involved in radiation protection.

In its report the committee proposed that the National Medical Board should cease to be the supervisory authority. Responsibility would instead devolve upon a new body, the National Radiation Protection Board (*Statens strålskyddsnämnd*), consisting of experts appointed by the National Medical Board, the Work Environment Authority (*Arbetarskyddsstyrelsen*) and the Atomic Committee. As director of the Radiation Physics Institute, Sievert would be an *ex officio* member of the board, providing a link between authority and operational work and "representing radiation physics expertise in it".[94] The chair of the board was to be an experienced administrator.

Supervision, which had been divided among three divisions for the control of diagnostic X-ray installations, X-ray therapy installations and radioactive substances, was reorganized into an X-ray control division and an isotope division - the latter later named the nuclear physics control division.[95]

In the early 1950s, Radiumhemmet complained that it was not receiving the service from the Radiation Physics Institute to which it considered itself entitled.[96] To guarantee Radiumhemmet sufficient support regarding existing installations and the development of new treatment methods, the committee proposed the establishment of a separate clinical physics division, later named the Division of Clinical Radiation Physics. This division would be responsible for dose control but could delegate or transfer this task to the X-ray control division when practical considerations allowed.[97] A small division for monitoring blood pictures in radiological staff was also proposed. What on paper appeared as a cleaner division of labour actually contained strong elements of interaction in continuity with the earlier structure. Indeed, in practice, routines changed little when the reorganization was implemented.

Sievert opposed this solution. The institute's other representative on the committee, Matts Helde, also opposed it, but from an entirely different standpoint. Helde wrote a separate opinion in which he wanted to separate supervision from research and replace the organizational bond with three organizationally distinct units.[98] Organized cooperation would be replaced with spontaneous cooperation based on "good will and mutual support". Sievert argued from the

opposite direction. The strength of the Radiation Physics Institute lay precisely in the close interaction between supervision, clinical physics and research. The committee's proposal assumed that the various activities would not encroach on each other, but, according to Sievert, this notion had its roots in insufficient resources—as the committee itself admitted in its comments on the previous organization. He wanted to keep the organization but with more money to run it effectively.

Sievert did not wish to relinquish control of any of the activities that had been his from the beginning. His position and arguments were strong. In no other country than Britain did radiation physics have as vigorous a position as in Sweden, precisely because of the strong interaction between supervision and daily radiotherapy. With his international experience, Sievert understood the difficulties of establishing an effective radiation-protection regime. Foreign examples, where radiation protection was organized either by health authorities or by physics institutes, showed that these bodies often lacked understanding of the other aspect of radiation protection. Sievert therefore wanted to maintain cooperation between biological and physical studies of radiation.[99]

The idea of an unwieldy Radiation Protection Board was not appealing to him. In the 1940s and early 1950s, he had in practice been able to determine how the National Medical Board should decide; "to my knowledge it never made any changes to our proposals", as he put it.[100] Sievert was grudging toward anything that smelled of unnecessary bureaucracy. A board composed of representatives from different authorities, before which he would have to justify his positions and risk conflicts of interest, did not attract him at all.[101]

In everyday work it was proposed that the institute's director, Sievert, would decide on permit matters, unless a decision by the Radiation Protection Board was deemed necessary.[102] However, the heads of the supervisory divisions were formally given the possibility to bypass Sievert in cases where agreement could not be reached within the institute. In contrast to the regular internal supervision meetings held at the institute before 1958, Sievert could no longer alone speak for the institute before the decision-making authority.

The institute's research remained almost entirely unaffected by the committee's proposals. It was here that the centre of gravity in Sievert's work was to lie, according to the committee. This was also one of the main arguments in Helde's proposal: Sievert should not need to engage in administrative tasks, but be able to devote himself wholeheartedly to research.

The committee supported Sievert's wish that Arne Forssberg, laboratory head in radiobiology, should become professor in the same field.[103] Sievert wrote to Gray about his expectations:

> "As you already know, I should like to do something to improve the position of Arne Forssberg at our institute. I hope that it will be possible to arrange a professorship for him [...]."[104]

The committee's report also dealt with a proposal to establish a National Radiation Protection Institute (*Statens strålskyddsinstitut*) which from a strictly administrative standpoint would be preferable, as it would entail a separation between research and ongoing radiation-protection work.[105] Such an institute was indeed later created - but not until 1965, after supervision had grown further.

The ever-expanding activity demanded an ever larger bureaucratic superstructure, stricter financial frameworks and more rational administration. This ran counter to Sievert's personality. He was not particularly economical in any respect other than obtaining private

funds. His chief clerk, Svea Forss, found it difficult to keep research grants, institutional funds and Sievert's own money - used to finance temporary projects - clearly separate.[106] In 1958 Parliament decided to approve the committee's recommendations. After a few years Sievert characterised the arrangement as "decent".[107] As chair and unifying force on the Radiation Protection Board served Yngve Samuelsson, Director-General of the Insurance Council.[108] In principle, the changes were not great.[109] Sievert had nevertheless managed to keep his "empire" together and in practice the main change was that the institute received more personnel.[110] The increased staff also created a greater need for space which the committee had foreseen and had proposed enlarging the premises. Construction of these new facilities, however, did not begin until 1962.[111]

8. An International Organizer

ICRP and UNSCEAR

For a long time, Sievert hesitated to become too deeply involved in international work. He detested travelling and dreaded the many and long journeys that would follow.[1] His reluctance to fly was as great as his reluctance to travel by ship. Sometimes he would book tickets both for a flight and for a boat, only to decide at the very last minute which means of transport was "best."[2] Sievert's awareness that he possessed extensive knowledge in radiation physics and had genuine opportunities to influence developments, however, overcame all his reservations and from the mid-1950s he became increasingly involved in international radiation protection work. This work mainly consisted of collecting material and preparing recommendations at home in Stockholm and it encroached upon his ordinary tasks.

In 1956 Sievert was elected chairman of the International Commission on Radiological Protection (ICRP). He succeeded the Englishman and radiologist Sir Ernest Rock Carling, who had held the chairmanship since 1950.[3] The year 1956 was an important one for the ICRP. In April that year, the commission, together with the ICRU (International Commission on Radiation Units and Measurements), held a two-week preparatory meeting in Geneva before the International Radiology Congress in Mexico City in July.[4] The ICRP confirmed its official relationship with the World Health Organization (WHO) as a non-governmental participating organization.[5] At the same time, the ICRP and the ICRU began closer cooperation which was surely made easier by the fact that the two remaining radiation-protection pioneers from before the Second World War - Sievert and Lauriston Taylor - after 1956 were chairmen of the two organizations respectively.[6]

In 1956 the ICRP consisted of about sixty members, organized in a main commission and four committees that worked out recommendations for different technical applications. Under Sievert's leadership, the old committees were later abolished and replaced by four specialist committees: "one for the biological effects of radiation, one for internal exposure, one for external exposure and one for the application of the commission's recommendations."[7]

At the Geneva meeting the commission addressed, for the first time, the radiation-protection problem for entire populations. It decided to issue recommendations for limiting the radiation dose to all individuals who might be exposed to radiation, whether occupationally or otherwise. The following year, the ICRP appointed an editorial committee led by the American biophysicist Gioacchino Failla to prepare recommendations. The editorial committee defined the permissible dose as follows:

> "The permissible dose for an individual is that dose, accumulated over a long period or arising from a single exposure, which, in the light of our present knowledge, involves a negligible probability of serious somatic or genetic injury; [...] The permissible dose to the gonads for the population as a whole is limited primarily by genetic considerations."[8]

The radiation dose was reduced from the previously permitted 0.3 rem per week to an average of 0.1 rem per week for persons working with radiation and to 0.01 rem per week for the general population.[9] At such low dose limits one approached the variations in natural background radiation.



Sievert presiding over one of UNSCEAR's meetings in the United States.

What was new in the ICRP's stance was that the commission decided to develop recommendations for the "genetic dose", based on a percentage increase in the natural mutation frequency due to radiation.[10] At the same time as the introduction of a new source of radiation was disadvantageous for the population from the genetic standpoint, it was in many cases advantageous in other respects. But deciding what should be allowed and what should not was not a scientific question: it was a political one. How Sievert reasoned on these matters is unclear. Sievert can be characterized as an optimist regarding development and perhaps one may therefore assume that he did not wish to draft recommendations that were too strict. In a letter to Failla he wrote, concerning precisely this problem:

"We may subsequently find that the accommodation of the organism to increased radiation makes radiation hazards less than we at present consider them to be."[11]

The ICRP itself did not take a position but proposed that the genetic dose should not exceed 5 rad per generation in addition to the expected doses from natural and medical radiation.[12]
In November 1956 UNSCEAR invited both the ICRP and the ICRU to jointly prepare a report for the United Nations.[13] In this report, the organizations were to attempt to determine how reliable data could be obtained on doses in different parts of the body - above all gonad doses - as well as data on the average dose to entire populations resulting from X-ray examinations.[14]
In Sweden, Sievert formed an informal group "consisting of four radiologists and three physicists in connection with the United Nations radiation committee's invitation."[15] Sievert himself regarded this work as highly important. It had meant that "the institution has been supplied with an extremely extensive and valuable body of data which [...] will probably be of significant use for the institution's radiation protection work and for research connected therewith."[16] The Swedish investigations were so extensive that the radiation-protection inspector Lars-Eric Larsson at the institute could present a doctoral dissertation based on his gonad dose measurements on Swedish patients.[17]
An overarching international and editorial study group consisting of eleven members (among them Sievert) was formed by the ICRP and the ICRU to prepare the actual report. The conclusion was that it was impossible to record the individual radiation dose for an entire

population. Instead, one should attempt, by statistical methods, to obtain as accurate a picture as possible of the total irradiation.[18]

In April 1959 UNSCEAR again invited the ICRP and the ICRU to carry out an in-depth study of the radiation doses resulting from the medical use of ionizing radiation. This time the study was aimed mainly at analysing the physical and biological radiation parameters that might be related to somatic effects of radiation:

> [...] the clear wish of the UNSCEAR was to stimulate, in analogy with the study performed two years ago on the genetical radiation burden connected with medical exposure, a further study on the somatic radiation exposures from medical procedures.[19]

This time a group of seventeen members was appointed, with Sievert, Bo Lindell and Larsson as Swedish representatives. Larsson served as secretary of the study group.[20] At the end of 1960 the group submitted its report, *Exposure of Man to Ionizing Radiation Arising from Medical Procedures with Special Reference to Radiation Induced Diseases*, to UNSCEAR. A substantial part of the material, Sievert wrote, had been contributed by researchers at the Radiation Physics Institute.[21]

A year after Sievert became chairman of the ICRP, Bo Lindell was elected secretary, in 1957. The strong Swedish participation made it practical to locate the ICRP secretariat at the Radiation Physics Institute in Stockholm where it remained until 1962, the year Sievert stepped down as chairman.

Sievert's greatest contribution to the ICRP did not lie in the scientific sphere but in the financial. In 1959 he turned to the Ford Foundation with which he had previously been in contact in another matter. As Sievert himself expressed it, he "succeeded in obtaining a lump-sum grant of 250,000 dollars to be used for the ICRP's activities over a period of five years."[22] In addition, there were occasional grants from the WHO, the international radiology congresses and the Rockefeller Foundation.[23] The following year, Sievert turned to the Royal Swedish Academy of Sciences with a request that the Academy administer the funds received on behalf of the ICRP which the Academy accepted.[24] The simple reason for this arrangement was that the ICRP had no status as an official organization. Otherwise, Sievert would have been forced to receive the money into his private account which would have caused taxation complications.[25]

During the years 1958–60, Sievert was chairman of UNSCEAR. During these two years, then, he held the two highest positions in the international radiation protection field. Research in this period was hectic and constant new findings made the reports quickly outdated. In parallel with the work that the ICRP and the ICRU carried out for UNSCEAR, both ICRP and UNSCEAR issued their own recommendations. Sometimes reports could be completed during a meeting - only to have become obsolete by the time they were printed. Lauriston Taylor wrote in a book on radiation protection in 1971:

> "These changes and addenda, made between the time the basic report was finished and the time it was actually published, had, as noted, appeared in various ways with the result that the actual chronology is difficult to establish. Also during this period, the presentations were so confusing that in the United States there seemed to be a tendency to ignore the whole period. Fortunately, this situation was rectified about 1960 and has not reoccurred since."[26]



Sir Ernest Rock Carling presided over the first meeting in Stockholm in 1952, where a new international organization for radiation protection was discussed. Rock Carling served as chairman of the ICRP from 1950 to 1956 - the period preceding Sievert.

The confusion between the various reports led Sievert and Lindell to make "drastic interventions" during the years 1960–62. The measures resulted in the committees and their work being reorganized in 1962.

The work within UNSCEAR's secretariat was located in the UN building in New York and was led by the Canadian Ray Appelyard, who reported to Ralph Bunche, Assistant Secretary-General to Dag Hammarskjöld. The working sessions lasted from one to four weeks, two to three times a year.[27] The work also affected the activities at the Radiation Physics Institute in Stockholm. This international orientation meant that the institute's researchers increasingly participated in international work. In his annual report for 1962, Sievert wrote:

"Among other things, the head of the Division of Clinical Radiation physics and of the institute's standard laboratory, Dr. R. Thoreus, has taken part in work within the ICRU. He is furthermore the institute's representative on the advisory committee for standard measurement of ionizing radiation at the Bureau International des Poids et Mesures in Paris. The head of the nuclear-physics division, Docent A. Hedgran, has participated in meetings concerning various radiation-protection issues within ENEA [European Nuclear Energy Agency, the nuclear-energy body of the OECD] and Dr. R. Thoreus in a conference on standardization of gamma-radiation measurements arranged by the International Atomic Energy Agency in Vienna."[28]

It is obvious that Sievert was the driving force behind the increased Swedish involvement in international questions. With the authority he possessed, it was not difficult for his "disciples" to travel into the wider world. Lars-Eric Larsson described, in a lecture on Sievert, Sievert's wish to open doors for his collaborators:

"He made sure that we were brought into various international committees, allowed to take part in congresses and symposia, etc. When he himself was abroad, he wanted to have us around him—not as lackeys, but in order to give us the opportunity to meet the leading figures in medical physics and radiation protection. When we travelled alone, he provided us with letters of introduction. These were like an "open sesame." One simply had to understand that the reception we received did not depend on ourselves but on the fact that we were "Sievert's boys.""[29]



Walter Binks served as secretary at the second meeting. Binks would later become the first recipient of the Academy of Sciences' radiation protection medal, which Sievert initiated in 1962.

When Sievert and Lindell left their posts in 1962, the ICRP's financial situation was secure. The Englishman E. Eric Pochin was elected as the new chairman and for the first time in the ICRP's history a full-time secretary could be employed, the Canadian David Sowby.[30] The secretariat was moved to England but Sievert remained a member of the ICRP's main commission, to which Lindell was also elected in 1962.[31]

A Common Organization

For several years, Sievert worked to create a new international radiation-protection organization that would be independent of other bodies. He envisaged that the ICRP and the ICRU would be freed from the international radiology congresses, that UNSCEAR would be detached from the UN and that all of these would be incorporated into the new organization.
The first impulse to create a completely independent international radiation protection organization came to Sievert during the international congress on radiobiology that he organized in Stockholm in 1952. The ICRP held two informal meetings during the congress, where the relationship between the ICRP and the International Congress of Radiology and possible future organizational forms was discussed. The first meeting was held at the Radiation Physics Institute on 15 September.[32] Sievert proposed that the ICRP be separated from the International Congress of Radiology, albeit only organizationally, since the ICRP's meetings would still take place in connection with the congresses every three years. The participants also agreed that it was not desirable for the commission to come under "Government Control." They wished to preserve "as much freedom as possible."[33] The participants also realized that an expanded field of work for the ICRP was necessary if it was not to find itself left outside new, important fields of application for radiation:

"It was most important to extend the scope of the work of the Commission to cover industrial hazards since otherwise a second International Committee might come into being to deal with radiation protection problems in the industrial field."[34]

In view of Sievert's position later, it seems that he already at this meeting had proposed an international society or an international academy for radiation protection, even though it cannot be established from the minutes that the proposal came from him. Several different possible structures for the ICRP were discussed, but it was decided not to pursue separation:

"It was, however, finally agreed that there was little to be gained at present by separating the Commission from the International Congress of Radiology but that certain changes in the constitution of the Commission were desirable."[35]

At a second meeting, three days later in Uppsala, Sievert presented a short memorandum containing a proposal for an "International Association for Radiological Protection."[36] The tasks of the organization were to prepare recommendations, establish international dosimetric quantities and units and indicate measurement methods for radiation. Furthermore, the organization was to arrange conferences, stimulate international cooperation and promote contacts between researchers working on practical radiation-protection problems. In addition, the organization was to function as an information bureau where all countries' laws and recommendations would be available.[37] Sievert also sketched the structure of the proposed organization. The proposal was discussed at length. The attitude of those involved seems to have been cautious. The participants were doubtful about creating a new organization, but thought that ICRP and ICRU should themselves take over the new fields in which radiation was being used. As for the proposed new organization, the participants expressed:

"... concern about separating I.C.R.P and I.C.R.U from the International Congress of Radiology and about the financial support which it could obtain. Professor Mayneord thought that Sievert's conception of an International Academy of Radiological Protection was attractive but he wondered where funds were to come from for its effective operation. Professor Sievert said that he envisaged support from private donors."[38]

The meeting agreed that the ICRP would remain associated with the International Congress of Radiology. Sievert's proposal had thus, with diplomatic tact and finesse, been voted down. He did not, however, abandon the idea of an overarching organization but returned to it already the following year. Before the forthcoming International Congress of Radiology in Copenhagen, 19 - 25 July 1953, Sievert approached Swedish organizations and major insurance companies to secure funding. He drafted a proposal (dated 30 June 1953) for an organization, which he sent to potential donors.[39] In other words, he was late, as is evident from his letters. In his proposal he argued from two deficiencies of the current situation.
(1) the strong link to the international radiology congresses had, with the increased industrial use of radiation, become ever less self-evident. He wrote:

"The need for radiation protection is nowadays not limited to medical radiology but constitutes an increasingly important factor in general public health care."[40]

By "general public health care" (*allmänna sociala hälsovården*), Sievert seems to have meant what we today would call preventive health care or public health. From this broadened definition of the applications of radiation protection followed his next main argument.
(2) Sievert maintained that radiation-protection questions required "intimate and effective cooperation" between researchers in different fields such as radiation physics, radiation biology, radiation genetics and radiation medicine.[41] Such breadth of expertise was not available within the ICRP and the ICRU:

"The expertise within them does not span all the research areas necessary for solving radiation protection problems. They operate only during or immediately before radiology congresses and they lack the firm organization that is indispensable for effective and successful work."[42]

As a prime example of the value of a comprehensive international organization, Sievert pointed to genetic investigations, since these require very large statistical material, which would be easier to obtain through an overarching international body. After specifying the tasks of the new organization - essentially the same as those outlined in 1952 - Sievert wrote:

"If one proceeds from what has here been said about the need for an international radiation-protection organization, its tasks and the demands that must be placed upon it, one's thoughts are naturally led to an international academy."[43]

Sievert described the academy as "a new and valuable instrument."[44] The academy was to be financed through a number of foundations based in different member countries. Concretely, he envisaged that the academy would have several secretariats, located in those countries that contributed funds and that "one of the secretariats would serve as the general secretariat."[45] In a memorandum attached to the proposal, Sievert made no secret of where this general secretariat should lie. The two chairmen of ICRP and ICRU had unofficially let Sievert know that they would welcome "the new organization's main secretariat being located in Stockholm," because Sweden's neutrality and its suitability for scientific cooperation, as manifested through the Nobel Prizes, constituted a guarantee of good stewardship.[46] Sievert calculated that a total sum of two million Swedish crowns would suffice to realize an academy. Of this total he believed that Sweden could contribute one quarter.[47]

As the congress in Copenhagen approached during the early summer of 1953, Sievert tried to persuade Swedish donors to contribute money. For the proposal to have any chance of survival, funds needed to be already available when the proposal was presented at the radiology congress.[48] During the few weeks remaining before the congress, Sievert pulled every string he could find. In a letter to the chairman of the Swedish Trade Union Confederation (*Landsorganisationen*), Axel Strand, he wrote:

"Without doubt our country is in such a position that in this case [radiation protection] we have so much to learn from abroad that the advantages are on our side. The importance of the opportunity that an international organization would give us to gain access at an early stage to foreign experience can hardly be overestimated."[49]

To persuade more profit-oriented donors in the corporate world, Sievert also stressed that "exaggerated fears of radiation injuries hinder technical progress, just as an underestimation of radiation risks can have extremely serious consequences."[50] Sievert approached, among others, the industrialist Axel Ax:son Johnson for funds - but without success. In a letter to Consul Harald Jeansson, Sievert wrote that he had anchored his proposal among important persons in Sweden:

"In addition to my colleagues in England, America and Germany, I have discussed the matter with the chairman of the Swedish Natural Science Research Council, Professor Bertil Lindblad, Professor Manne Siegbahn and University Chancellor Arthur Thomson, all three of whom were very positively disposed and recognized the great importance of bringing the proposed organization into being. Next week I shall discuss the proposal with the Foreign Minister, who has already shown interest in it."[51]



The Swedish Radiation Protection Institute's (SSI) new premises were located immediately adjacent to the Department of Radiation Physics. Later, the SSI and the Department were connected by a walkway.

Sievert painted the picture of a Swedish financier at the forefront in creating an international organization, who would be "the object of the greatest gratitude from scientists and authorities all over the world."[52]

The insurance companies also became targets of Sievert's petitions. Nine large Swedish insurance companies received his letter requesting funds.[53] He reckoned that together they might contribute 200,000 Swedish crowns.[54] The directors of the various companies all contacted their umbrella organization, the Association of Life-Insurance Companies, whose managing director Waldemar Odhnoff - through a letter from director Iwar Sjögren at Skandia - let it be understood that no money could be expected "with regard to the company's international character."[55]

Sievert received refusals across the board. The Trade Union Confederation declined curtly, as did companies and insurance firms. It thus appears that Sievert arrived empty-handed in Copenhagen. From the material available, it is not possible to determine whether he nevertheless presented his proposal at the international radiology congress. He did, however, succeed in anchoring his idea among his colleagues in the ICRP. In a letter from W. V. Mayneord in England to Sievert in 1954, we read:

"... Sir Ernest and I are still struggling with the problem of finance for your proposed international protection organisation. So far, I cannot say that we have made very much progress but we have not yet given up hope. When I was in Stuttgart recently Holthusen gave me a rather depressing view of the possibilities in Germany, but perhaps you have heard from him directly."[56]

The fact remains that no organizational change occurred and in 1957, when he served as chairman of the ICRP, Sievert wrote:

"The ICRP is still associated with the International Congresses of Radiology, to which its recommendations are submitted for formal approval."[57]

Sievert appears here once again as the driving organizer and centralist. He expressed most clearly and most radically the thoughts that seem to have existed among members of the ICRP and ICRU. Had Sievert succeeded in financing the Swedish share of the organization, it is entirely possible that other countries would have followed suit. In retrospect, it is easy to note that Sweden might have become the country of origin for an international, overarching and regulatory radiation-protection organization. The first major challenge for this organization

would have been the approaching nuclear test explosions. Sweden could thereby have played a prominent role in an area that today appears as a significant future issue for humanity.
Despite these setbacks, Sievert did not abandon his hopes for an international radiation-protection organization. When, after 1958, he simultaneously served as chairman of the ICRP and UNSCEAR, he worked energetically toward this goal. His formal position gave him a unique opportunity to act with great weight. In September 1957 UNSCEAR, together with the ICRP and the ICRU, presented its first report to the UN General Assembly.[58] In a draft of a speech to the UN in conjunction with the presentation of the report, Sievert wrote - after listing all the different international organizations that were in one way or another involved in the effects of radiation - that:

"The appropriate machinery for effective current co-operation in the relevant fields has however not yet been established. It seems to the Swedish delegation that one of the most necessary ways to accomplish this would be to try to concentrate the pertinent activities to one suitable place."[59]

Whether Sievert actually used this passage is unclear. It is clear, however, that he had certainly not laid his plans for a unified organization on the shelf. At the beginning of 1958 it seems that the discussions had shifted toward a merger of the ICRP and the ICRU into a joint organization. In March, Sievert, Failla, Lindell, Taylor and Wyckoff gathered in New York to discuss a draft of statutes for the new organization.[60] At the end of the same year Sievert sent a memorandum on a cooperative organ to all delegates in UNSCEAR, ICRP and ICRU. He wrote in the accompanying letter: "I believe that a decision on the organization of a world-wide cooperation on radiation safety is urgently needed."[61] There was thus a conflict over the level at which such cooperation should lie. In his memorandum Sievert listed no fewer than ten different organizations, each with one member which would be included in the proposed cooperative body.[62] Here, too, the result appears to have been negative.
Sometime before 1959 he had been in contact with the Ford Foundation to interest it in an international radiation-protection organization. In this context, he also tried to secure an expression of support from UN Secretary-General Dag Hammarskjöld. He did not, however, receive any money from that source either.

KRA and Preparedness

In June 1960 the government appointed an Expert Committee for Advice in Nuclear Accidents (KRA). The immediate cause was a state investigation into preparedness against nuclear accidents, which had submitted its report to the Ministry of the Interior in November the previous year. The indirect cause was the Windscale accident in England in 1957 which had received extensive publicity in the mass media worldwide.
After the Windscale accident, the British Medical Research Council drew up a programme with various intervention levels for reactor accidents. Already in 1955, however, the Americans J. W. Healy and H. M. Parker had attracted attention when, in a lecture at the UN's Geneva conference on the peaceful uses of atomic energy, they discussed environmental effects of a major reactor accident.[63] In the United States, the Atomic Energy Commission published two years later the Brookhaven Report which also examined a hypothetical major accident.[64] These discussions were reason enough for the Minister of the Interior to appoint an investigator -

Yngve Samuelsson, Director-General of the Insurance Council - who in turn surrounded himself with experts from FOA, AB Atomenergi and the Radiation Physics Institute, as well as a legal expert. From the Radiation Physics Institute, Arne Hedgran participated.[65]

When the investigation was launched, Sievert suspected that it might restrict his freedom to act in the event of an accident. He had measuring instruments installed around the Ågesta reactor and, through the Telegraph Administration, he arranged that high radiation levels could be monitored directly from the Radiation Physics Institute. Sievert was very keen to be able to get out to the scene of an accident immediately after an alarm, so that from there he could give advice and instructions to the responsible authority - in this case, the county administration (*länsstyrelsen*).[66]

The anxiety and publicity following the Windscale accident gave Sievert good opportunities to strengthen the financial position of radiation physics. Sievert saw two possible paths of development before him:

(1) The institute could, through state appropriations, be supplied with substantial resources and thereby recruit a number of experts from other fields - such as biologists, physicists and ecologists - who might be of importance in a nuclear-accident scenario.

(2) The various experts could, through informal contacts, be linked to the institute but remain in their respective research environments.[67]

Sievert advocated the latter model. The reason was that he feared experts who were torn away from their specialized research environments would lose the crucial influence of their primary field and soon become second-rate radiation-protection specialists.[68]

The first idea Sievert had in connection with the discussions on a nuclear accident was to create a group of experts - researchers from various institutions and institutes - who together would constitute a complete set of the knowledge needed in a catastrophe situation. Sievert maintained this view and succeeded in implementing it. He had a rather romantic image of a kind of "accident commission" (*haverikommission*), which, with expert sobriety, could come to the aid of the county administrations and assist the affected population with knowledgeable advice.[69]

This solution to the county administrations' knowledge dilemma in a reactor accident he certainly had presented to the investigation both in person and through Arne Hedgran. When the investigation delivered its report in 1959, it indeed contained a passage on precisely this point:

> "The county administration would certainly need advice and instructions from central civil and military authorities with expertise in various areas such as radiation protection, agriculture, fisheries and food control. Such authorities can also support the county administration by sending experts and technical equipment to the site. One way which may prove valuable is to form, from leading specialists at various authorities and bodies, a nationwide expert commission that could be called in the event of an accident at a nuclear-energy facility."[70]

At roughly the same time as the law on preparedness for nuclear-energy accidents was enacted, the Minister of the Interior issued a letter to the Radiation Physics Institute instructing Sievert to assemble an expert commission for advice in nuclear accidents. The commission included Sievert and Arne Forssberg from the Radiation Physics Institute, Torsten Magnusson from FOA, Professor Ernst Abramson from the Institute of Public Health and Gunnar Nybrant from SMHI. All members of the commission also had deputies: Arne Hedgran from the Radiation

Physics Institute, senior physician Bertil Swedin at Karolinska Hospital, Göran Dahlen and Kay Edvarson (both deputies for Torsten Magnusson), laboratory director Bertil Åberg at the Veterinary College and Olov Lönnqvist from SMHI.[71] The first secretary of the commission was Carl Lidbom, later replaced by Rune Berggren, who would eventually become Director-General of the National Audit Office.

Alongside KRA, Sievert maintained contact with and supported researchers from various fields who could contribute to knowledge about radioecology, among them Lennart Hannertz, water expert at the Fisheries Board as well as Lars Fredriksson and Bertil Åberg. Hannertz undertook a study trip to the United States with funds from Sievert in order to study the relationship between radioactivity and water pathways. The Radiation Physics Institute was not, however, the self-evident centre for studies of a radioactively contaminated environment. Parallel to it, for example, FOA sought to tie up researchers in the same fields as Sievert.

After KRA had been established, the Soviet Union announced its nuclear-weapons tests at Novaya Zemlya, northeast of the Kola Peninsula. The tests, particularly when conducted in the troposphere, were geographically close to Sweden and thus gave rise to serious concern. Under normal circumstances the winds would carry the fallout eastward, but there was fear that a failed test at too low an altitude with south-westerly winds might spread radioactive dust over the country. Since Sievert, through KRA, had access to a number of experts, he called them together in order to be able to give advice in a possible fallout situation.[72] Because the Radiation Physics Institute belonged under the Ministry of the Interior, Sievert conducted a dialogue with the Interior Minister Rune Johansson.

In spring 1961, Sievert drafted a special preparedness plan with proposed measures in the event of radioactive fallout over Sweden. The proposal entailed an expansion of the existing measurement activities of SMHI and the Radiation Physics Institute. The emergency organization had a central leadership placed in Stockholm, even though the most likely contamination would occur in Norrland, if anywhere. The ultimate responsibility for the organization lay with the Minister of the Interior.[73]

The organization would be activated when wind conditions were such that a failed test at Novaya Zemlya could cause fallout. KRA and in practice - Sievert, would be responsible for the state of readiness and for calling the organization into action. Directly subordinate to the central leadership would be an operations section with a special radiation-control centre for developing measures and compiling reports on radioactive deposition in the country. In addition, there would be a meteorological section, a foreign-affairs section and a communication section, each responsible for different parts of the preparedness system. At county level a smaller but structurally similar organization was to exist.[74]

In a hypothetical scenario, Sievert described the course of events when an unfavourable wind situation and a failed test coincided:

"If a bomb test takes place while a precarious weather situation prevails, the Radiation Physics Institute [RI] receives information from the Seismological Institute about an hour after the test. RI then immediately calls in the staff of the central leadership. The alarm is given by telephone according to prepared alarm and telephone lists. All three staff shifts in the central leadership are alerted. The organization is filled with those staff members who arrive first. The others are sent home. Communication links are established with the county administrations.

About three hours after the test, a meteorological deposition forecast is expected to be available. On this basis, an assessment is made of which regions of the country can be expected to be affected by radioactive fallout. The county leaderships in these areas are instructed to call in their county emergency organizations. The decision is taken within the central leadership, which is to be functioning at this time. The county leaderships seek contact with Swedish Radio's regional representatives. Aircraft for measurements and the measuring stations within probable fallout areas are alerted by the central leadership. Contact is sought with radiation-control bodies in neighbouring countries. In general, there must be a need for established communication links with neighbouring countries' radiation-control bodies also in cases other than those in which there is a risk of an acute situation.
During the remaining time - six hours to two days - before the radioactive fallout is expected to begin, the public should be informed about the situation and given instructions regarding the basic measures which in all circumstances should be taken. These communications must take place in such a way that panic is avoided. They should be communicated to the entire population from the central leadership. [...]
If it is decided that action shall be taken, the public should be informed centrally via, for example, the Swedish Radio. If the authorities are to intervene, orders are given to the affected county leaderships and the public is informed, preferably centrally. In some cases it may be suitable for messages from the county leaderships to the county's population to be transmitted via Swedish Radio's regional transmitters.
During the continuing fallout, continuous measurements are carried out mainly under central direction. Reinforcement personnel may possibly be sent from the central leadership to the county leaderships.
The radiation-control centre in the central leadership continuously compiles measurement reports. The compilations are presented to the central leadership. Consideration is given to whether there are grounds for changing earlier decisions. [...]
The central leadership can probably be dissolved about a week after the bomb test. The county leaderships will be dissolved successively; the assessment is made regionally."[75]

There can hardly be any doubt as to where Sievert pictured himself in this situation. In November 1961 the preparedness was placed in abeyance but the actual organization was retained. On none of the occasions in 1961 and 1962 when preparedness might have been relevant did the need arise to call the organization into action.

Concern about fallout naturally existed in the other Nordic countries as well. In 1958 the Danish radiation protection authority found that activity in drinking water on Saltholm exceeded the limit values for mixed fission products recommended by the ICRP. The Danish authorities banned the use of the water which echoed in the Swedish and Norwegian press. The water issue prompted cooperation between experts in Denmark, Norway and Sweden. During spring 1959 the Nordic experts gathered in Stockholm and Copenhagen to discuss the situation. In the summer of the same year they prepared a report entitled *Det radioaktiva nedfallet över Skandinavien* ("The radioactive fallout over Scandinavia").[76] The report concluded that no contamination exceeded the international limit values recommended by the ICRP and that there was therefore no need for practical protective measures by the health authorities.

The driving force behind the Nordic expert group was Sievert. As early as 1955 he had envisaged a cooperative arrangement between the Nordic radiation protection authorities for exchanging information, arranging conferences and conducting joint measurements - but nothing came of it. The cooperation initiated between the Nordic health authorities in 1959, however, led to a recommendation by the Nordic Council the same year to continue the collaboration. Finland and Iceland, which had not participated in 1959, showed great interest. In total, some ten Nordic expert meetings were held in the 1960s in Helsinki, Copenhagen, Oslo, Reykjavik and Stockholm. As long as he lived, Sievert remained the driving force.[77]

In the early 1960s, the Health Physics Society was formed in the United States. This radiation-protection organization advocated that other countries also join a corresponding international activity. Sievert was contacted by the society and was attracted by the idea. Since there was no Swedish association that could join, Sievert took the initiative to form a Nordic society, the Nordic Society for Radiation Protection (*Nordiska sällskapet för strålskydd*, NSFS). The society became an affiliated organization of the International Radiation Protection Association (IRPA) when IRPA was formed in Paris in 1964.[78]
Preparedness, which took much of Sievert's time in the 1960s, continued to interest him even after the test ban treaty of 1963 removed the danger of fallout. After his retirement in 1965, Sievert devoted much of his time to attempting to write a general handbook on preparedness for the government.[79]

The National Swedish Institute of Radiation Protection (SSI)

In the official state investigation presented in 1956 - which resulted in a radiation protection organization in which the Radiation Physics Institute retained supervisory activities under the Radiation Protection Board (*Strålskyddsnämnden*) the establishment of a special authority, the National Swedish Institute of Radiation Protection (*Statens strålskyddsinstitut*, SSI), had been mentioned as a potential alternative for radiation supervision. At that time, however, the proposal stopped at recommending an expanded institute. The organization decided by Parliament later did not meet expectations and in 1965 Sievert implemented the last reorganization before his retirement. The National Swedish Institute of Radiation Protection became the central administrative authority in radiation protection matters and the Radiation Physics Institute became an ordinary university department. The radiobiological research that Sievert had built up within his institute was separated and formed an independent Radiobiological Institute.
The "empire" that Sievert had created was thereby divided into three parts when he stepped down in the summer of 1965. Hospital physics at Karolinska Hospital and Radiumhemmet was initially administered by the National Swedish Institute of Radiation Protection. From an experimental corner of 5 m², he had created a state authority and two institutes, all with favourable conditions for close and fruitful cooperation. He had the satisfaction of seeing his own hopes regarding successors fulfilled. Bo Lindell was appointed professor and head - and later Director-General - of the Radiation Protection Institute. Rune Walstam became professor and head of the Radiation Physics Institute and Arne Forssberg likewise professor and head of the Radiobiological Institute.[80]

Work at the Royal Swedish Academy of Sciences

During the last year of his life, Sievert was heavily engaged in an investigation concerning the activities and working methods of the Royal Swedish Academy of Sciences (KVA). Sievert's involvement and work within the Academy, however, reached much further back, through his chairmanship of the interim board for Upper Norrland, which has already been described in connection with the Kiruna Geophysical Observatory. The board's meetings were very often



A caricature of Sievert shortly before he retired.

held at the Radiation Physics Institute and primarily in the evenings. Engagement in research in the far north was not the only link connecting Sievert to the Academy.

In spring 1962 the Academy decided, on Sievert's initiative, to establish a radiation protection fund. The fund was to award, every third year, a gold medal to a person who had made a particularly valuable contribution to international radiation-protection work.[81] In connection with the establishment of the fund, Sievert proposed that the first medal be awarded jointly to Walter Binks (England) and Karl Z. Morgan (USA). Sievert assumed that each of them would receive his own copy of the medal in gold.[82] The Academy approved the proposal but only a few years later, in 1967, it was necessary to change the periodicity of the award because the endowed capital was insufficient to cover the cost of the relatively large gold medal.[83] In 1967 it was recorded in the minutes:

"When the accumulated interest on the fund reaches an amount sufficient to cover the cost of awarding the medal, measures shall be taken, in accordance with the fund's statutes, to select a medallist to receive the award at the next International Radiology Congress."[84]

State radiation protection activities in Sweden had since 1958 been regulated through the Radiation Protection Board and the Radiation Physics Institute. Research at the institute had also been regulated through government decisions. Sievert nevertheless felt the need further to strengthen radiation protection research:

"There is now, however, a strong need for a scientific body that can give cooperation within radiation-protection research the desired continuity and ensure a broad discussion of its problems."[85]

The Academy accepted Sievert's proposal and established the Swedish National Committee for Radiation Protection Research. The committee's tasks were above all to promote radiation protection research but also to maintain contacts with the other Nordic countries, to foster

international exchange of information and, via the Academy, to make proposals to the government that could further the committee's aims.

Sievert's last contribution within the Academy was perhaps also the most controversial. After his retirement he had more time to reflect on the Academy's future function. In spring 1966, on Sievert's initiative, the Academy's administrative council appointed an investigative committee to examine KVA's organization and tasks. When Sievert died in December that year, he had not yet completed the work. He remained fully occupied with the investigation until his death.[86] At the end of 1968 the committee submitted its report, which dealt primarily with the Academy's institutions - including the Kiruna Geophysical Observatory - and their future financial situation. It was clearly stated that the Academy could not maintain its activities on the basis of income from the almanac privilege alone.[87] The report quickly came to be overshadowed by a much broader revision of the Academy's organization and finances when the government signalled that the almanac privilege could no longer be taken for granted.

9. The Person Rolf Sievert

Rolf Sievert became the father of seven children in two marriages. In his first marriage to Ingrid Sandberg, in 1918, four children were born: Bo (1919), Max (1920), Bengt (1922) and Kerstin (1926). The marriage lasted 13 years before the couple divorced in 1931. Sievert's marriage to Astrid Östergren in 1932 continued until his death in 1966. In this second marriage three children were born: Rolf (1933), Johan (1935) and Christina (1938). During the Finnish Winter War the family took in a Finnish war child, Veijo Kankare, who later remained as a foster child in the family.[1]

Sievert lived with his first wife and children on Riddargatan in Stockholm, where he was co-owner of a property. After the divorce, Ingrid Sandberg remained there with the four children. Following his marriage to Astrid Östergren in 1932, Sievert moved to Klippgatan on Södermalm in Stockholm. At that time Radiumhemmet had its premises on Fjällgatan in the same district.

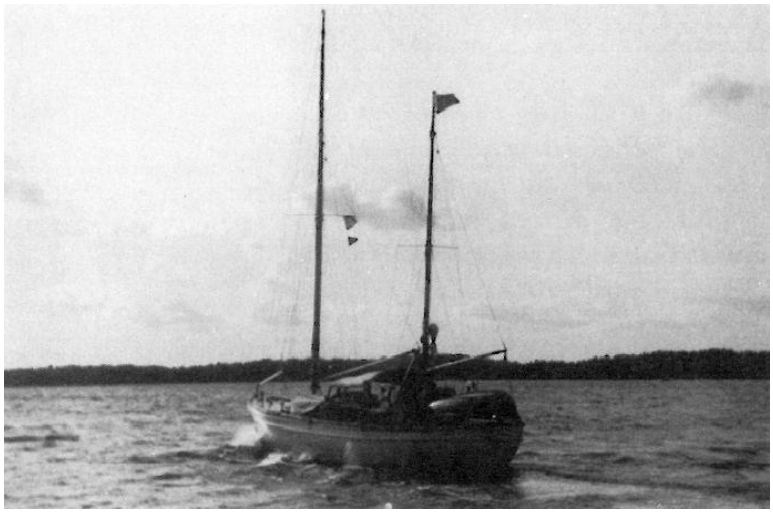
After the Radiation Physics Institute was built in Solna in 1938, Sievert moved into the official residence on the upper floor where he and his family remained until his retirement in 1965. When his first wife, Ingrid Sandberg, died of cancer, the older children moved into the official residence. Sievert's housekeeper, Märta Larsson, also moved from Riddargatan out to Solna.

The younger children attended the *Sigtuna Humanistiska läroverk* and lived at the manor Tvartorp in Östergötland during the school holidays. Astrid Sievert therefore spent a large part of her time at Tvartorp in order to look after the children, the farm and its more than 1,000 hectares of land. She commuted between Stockholm and Tvartorp so that she could take part in official entertaining and assist Sievert in various matters, such as the interior design of the Military Physics Institute's premises at Grindsjön.

The large family meant that Sievert devoted a great deal of time to family life. He was widely known to be very fond of children and could spend a lot of time with them. There was scarcely any time left over for a private social life and purely private invitations were very rare.

Sievert lived relatively isolated from the world outside his work. During the last 25 years of his life he both lived and worked at the Radiation Physics Institute. He very seldom expressed any political interest and any comments he made on political decisions concerned only those that might affect the institute's operations. When Sievert wanted to relax, he took the car down to Tvartorp to meet the whole family. At Tvartorp he devoted himself to his interest in music and, in a separate chapel next to the manor, he had an organ built in 1943, in whose construction he himself took part. He was a personal friend of Alf Linder, the organist of Oscarskyrkan. Every year he invited the staff and tenant farmers to a concert, at which he usually played, among other things, Bach and Buxtehude. One might expect that a person with such a lively interest in music would be visible in Stockholm's musical life but Sievert attended concerts seldom, if at all.

One interest to which Sievert devoted much time was butterflies. His interest in butterflies was awakened already in childhood and he tended his butterfly cabinets with care. Collecting butterflies was also something Sievert took the opportunity to do when he was travelling. Hannes Alfvén sometimes teasingly called him the *Macrolepidopterologist*, which can mean either "collector of large butterflies" or "the large-bodied butterfly collector." Alfvén recalls



One of Sievert's great pleasures was sailing. The picture shows his own sailboat, which he had transported by truck between Tvartorp and the Stockholm archipelago.

how, during work on the Kiruna Geophysical Observatory, Sievert would go out into the mountain landscape with a net and, by hopping from tussock to tussock, hunt butterflies.

A characteristic trait in Sievert was his ambition also to master and possess sound knowledge of his leisure interests. He acquired books on the subject in question and immersed himself in them before setting to work. In the later part of his life, for example, Sievert became interested in flowers, particularly cacti, which he cultivated in greenhouses prepared specifically for the purpose. All the cacti were catalogued and their flowering times recorded. Sievert's interest in flowers and butterflies was in itself rather remarkable, given that he suffered from reduced colour vision. This meant that he often preferred greyscale and black in interior design and in the appearance of his instrument cases.

At Tvartorp, Sievert installed his own power plant, which supplied the manor with 220 volts. According to those who experienced it, the plant functioned entirely reliably, even if it did not always maintain a frequency of 50 Hz. In addition to the manor, Sievert owned a sawmill and a planing mill. For a time, he also had manufactured the so-called Tvartorp cottage, a sports cottage with possibilities for extension. Sales of the cottage, however, were no success and production was discontinued.

The largest private business deal Sievert undertook was of another kind. After Reijmyre glassworks encountered financial difficulties, Sievert - probably after appeals from the municipality - entered as co-owner of the company together with his childhood friend Harald Almqvist. In doing so, Sievert saved the glassworks from bankruptcy and the municipality from suffering unemployment.

In 1963 Sievert turned 67 and was thus due to retire but through applications for dispensation he postponed his own retirement by two years, until 1965, when he retired in the summer. After retirement, Sievert kept an office at the institute and the household moved to a newly built flat on Kristinelundsvägen in Solna, just outside Stockholm. Sievert's secretary, Torborg Hammarberg, remained as his secretary.

On 1 December 1966, Sievert underwent gastric surgery at Karolinska Hospital. At first the operation appeared successful, but two days later he suffered a blood clot and died unexpectedly. His wish was to be buried at his manor Tvartorp in Östergötland. The small chapel by the lake was to serve as the burial place. Since this was not permitted under Swedish

law, Sievert was first buried at Norra Begravningsplatsen in Solna. Through the efforts of the Minister of Ecclesiastical Affairs, Ragnar Edenman, Sievert's family was later able to move his ashes to Tvartorp.

Sievert's life was filled with creative energy and originality. He was interested in much and everything he came into contact with he wished, if possible, to reshape according to his own ability. Forssell undoubtedly sensed what a dynamic person he had taken as collaborator from the very beginning, but he could find confirmation by looking at Radiumhemmet's annual reports for 1923 and 1924. In the first year, Forssell mentioned that the institute had enjoyed the benefit of voluntary and unpaid collaboration with a physicist. The next year, the same physicist had his own report for his laboratory at Radiumhemmet.

Sievert's creativity and almost unbending will to promote the interdisciplinary field that was to a large extent his own creation - radiation physics - were surely experienced quite differently by the many people who came into contact with him. In some situations, he could appear as highly dominant, in others as distinctly dynamic and spontaneous.

The physical frame that nature had given Sievert was impressive. After he had passed the age of twenty, his weight never sank below one hundred kilos. His tall figure and powerful voice gave Sievert an extra authority which he only gradually learned to exploit. The sharp, brown-eyed gaze under his heavy eyebrows and his high forehead gave him a stern appearance that created respect in those he spoke with. In the photographs that exist of Sievert he looks tight-lipped and serious. This is said to be explained by the fact that he disliked being photographed and became nervous and tense.

To describe Sievert the person, one must adopt different perspectives. From one perspective one regards Sievert as director and the undisputed leader of the institute. From another, one sees him as an academic colleague, someone one meets at meetings to discuss organizational problems and new ideas. Employees encountered Sievert the constructor, his academic friends met Sievert the organizer. As employer and head, Sievert was typical of his time.[2] The working climate at the Radiation Physics Institute was marked by the era's demands that outward forms be respected: working hours, breaks, clothing and forms of address. To uphold respect for this order, it could happen that Sievert met the staff at the entrance in the morning with a watch in his hand. The employer Sievert, however, combined his demand for devoted work with personal enthusiasm and his own impressive work effort as an example. Radiation physics was Sievert's great interest and he could convey a sense of professionalism and of the great importance of the work. At the same time, he could probably find it rather hard to understand other people's more reserved attitude towards work. Those who worked in his immediate vicinity thereby had long working days. When the ordinary working day was over, he would take his secretary Torborg Hammarberg to the official residence, eat a quick dinner and then continue working late into the evening.

Many experienced Sievert as old-fashioned and formal in everyday dealings. For example, he never dropped titles with anyone who did not have an academic education. The prescribed distance and his attitude to work made him a dominant person, something that could sometimes create conflicts when he came into contact with new people. The personal chemistry did not always work. Some people who started working at the Radiation Physics Institute found it hard to accept Sievert's dominance and therefore left soon afterwards. At the same time, Sievert was



Perhaps this is how many perceived Sievert? Like the boss who leaned over one's shoulder to ensure everything was proceeding correctly. Seated at the electrometer: Robert Thoræus.

not attracted to those who uncritically swallowed all his opinions. Instead, he demanded response and constructive criticism of his ideas. He wanted to feel respect but also strength of will from his colleagues.

Sievert is also characterized as a generous and protective head. He arranged staff outings and every year Sievert and his family held a much-talked-about Lucia celebration for the entire staff. In time, he introduced a regular Wednesday gathering (where he treated everyone to coffee and buns) to stimulate contact between the various departments of the institute.

In everyday life he could demonstrate his blend of concern and demands. If he required someone to work overtime in the evening - for example to finish a new instrument - he always had a tray prepared with sandwiches and beer which he personally carried down to the person working. He was curious whether the staff were happy and he could help employees out of temporary financial difficulties. The Radiation Physics Institute was thus Sievert's patriarchy where he reigned with fatherly and unrestricted authority. At first the institute was not particularly large but it grew to about seventy employees by 1965, which increasingly limited his possibilities of micromanaging the institute.

A certain degree of cheek and boldness was something that appealed to Sievert. Job interviews were a *"speciality"* that Sievert conducted in his own original way. The applicant was placed on a low sofa in front of his large desk and thus found themselves, from the outset, in a

distinctly subordinate position. The questions were often irreverent and it took some nerve not to give in. Bo Lindell recounts that at his job interview, Sievert probed how far Lindell's willingness to work extended and therefore asked whether the engineering student Lindell was prepared to carry out whatever tasks might be required of him. The answer was no. "Oh really!". "No, he would not go so far as murder." An answer entirely to Sievert's taste.[3]

Sievert also had a penchant for testing other people, advancing opinions in order to provoke contradiction. Radiation protection inspector Lars-Eric Larsson relates that his job interview began with Sievert asking about Larsson's home town which was Gävle. "What does Larsson think of the mayor in Gävle?" "Some people are not so fond of him," came the truthful answer. "Ha ha, I shall tell him that, we are related," chuckled Sievert. Larsson naturally could not believe anything other than that this was the first and last time he saw the inside of the Radiation Physics Institute building. He therefore pointed out that he did not think it was fair play not to have announced the family connection at the outset. To his surprise, Larsson was given the position - perhaps precisely because he had dared to criticize Sievert's interview technique. This penchant for provocation could lead Sievert, in discussions, to defend opinions that he did not in fact hold, simply to gauge his interlocutor's reaction. Such behaviour sometimes distorted the image of him in the eyes of those who did not know him.

After the war, many of Sievert's foreign research colleagues in Europe suffered from food rationing and he therefore sent parcels with various necessities to assist them. The German colleague Robert Jaeger came to Stockholm after the war and spent six months at the institute to conduct research but also to have an opportunity to recuperate. Since Jaeger was an excellent violinist, he and Sievert spent their evenings making music together in the residence where Sievert had a grand piano.

Parallel to the picture of Sievert as self-assured and humorous, there is another which portrays him as a shy and sensitive person. For example, Sievert was endlessly nervous every time he had to appear before large gatherings or at socially obligatory events. He could polish speeches for such occasions to perfection. If anyone directed criticism - even mild - at his performances, he always took it very much to heart.

His desire to do everything as flawlessly as possible meant that he could have a letter rewritten several times before he approved it. Likewise, he frequently used professional translators when he wrote letters abroad or prepared manuscripts for international talks even though his own language skills were far from poor. The letters are usually couched in a formal and polite tone. There is never any lengthy digression, no subtle wordplay or smuggled irony. They almost always give the impression of having been written by a fully occupied man who in reality does not have time to correspond. Not infrequently the letters open with an apology for the late reply.

Over time, Sievert became increasingly attentive towards other people. For all his constructions and organizational creations, it was nevertheless the friendship with his research colleagues that in the long run he said he valued most highly. This change in Sievert's personality coincides with the gradual shift in his duties. From having been the creative constructor, he came in the later part of his life to devote more and more time to national and international activities in which receptiveness and cooperation were what led to success. Sievert's creativity could find an outlet at the most varied times of the day. After a few quick sketches on a pad, he might telephone his co-workers in the middle of the night to hear their views. Ideas flowed

freely. The uninitiated observer had difficulty discerning what was a passing fancy and what concealed deeper reflections. One of Sievert's disciples, Lars-Eric Larsson, early learned a method for separating the wheat from the chaff. Each time Sievert presented a new idea, Larsson would note it down afterwards. If Sievert asked a second time how the investigation was progressing, there was reason to examine the matter more closely. Sievert himself, who had wondered about Larsson's accuracy, found the method extremely amusing when, after many years, he learned of it.

As constructor, Sievert was impatient and impulsive. Ideas for a construction often came when he was laying solitaire in the residence. Each construction was changed several times before he was satisfied with the result. The workshop manager Axel Berggren, who lived in a small official flat at the Radiation Physics Institute, most often received a call from Sievert late in the evening to give an opinion on the latest idea. Once Sievert had convinced Berggren of the construction, Berggren would devise a practically workable solution. Berggren recounts that the reverse procedure then ensued, with Sievert acting as "prosecutor" and Berggren as "defender" of the entire construction. If Sievert considered Berggren's answers sufficiently substantial, the work continued to the finished product. The design of the instruments had to be aesthetically pleasing and the impression first-rate. What mattered was the feeling of the user. Sievert believed that if the user had confidence in the appearance of the instrument, they would also have confidence in its function and handle the instrument carefully. Many instruments were finished in black, even though chrome plating and matt-enamel finishes were also important elements.

This eagerness to create is likened by those who met him to a child's fascination with a Meccano set. The large body contained a little boy. The former information officer at SSI, Sven Löfveberg, has perhaps summed it up best when he writes:

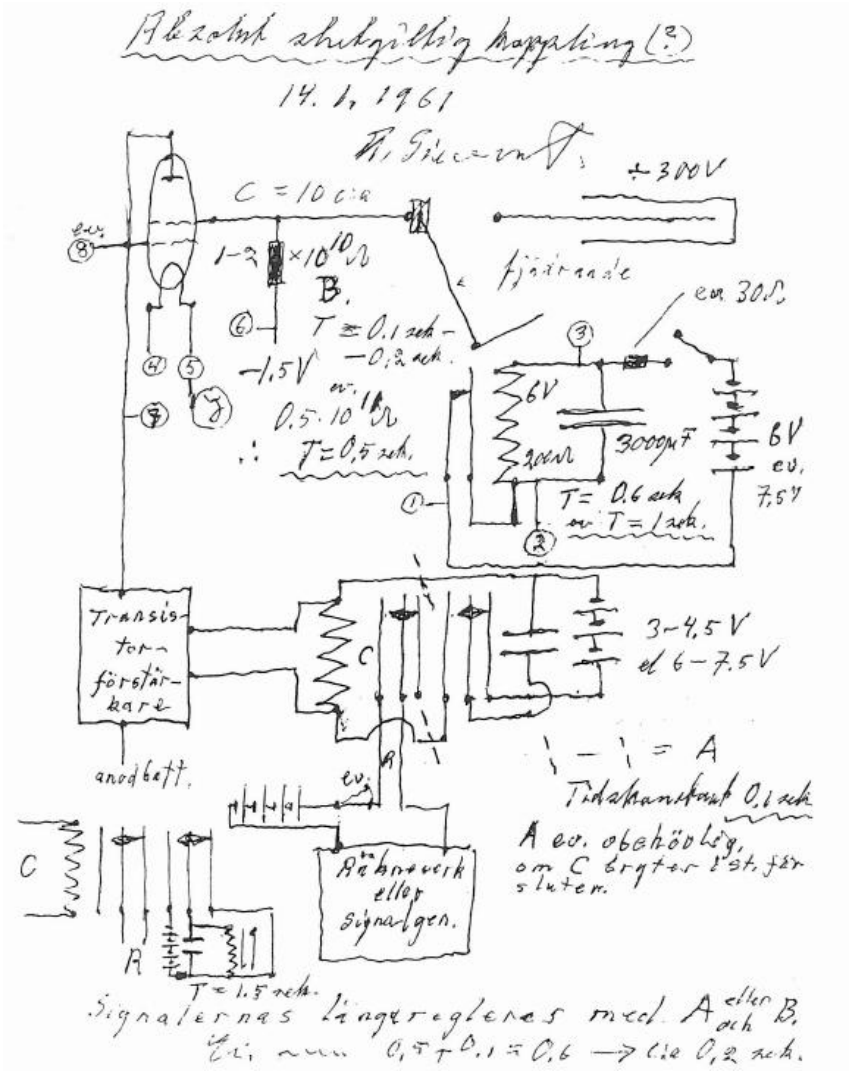
> Rolf loved to design and invent ingenious instruments and devices. When he was occupied with these, he forgot time and place. He liked to make small and neat instruments - so small that they disappeared into his enormous fist. The tiny things made him happy."[4]

In the final phase of the actual construction process, Sievert could spend his time down in the workshop, impatiently waiting for Axel Berggren or Bengt Håkansson to give the go-ahead for testing. Rumour has it that he burned holes in several suits when, leaning eagerly over the workbench, happened to brush against the soldering irons.

Sievert was a lone researcher. Perhaps he was one of the last lone researchers in the history of physics. He himself expressed his confidence in this way of working in *Teknisk tidskrift* in 1951:

> Cooperation is the watchword of our time. But we must not forget the individual. Behind all the talk of "team work" and cooperation one can generally discern the individual researcher's still fundamentally individualistic attitude. The subject is a sensitive one. Let it merely be pointed out here that most disagreements when it comes to the practical exploitation of a researcher's idea can essentially be traced to differences of opinion as to how great a value should be attributed to the idea itself and how great a value belongs to the initiative that drives the idea on to practical application and to the more or less extensive technical development work."[5]

Sievert therefore did not want to be forgotten and disappear into the collective of technology. In the quotation above there are two key sentences that show the conflict in which Sievert found



Designing was Sieverts' hallmark. He revised his designs several times before he was satisfied. This is what the drawings he handed to his instrument makers looked like. Note the ambivalent heading "Absolut slutgiltig koppling (?)" - absolutly final circuit (?).

himself in the later part of his life: *"We must not forget the individual"* and *"The subject is a sensitive one."* Here he defends himself against the increasingly strong demands for changed forms of work, co-determination and "team work."

During the 1940s and 50s, Sievert patented some of his constructions. At the Patent Office there are in all five patents issued with Sievert as inventor. Two of the patents concern the X-ray tube that Sievert designed for the high-voltage hall where the conical anode had a special shape. The other three patents concern various instruments for the measurement of ionizing radiation. The number of patents is not in itself impressive. One explanation may be that Sievert found the patent procedure too troublesome, another that he worked within a field (health care) that was to serve the public good and where personal financial gain may have been considered unethical. A third explanation may be that Sievert did not feel the need to protect the patents, since he did not need to market and manufacture them himself and his private finances were very good.[6]

The picture of Sievert the organizer is in part a different one. There, the more listening and diplomatic traits came to the fore. There, he had to argue and there the formal side of his personality came into its own. Once he had made up his mind, it was difficult to stop him. In the organizational sphere he succeeded in realizing many of his ideas, while at the same time

he there encountered the toughest resistance. The impression of Sievert as organizer is therefore varied. The remaining impression is that Sievert had a strong belief in the blessings of organizing, but he was pragmatic and created organizations adapted to the available staff. Centralization and increased resources would automatically yield better and cheaper operations, regardless of the nature of the activity. This belief in centralization also presupposed that those in decision-making positions made the right decisions. It is possible to interpret Sievert's attitude as an expression of elitism, even if the aim of the decisions was the good of humanity. Sievert's belief in centralization rested implicitly on the assumption that he – Sievert - was at the centre of power. The overarching ideology in Sievert, however, was technological optimism. He experienced how development was accelerating ever more rapidly. It is the social builder and improver who speaks:

"We are in a phase of the development of scientific research when an unceasing stream of new methods and aids is pouring forth, opening up new paths in all fields of activity. […] Characteristic of our time is the speed with which scientific findings are put to use for practical purposes."[7]

It is also likely that Sievert reacted very negatively if anyone questioned his intentions in connection with his organizational proposals. He himself acted from what he believed to be the best for people or for the nation. Sievert was, however, no idealist and he had good understanding for the fact that scientists could earn money from their own discoveries.
As organizer he was constantly on the lookout for money. The annual reports of activities often begin with an account of how the meagre resources had made it impossible to conduct research or radiation supervision to the desired extent. The lists of funding applications were long and not infrequently Sievert spent in advance from the annual appropriations. It is said that one of the greatest honours that can befall a scientist is to have a unit named after him. The unit of dose equivalent in the SI system was given the name *sievert* in 1979.[8] In this way his name will live on as part of science.

Some short facts about Rolf Sievert

- Born 6 May 1896 in Stockholm, died 3 December 1966 in Stockholm.
- Married to Ingrid Sandberg 1918-31 and Astrid Östergren 1932-66.
- School-leaving examination at Nya Elementarskolan in Stockholm, 1914.
- Fil. kand. (B.Sc.) at Uppsala University, 1917.
- Fil. lic. (Licentiate) at Stockholm University College, 1924.
- Fil. dr (Doctor of Philosophy) at Uppsala University, 1932.
- Docent in medical physics at Stockholm University College, 1932-42.
- Professor of radiation physics at the Karolinska Institute in Stockholm, 1941.
- Head of Radiumhemmet's physical laboratory 1924-37 and head of the Radiation Physics Institute at Karolinska Hospital 1938-65.
- Member of the International Commission on Radiation Units and Measurements (ICRU), 1928.
- Member of the International Commission on Radiological Protection (ICRP), 1928 and its chairman 1956-62.
- Secretary of the Swedish National Committee for Physics, 1941-45.

- Initiator and leader of the Military Physics Institute (MFI) and executive member of its board, 1940-45.
- Member of the Defence Research Board, 1943-45.
- Member of the Royal Swedish Academy of Sciences, 1944.
- Commander of the Order of the Polar Star, 1945 and First Class, 1961.
- Secretary of the Cancer Society (*Cancerföreningen*), 1945 and board member 1946.
- Honorary member of the British Institute of Radiology, 1948.
- Vice-chairman of the Board for the Academy of Sciences' research stations in Upper Norrland, 1952 and its chairman 1961-66.
- The Academy's Small Linnaeus Medal in Gold for his contribution to the Kiruna Geophysical Observatory, 1957.
- Chairman of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), 1958-60.
- Vice-chairman of the Radiation Protection Board of the National Medical Board, 1958.
- Member of the Royal Swedish Academy of Engineering Sciences, 1959.
- Honorary member of the Deutsche Röntgengesellschaft, 1959.
- Chairman of the Expert Committee for Advice in Nuclear Accidents (KRA), 1960.

Common abbreviations and explanations

CFÅ = Annual report of Cancerföreningen i Stockholm from 1923 onwards National Library of Sweden.

FOA = Swedish Defence Research Agency

IAEA = International Atomic Energy Agency

ICRP = International Commission on Radiologial Protection

ICRU = International Commission on Radiation Units

IGY = International Geophysical Year

IVA = Military Physics Institute

KRA = Expert Committee for Advice in Nuclear Accidents

KTH = Royal Institute of Technology

KVA = Royal Swedish Academy of Sciences

LSA = Archives of the County Administrative Board in Stockholm

MFI = Military Institute of Physics

RA = Swedish National Archives

Radiumhemmet = radiotherapy research institution and clinic at the Karolinska Hospital

SMHI = Swedish Meteorological and Hydrological Institute

SSI = Swedish Radiation Protection Institute (now Swedish Radiation Safety Authority SSM)

UNSCEAR = United Nations Scientific Committee on the Effects of Atomic Radiation

UUA = Uppsala University Archives

Image sources

All images in this book are held at the Swedish Radiation Safety Authority (formerly Swedish Radiation Protection Institute - SSI), except for the images specified below. The images from SSI were taken both by employees and by private individuals associated with SSI.

The images on pages 5, 6, 7, 8 and 9 are taken from Glasser 1944.

The images on pages 16, 17 and 22 are taken from Hildebrand 1938.

The images on pages 42 and 43 are taken from the Manne Siegbahn Archive at the Centre for History of Science.

The image on page 48 is taken from J. J. Thomson, Recollections and Reflections (1938).

Professor Bengt Hultqvist, Kiruna, kindly privided the image on page 68. The images on pages 76 and 77 come from Pressens Bild.

The image on page 49 comes from Reportagebild.

References

Note that Swedish titles of books and articles are translated into English. German titles are in original. Names of Swedish journals and organisations are kept in original. Formatting in italics is kept as in the original book.

Chapter 1. The *D*evelopment of *R*adiology, 1895–1920

1. Glasser et al., *Physical Foundations of Radiology* (New York, 1944), 97.
2. Emilio Serge, *From X-rays to Quarks: Modern Physicists and Their Discoveries* (New York, 1980), 21f.
3. Ibid., 21. In the primary X-ray image the rings will be white, not black. If a photograph is made of the image, the rings become black.
4. Otto Glasser, *Dr. W.* C. *Röntgen* (Springfield, 1945), 41-52.
5. Serge 1980, 26.
6. Ibid., 28f.
7. Ibid., 29.
8. Loc.cit.
9. Loc.cit.
10. Ibid., 34.
11. Ibid., 35.
12. Ibid., 44.
13. Schuck, et al. *Nobel: The Man and His Prizes* (Amsterdam, 1962), 449.
14. Ibid., 453.
15. Elis Berven, "The General Department at Radium hemmet 1910-1950" in Berven et al. *The First Fifty Years, Radiumhemmet 1910-1937 and King Gustaf V Jubilee Clinic 1938-1960,* Acta Radiologica supplementum 250, (Stockholm, 1965), 11.
16. Otto Glasser, *Wilhelm Conrad Röntgen und die Geschichte der Röntgenstrahlen* (Springer Verlag, 1931), 211. This fact-packed book is generally regarded as the fundamental source on the early history of radiology.
17. Ibid., 188.
18. See, e.g., Otto Glasser, "First Observations on the Physiological Effects of Roentgen Rays on the Human Skin", *American Journal of Roentgen* 28 (1932), 75-80. The article contains a handful of examples of radiation injuries caused during demonstrations of X-rays. A couple of cases concern young boys who, for payment, were fluoroscoped before an audience. After a week or so, erythema (like severe sunburn) and swelling developed. Hair loss among these subjects was also common. The researchers discussed the cause of the radiation injuries and a number of different alternative explanations were published in the medical press.
19. Glasser et al. 1944, 5.
20. Lauriston S. Taylor, *Radiation Protection Standards* (Cleveland, 1971), 9.
21. Glasser et al. 1944, 5.
22. Bo Lindell & Sven Löfveberg, *Nuclear Power, Man and Safety* (Stockholm, 1972), 157.
23. Glasser 1932, 75.
24. Emil Grubbe, *X-ray Treatment: Its Origin, Birth and Early History* (Saint Paul & Minneapolis, 1949), 49 and 55.
25. Glasser 1931, 246.
26. Ronald Kathren, Wiliam H. Rollins (1852-1929): X-ray Protection Pioneer*, Journal of the History of Medicine* July 1964), 289.
27. Ibid., 290. Rollins had irradiated a pregnant guinea pig, whose foetuses died. Rollins also reported that a pregnant woman who had been exposed to X-rays subsequently suffered a miscarriage.
28. Loc.cit.
29. Ibid., 292.
30. Glasser 1932, 75.
31. Taylor 1971, 10
32. Loc.cit. Taylor cites Rollins' book: *Notes on X-light* (Boston, 1903), 290. Rollins received little attention from his scientific contemporaries. For example, he had to finance *Notes on X-light* out of his own pocket.
33. Loc.cit.
34. Loc.cit. See also: Kathren 1964, 291. Kathren, who wrote about the early history of radiation protection in the USA, nevertheless argues that Rollins did not intend to establish a tolerance dose at all, but was interested only in providing a guideline for shielding X-ray tubes.
35. Glasseret al.1944, 115.
36. An exceptionally good review of the development of radiation protection in radiology is Daniel Paul Serwer's 1977 doctoral dissertation: *The Rise of Radiatian Protection: Science, Medicine and Technology in Society 1896-1935* (Princeton, 1977).
37. Åke Åkerlund, Gösta Forsell – biographical memoir, *Yearbook of the Royal Swedish Academy of Sciences 1953* (Stockholm 1953), 372.
38. Lindell & Löfveberg 1972, 158.
39. Åkerlund 1953, 372.
40. Elis Berven, "The General Department at Radiumhemmet 1910-1960" in Berven et al. 1965, 12.
41. Loc.cit.
42. Loc.cit.
43. Åkerlund 1953, 374. 44. Ibid., 373.
45. Ibid., 374.
46. Ibid., 374 & 397.

47. Ibid., 397.
48. Loc.cit.
49. Berven et al. 1965, 13.
50. Ibid., 18.
51. Loc.cit.
52. Interview with Jerzy Einhorn, 1988.
53. Åkerlund 1953, 375.
54. Ibid., 400
55. Berven et al. 1965, 141.
56. Åkerlund 1953, 376.
57. Berven et al. 1965, 22.
58. Ibid., 43.
59. Lauriston S. Taylor, *Organization for Radiation Protection - the Operations of the ICRP and NCRP* Assistant Secretary for Evironmental Research and Office of Technical Information U.S. Department of Energy, 1-001. 60. Ibid., 2-001 f.
61. Ibid., 2-002.
62. Åkerlund 1953, 402 f.

Chapter 2. Childhood and *S*tudent *Y*ears

1. Karl Hildebrand, *Sievert's Cable Works: Commemorative Publication on the First 50 Years* (Stockholm, 1938), 19.
2. Ibid., 20.
3. LSA, extract from the trade register, 1888/89.
4. Max Sievert, *Catalogue* (Stockholm, 1888), 3.
5. Hildebrand 1938, 22.
6. Ibid., 30
7. Stockholm City Archives, census records 1901, district 9, 4473.
8. Interview with Astrid Sievert, 1988.
9. Interview with Rune Walstam, 1988.
10. Interview with Astrid Sievert, 1988.
11. Op.cit.
12. KTH, card-index record.
13. UUA, Faculty of Philosophy archives DI:13, register of philosophy students 1914-1918, information on Rolf Maximilian Sievert.
14. Carl-Olov Stawström, "Historical perspectives on ideas in the content of certain writings by Carl Wilhelm Oseen", (Stockholm Papers in History and Philosophy of Technology, Stockholm, 1986), 12.
15. Ibid., 13.
16. UUA, DI:13.
17. Stawström 1986, 16.
18. Carl-Olov Stawström, "Views on how Swedish physicists and philosophers perceived Einstein's theory of relativity", (Stockholm Papers in History and Philosophy of Technology, Stockholm, 1986), 13. Swedish physicists were for a long time divided into two camps over Einstein's theory of relativity. Experimental evidence for the theory was virtually non-existent and the experimentalists therefore could not accept it. The conflict between theoreticians and experimentalists had an outcome that was less than flattering for the Nobel Committee: in 1921 Einstein was awarded the Nobel Prize for the discovery of the photoelectric effect and not for his theory of relativity. Thus one of the theoretical cornerstones of physics was never awarded a Nobel Prize.
19. See, e.g., Rolf Sievert, "Zur Frage der lntensitätsverteilung der gamma-strahlen in der Nähe medizinischer Radiumpräparate", *Acta Radiologica,* 2, (1923), 70.
20. Rune Walstam, "Rolf M Sievert – the father of Swedish medical physics", 7 *Naturvetaren* (1986), 24. Cf. Sven Benner, *Radiophysics in Sweden: A Brief Historical Overview* (Umeå, 1976), 2.
21. SSI, information form for Who is Who, Information Department file on Rolf Sievert.
22. Hildebrand 1938, 174. 23. Ibid., 102.
24. Rolf Sievert, "Cooperation between medicine and technology", *Teknisk tidskrift* (1951), 557.

Chapter 3. The Physics Laboratory, 1920–1938

1. Tycho E:son Aurén, three articles in Communications from the Royal Swedish Academy of Sciences: "The Absorption of X-rays" (1919), (Meddelanden, volume 4, no. 3, Stockholm 1920-1922), "Absorption of X-rays in crystals" (1921), (Ibid., no. 11), "Measurements of the absolute intensity of X-rays" (1925), (Meddelanden, volume 6, no. 13, Stockholm 1927). Sievert was thus already familiar with work concerning the absorption and intensity of X-rays when he came to Radiumhemmet.
2. SSI, Rolf Sievert, History of Swedish radiation protection activities, speech, (1964), SSI: 1975-028, 13.
3. Rolf Sievert, "Medical radiophysics in Sweden 1920- 1950." *Acta Radiologica* 33 (1950), 192.
4. Gösta Forssell, "Rolf Sievert on His Fiftieth Birthday May 6th, 1946", *Acta Radiologica* 27 (1946), 210.
5. Sievert, 1975, 3.
6. Ibid.
7. Rolf Sievert, *Production of radioactive preparations for medical purposes by concentration of radium emanation* (Stockholm, 1931).
8. Sten von Friesen, *On Measures and Men*

(Höganäs, 1987), 184.

9. Interview with Bo Lindell, 1988.
10. Report of the Board of Cancerföreningen in Stockholm for the year 1923, Cancerföreningen (1923), KB.
11. Loc.cit.
12. Loc.cit. The annual report states that "The Board decided to take steps to arrange an extension at Radiumhemmet[...]". Cf. Forssell 1946, 210.
13. Rolf Sievert, "The Institute of Radiophysics" in Berven et al. 1965, 92.
14. SSI, copy of deed of gift to Cancerföreningen in Stockholm, dated 1924-01-16. Unknown sender in Rolf Sievert's papers.
15. Op.cit.
16. Op.cit.
17. Rolf Sievert, "Einige Untersuchungen über Vorrichtungen zum Schutz gegen Röntgenstrahlen", *Acta Radiologica,* vol. 4, (1925), 129.
18. CFÅ 1924. It is worth noting that Sievert is mentioned for the first time in the 1923 annual report and that already the following year he has his own report on the Physical Laboratory.
19. Loc.cit.
20. CFÅ 1926.
21. CFÅ 1928.
22. CFÅ 1929.
23. CFÅ 1927.
24. CFÅ 1929. "Construction work began in June and in November the new premises could be occupied," Sievert wrote in the annual report. In the basement at Fjällgatan 20A, Sievert and Robert Thorreus installed an "X-ray apparatus" that had previously belonged to the Nobel Institute for Physical Chemistry.
25. (Sievert, 1975)
26. CFÅ 1929. Sievert wrote in the report: "Because of the great risks that are always associated with large quantities of radium, the investigations have been divided among five different assistants, thereby considerably reducing the risk of radium injuries."
27. Rolf Sievert, "The new apparatus for teleradium treatment used at Radiumhemmet", *Acta Radiologica* 14 (1933), 198ff. In the summary of the article in *Acta Radiologica*, Sievert wrote: "The article is a description of the types of teleradium equipment recently designed by the author and now in use in several places in Sweden and Norway." Work on the radium cannon for distance treatment had already begun in the autumn of 1929, thanks to a donation from the King Gustaf V Jubilee Fund for the purchase of radium.
28. CFÅ 1925.
29. Rolf Sievert, "Untersuchungen über die an verschiedenen schwedischen Krankenhäusern zur Erreichung des Hauterythems gebräuchlichen Röntgenstrahlmengen, unter Einführung der R-einheit", *Acta Radiologica* 7 (1926), 461ff.
30. Ibid.
31. Serwer 1977, 167. A similar study had been carried out in Germany in 1924, with approximately the same results.
32. CFÅ 1926.
33. Sievert 1975. Sievert said: "After a year I had actually grown tired of these journeys; it was not possible to manage anything at the laboratory and also make the trips."
34. CFÅ 1929.
35. Loc.cit.
36. Manne Siegbahn et al., *Recommendations of the International X-ray Unit Committee* (Stockholm, 1929), 1.
37. Rolf Sievert, "Dosage Units and the Ionisation Method", *Acta Radiologica* 18 (1937), 742ff.
38. Rolf Sievert, "Die lntensitätsverteilung der primären g-strahlung in der Nähe medizinischer Radiumpräparate", *Acta Radiologica* 1 (1921), 118.
39. Ibid., 89
40. Serwer 1976, 132. Together with the physicist Knipping, Friedrich had shown in a famous diffraction experiment that X-rays were of the same nature as electromagnetic waves. In 1923 Friedrich founded a research institute for radiation in Berlin.
41. Rolf Sievert, "Zur Frage der Intensitätsverteilung der gamma-strahlen in der Nähe medizinischer Radiumpräparate", *Acta Radiologica* 2 (1923), 70.
42. Ibid., 73.
43. Rolf Sievert, "Einige Bemerkungen zu der Abhandlung W. Friedrich und O. Glasser, 'Intensitätsverteilung der gamma-strahlen radioaktiver Substanzen im aborbierender Medium'", *Zeitschrift für Physik* Sonderabdruck Band 12, Heft 3/4 (1923).
44. It should be mentioned that Glasser emigrated from Germany to the USA in the early 1920s, which may have caused the controversy to peter out while Glasser was occupied with arranging his new life.
45. Rolf Sievert, "Secondary Rays in Radium Therapeutics", *Acta Radiologica* 2 (1923), 268 ff.

46. Ibid., 294.
47. The documents are held by Sievert's close associate Bengt Håkansson, who, out of curiosity, saved some of the many brochures that came to the attention of the institute.
48. Rolf Sievert, "Some observations on radium cloths from a physical point of view", *Hygienisk revy* (1927).
49. Whether Sievert was the first to formulate the actual principle of separating the ionisation chamber from the electrometer is unclear. Gösta Forssell wrote in Forssell 1946, 212: "Only many years after his invention did he find out that a construction which was the same in principle as his first design had earlier (1925) been used by Halledauer for a specific purpose."
50. Rolf Sievert, "Eine einfache, zuverlässige Vorrichtung zum Messen von Tiefendosen", *Acta Radiologica* 5 (1926), 457.
51. Rolf Sievert, "A New Method for Determing the Intensity of gamma- and X-Ray Radiation", *Acta Radiologica* 12 (1931), 190.
52. Rolf Sievert, *Eine Methode zur Messung von Röntgen, Radium- und Ultrastrahlung nebst einige Untersuchungen über die Anwendbarkeit derselben in der Physik under der Medizin* Acta Radiologica supplementum 14 (Stockholm 1932), 3.
53. Sievert, 1975.
54. Rolf Sievert and Arne Forssberg, "The Time Factor in the Biological Action of X-rays", *Acta Radiologica* 7 (1931), 555 ff.
55. Rolf Sievert, "Determination of Ionisation in Biological Objects", *Acta Radiologica* 21 (1940), 203.
56. Arne Forssberg, *Studien über einige biologische Wirkung- en der Röntgen- und Gammastrahlen, insbesondere am Phycomyces Blakesleeanus* Acta Radiologica supplementum 49, (Stockholm 1943).
57. Rolf Sievert, "Notes on International Units for Roentgen- and Radium Dosage", *Acta Radiologica* 7 (1931), Jv2-304.
58. Ibid., 300.
59. The unit "r" has a somewhat confusing history. Until the 1930s the unit was written with a capital R; during the 1930s, 1940s and 1950s it was written "r". Following a redefinition of the unit, it has again been written with a capital "R" since the beginning of the 1960s.
60. Gunnar Eriksson, *The Mappers: The Growth and Applications of Natural Science in Sweden's Industrial Breakthrough, 1870-1914*, Acta Universitatis Umensis, (Umeå, 1978).
61. Interview with Bo Lindell, 1988.
62. Elis Berven, "The General Department 1910-1960" in Berven et al. 1965, 30 ff.
63. Ibid., 31.
64. Åkerlund 1954, 380.
65. Elis Berven, "The General Department 1910-1960" in Berven et al. 1965, 30 f.
66. Rolf Sievert, "The Institute of Radiophysics" in Berven et al. 1965, 97.
67. Sievert 1975, 6.
68. Elis Berven, "The General Department 1910-1960" in Berven et al. 1965, 36.
69. Loc.cit.
70. Ibid., 38.
71. Rolf Sievert, "The Institute of Radiophysics" in Berven et al. 1965, 94. Cf. Swedish Government Official Reports (SOU) 1956:38, "Radiation protection – proposal submitted by the 1951 Radiation Protection Committee", 44 ff.

Chapter 4. International Engagement

1. Glasser et al., 1944, 10.
2. Taylor 1971, 11. Taylor writes that attention became focused on radiation risks around 1920 after a deluge of publicity surrounding deaths from aplastic anaemia.
3. Ibid, 12ff.
4. Ibid, 12.
5. Schück et al. 1962, 252
6. Taylor 1971, 11.
7. Ibid., 14.
8. Rolf M. Sievert, "Radiophysics" in History of the Karolinska Medico-Surgical Institute 3 (Stockholm, 1960), 657.
9. Åkerlund 1953, 387.
10. Ibid., 383.
11. SSI, Protocol for the General Assembly of the Second International Congress of Radiology at the House of Parliament in Stockholm, 27th July 1928.
12. Taylor 1971, 16.
13. Ibid., 11.
14. Bo Lindell, offprint, "ICRP 1928-1978", *Radiological Protection Bulletin* 24 (1978), 5.
15. Ibid., 6.
16. Loc.cit.
17. Rolf Sievert, "Erd-γ-strahlung und Ultrastrahlung", *Acta Radiologica* 16 (1935), 155-168.
18. Olle Edqvist, "Manne Siegbahn", *Kosmos* 63 (1986), 173.
19. Ibid., 173.
20. Ibid., 170.

21. Rune Walstam, "Professor Robert Thoræus 1895 - 1970", *The American Journal of Roentgenology, Radium Therapy and Nuclear Medicine* 111, No 2, (1971), 422f.
22. Edqvist 1986, 169.
23. Ibid., 172.
24. Rune Walstam, "Sven Benner in memoriam", unpublished speech, in Rune Walstam's possession.
25. Ibid. The interviews reveal a large number of small anecdotes that are really outside the subject, but nevertheless say a great deal about how those who were there remember events and people. A standing "joke" at the Institute of Radiophysics was that Sven Benner should not be allowed to take holidays, because Benner, a living encyclopaedia, was always needed at work.
26. Op.cit.
27. SSI. The archive contains very extensive correspondence. The letters are filed partly under the subject dealt with in the letters and partly under the name of the correspondent, which means that correspondence concerning one subject is sometimes split between several different archive locations.

Chapter 5. During the Second World War

1. SOU 1956:38, 25.
2. Ibid., 90.
3. Ibid., 90ff. 4. Ibid., 90. 5. Ibid., 91.
6. Sievert, 1975, 4.
7. CFÅ and the annual report of the Institute of Radiophysics from 1938 onwards.
8. Lars-Eric Larsson, "Rolf Sievert – our pioneer in medical physics and radiation protection", unpublished speech, presented to the Swedish Association of Medical Physicists, September 1986, in Lars-

Eric Larsson's possession.

9. sou 1956:38, 45.
10. Sievert 1975, 8. In the speech Sievert said that they "sat in the evenings and scribbled away" at the proposal. See also: Rolf Sievert, "Medical Radiophysics in Sweden 1920-1950", *Acta Radiologica* 33 (1950), 209f.
11. Larsson 1986, 8. The conclusion is Lars-Eric Larsson's, but there is nothing to contradict it and much to suggest that the reason really was the one stated.
12. Sievert, 1950, 211. The permitted quantity of radium for medical use or other activities that could involve bodily contact with the substance was only one tenth of the quantity permitted in storage, i.e. 0.01 milligram.
13. Ibid., 201.
14. Ibid., 217.
15. Sievert 1960, 648f.
16. Interview with Lindell, 1989.
17. Sievert 1960, 648f.
18. Gunnar Dahllöf, *The Technology War that Changed the World* (Stockholm, 1985).
19. Thorsten Nybom, "Bernalism and research organisation: scientific ideology and research policy in Sweden in the 1930s", Daedalus 55 (1986), 83-93.
20. Jan Glete, Coastal Defence and Technological Transformation: Technology, Doctrines and Organisation in Swedish Coastal Defence 1850-1880 (Lund, 1985), 46f. The work also provides a good background for interpreting the conflict between military officers and physicists.
21. Wilhelm Agrell, *Science in the Service of Defence* (Lund, 1989), 90f. The book is an excellent introduction to Swedish defence research as a whole from the turn of the century to the present day. Its emphasis, however, is on the period after the Second World War and it deals mainly with the relationship between military research and contemporary doctrine.
22. Gustaf Ljunggren, Swedish Defence Research before FOA: The New Weapons, Defence Research and the Struggle over the Structure of Swedish Defence (Stockholm, 1965), 8.
23. SSI, letter from Sievert to Professor Gudmund Borelius at KTH, 5 September 1939.
24. Gilbert Whittemore provides an illuminating example in an article of how chemists in the USA tried to help the country during the First World War: "World War 1, Poison Gas Research and the Ideals of American Chemists", *Social Studies of Science* 5 (1975), 136. See also: Nybom 1986, 83f.
25. KVA, In a letter to the Minister of Defence, the heads of the country's physics institutes explained that they had followed developments abroad during the First World War and had found there to be a great need for physicists. They referred to the English physicist J. J. Thomson's book *Recollections and reflections* and to the Board of Invention and Research established in England to underline the necessity of physics research in Sweden as well. (Minutes of meeting, Swedish National Committee for Physics)
26. SSI, Rolf Sievert, manuscript for a lecture at the Defence Staff on 12 December 1941.
27. SSI, Rolf Sievert, manuscript for a lecture of unknown date sometime after 1945, probably at the inauguration of the

High-Voltage Hall.

28. Sievert lecture 1941. Among those present at the lecture were Minister of Defence Per Edvin Sköld and Supreme Commander Olof Thörnell. After this lecture, which convinced the Minister of Defence, Sievert had something of a "carte blanche" to realise MFI.
29. Op.cit.
30. Op.cit.
31. Op.cit.
32. Op.cit.
33. SSI, Rolf Sievert, manuscript for a lecture during the Research Board's visit to Grindsjön, 10/3 1943. The manuscript probably consists of two separate parts, of which part 2 lacks a title and date. Information taken from part 2, 4.
34. Op.cit.
35. Sievert lecture 1941.
36. Sievert lecture after 1945.
37. Sievert lecture 1941. 38. Dahllöf 1985, 108.
39. Sievert lecture 1941.
40. Op.cit.
41. Ljunggren 1965, 11.
42. SSI, Rolf Sievert, Experiences from military-physics activities during 1939/44 and from the Defence Research Board 1943/44.
43. RA, No. 293, Royal Majesty's bill to Parliament concerning the establishment of the Defence Research Institute, 4. The bill is an excellent review of the research conducted up to that time and also provides an exhaustive analysis of the arguments surrounding the establishment of FOA.
44. Agrell 1989, 104.
45. Ibid., 1 lf.
46. Ibid., 12.
47. SSI, Rolf Sievert, paper among his effects dated 14 November 1944.
48. Agrell 1989.
49. Sievert 1975, 9.

Chapter 6. Return to research, 1945–1951

1. See, e.g., Robert Jungk, *Heller als tausend Sonnen, das Schicksal der Atomforscher* (Hamburg 1964). A substantial literature has developed in this field. See also: Arthur H. Compton *Atomic Quest* (1956), Spencer R. Weart *Nuclear fear: A History of Images* (Cambridge, 1988) 77-151, Ronald W. Clarke *The Birth of the Bomb: The Untold Story of Britain's in the Weapon that Changed the World* (Liverpool, 1961). A detailed description of radiation protection during the Manhattan Project is given in Barton C. Hacker *The Dragon's Tail: Radiation Safety in the Manhattan Project 1942-1946* (Berkeley, 1987).
2. Ibid.
3. Olof Forssberg, *Swedish Nuclear Weapons Research 1945-1972* (Stockholm 1987).
4. Op.cit.
5. Atomkommittén, Report 1-2, Part 1: Report concerning preliminary organisational measures for the promotion of atomic-energy research (Stockholm, 1946), 4.
6. Atomkommittén 1946, 45.
7. Ibid., 45f.
8. Atomkommittén, Report on the activities of Atomkommittén 1945-1949 (Stockholm, 1950), 95f.
9. Ibid., 50
10. Ibid., 46.
11. Ibid., 47.
12. Atomkommittén 1946, 51.
13. Atomkommittén 1950, 97.
14. Ibid., 95.
15. Ibid., 96f.
16. Ibid., 99f. Also from interview with Bo Lindell, 1988.
17. Ibid., 99.
18. Atomkommittén 1950, 96.
19. Interview with Bo Lindell, 1988.
20. Op.cit.
21. Op.cit.
22. SSI, inauguration of the High-Voltage Hall.
23. Interview with Bo Lindell, 1988.
24. Interview with Sven Lövfeberg, 1988.
25. See, e.g., Boel Berner, *The World of Technology: Technological Change and Engineering Work in Swedish Industry* (Kristianstad 1981),
89. The book can serve as a gateway for anyone interested in this large and fascinating problem.
26. Atomkommittén 1946, 53.
27. Ibid., 49.
28. Ibid., 49.
29. Atomkommittén, Report on the activities of Atomkommittén during the financial year 1951/52, (Stockholm 1953), 67
30. Interview with Rune Walstam, 1988.
31. Interview with Bengt Håkansson, 1988.
32. Atomkommittén 1950, 102.
33. Loc.cit.
34. Ibid., 103.
35. Rolf Sievert, "The Institute of Radiophysics" in Berven et al. 1965, 108.
36. Interview with Bengt Håkansson, 1988.

37. Atomkommittén 1953, 68.
38. Ibid., 71.
39. Ibid., 68.
40. Ibid., 69.
41. Ibid., 72
42. Ibid., 70.
43. Interview with Bengt Håkansson, 1988.
44. Bengt Hultqvist & Rolf Sievert, "Variations in natural gamma-radiation in Sweden", *Acta Radiologica* 37 (Stockholm, 1952), 388-398.
45. Bengt Hultqvist, *Studies on Naturally Occuring Ionizing Radiations,* Proceedings of KVA, fourth series, volume 6, no. 3 (Stockholm, 1956), 113.
46. David J. Benner, *Radon: Risk and Remedy* (New York, 1989), chapters 2 and 3.
47. Swedish Government Official Reports SOU 1947:6, Report with proposal for a Geophysical Observatory in Kiruna, etc., submitted by the Royal Swedish Academy of Sciences, the Swedish Meteorological and Hydrological Institute and the Royal Swedish Maritime Administration (Stockholm, 1947), 11.
48. Ibid., 12.
49. Interview with Hannes Alfvén, 1988. 50. SOU 1947:6.
51. Ibid., 29f.
52. Ibid., 27.
53. Ibid., 28.
54. Ibid., 16.
55. Ibid., 30.
56. Ibid., 31.
57. Ibid., 49.
58. Ibid., 40.
59. Interview with Hannes Alfvén, 1988. 60. SOU 1947:6, 21.
61. Ibid., 6.
62. Bengt Hultqvist, "Kiruna Geophysical Observatory", *Kosmos* 35 (1957) 27ff and interview with Bengt Hultqvist, 1988.
63. *Yearbook of the Royal Swedish Academy of Sciences 1949* (Stockholm, 1949) 42f.
64. KVA, Interim Board for Upper Norrland, minutes 1-15, 1948-1950, box A.
65. Interview with Bengt Hultqvist, 1988.
66. Hultqvist 1957, 28.
67. Ibid., 44.
68. *Yearbook of the Royal Swedish Academy of Sciences 1953* (Stockholm, 1953), 22f.
69. Hultqvist 1957, 28f.
70. KVA, "Board for Upper Norrland, minutes 1952-1973", box A.
71. Hultqvist 1957, 29f.
72. Ibid., 42.
73. Brita-Stina Nordin-Pettersson, KVA Art Collections: Catalogue of Portraits, Medals and Other Works of Art (Stockholm, 1971), 55.
74. Interview with Bengt Hultqvist, 1988.

Chapter 7. Nuclear energy: A Double-Edged Sword

1. Interview with Bo Lindell, 1988.
2. Lindell & Löfveberg 1972, 87. 3. Ibid., 344.
4. SSI, Rolf Sievert, typescript manuscript for a speech at the first regular meeting of the Nordic Society for Radiation Protection, 2.2.1966, 10.
5. Lindell & Löfveberg 1972, 161.
6. Schück et al. 1962, 252f.
7. Sievert speech 1966, 11.
8. Lindell & Löfveberg1972, 161.
9. Sievert, speech 1966, 11.
10. Lindell 1978, 6.
11. Sievert speech 1966, 12.
12. Rolf Sievert, "The lnternational Commission on Radiological Protection (ICRP)", offprint from *International Association* (1957), 5.
13. Taylor 1971, 38.
14. Lindell & Löfveberg 1972, 174.
15. Schück et al. 1962, 252f.
16. Lindell & Löfveberg,1972, 167.
17. Ibid., 167f. 18. Ibid., 168.
19. Ibid., 169
20. Sievert 1957, 5.
21. Lindell & Löfveberg 1972, 170.
22. Lindell 1978, 7. 23. Taylor 1971, 40.
24. Sigvard Eklund, "The first Swedish atomic reactor", *Kosmos* 32 (1954), 161. Cf. Karl-Erik Larsson, "The R1 nuclear reactor – a piece of pioneering high-technology history", *Daedalus* 50 (1981), 105 ff.
25. Sievert, lecture 1941, 18. Cf. Karl-Erik Larsson, "The history of nuclear power in Sweden", *Kosmos* 64 (1987), 128.
26. Sigvard Eklund, "Fission processes, a new kind of nuclear reaction", *Kosmos* 19 (1941), 39ff.
27. Larsson 1981, 131 f. The change was implemented on 1 July 1950.
28. Ibid., 131. Larsson believes that two people in particular actively contributed to the location of the reactor, namely the director of IVA, Edy Vilander and Professor Hannes Alfvén. Larsson judges that this location was of "truly great importance".
29. Eklund 1954, 141. Eklund uses the words "formal decision".
30. Interview with Sigvard Eklund, 1988.

31. Op.cit.
32. Op.cit.
33. Larsson 1987, 129.
34. SSI, letter from Eklund to Sievert, dated 9.7.1948, El:3. Eklund summarised his impressions of the trip and noted: "We too are sometimes enthusiastic, but life is somewhat harder here and some of the delight drains away during the so far fruitless attempts to obtain permission to build a small hut outside the experimental station."
35. Larsson 1981, 109. Interview with Sigvard Eklund, 1988.
36. Op.cit. See also: Larsson 1981, 109.
37. SSI, letter from Sievert to Eklund, 23.9.1948, El:3.
38. Interview with Sigvard Eklund, 1988.
40. Larsson 1981, 109
41. Telephone interview with Karl-Erik Larsson, 1988.
42. Op.cit.
43. CFÅ 1950.
44. CFÅ 1951, 34.
45. Interview with Sigvard Eklund, 1988. Eklund says in the interview: "I am convinced that Sievert knew that Magnusson and I were carrying out studies of the preliminary conditions for producing an atomic bomb."
46. Christer Larsson, "The history of a Swedish atomic bomb 1945-1972", *Ny teknik* 17 (1985), part 3, 57, column 3. Larsson cites a debate article in *Dagens Nyheter* in August 1955 written by Eklund.
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48. Ibid., 25. 49. Ibid., 125.
50. Swedish Government Official Reports SOU 1959:38, Preparedness for Atomic-Energy Accidents, 48.
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53. Ibid., 159.
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86. Op.cit.
87. sou 1956:38, 25.
88. Ibid., 7. 89. Ibid., 137.
90. Ibid., 132ff.
91. SSI, letter from Sievert to Failla, 16.2.1954, El:3.
92. Interview with Sigvard Eklund, 1988. 93. SOU 1956:38, 295.
94. Ibid., 268.
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97. SOU 1956:38, 280.

98. Ibid., 338.
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100. Sievert 1975, 10.
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102. SOU 1956:38, 267 ff.
103. Ibid., 297.
104. SSI, letter from Sievert to Gray, 25.11.1954, El:4.
105. SOU1956:38, 264.
106. Interview with Torborg Hammarberg, 1988 and interview with Svea Forss, 1988.
107. Sievert 1975, 10.
108. Letter from Professor Arne Hedgran to the author, 1989.
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110. Ibid., 9f.
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2. Interview with Bo Lindell, 1988.
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8. Lindell & Löfveberg 1972, 180. 9. Ibid., 182.
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Chapter 9. The person Rolf Sievert

1. To portray Sievert as a person, insofar as this has not emerged from the preceding chapters, the author has used all the interviews with people who knew Sievert. Since the picture of Sievert developed gradually during the course of the work, it is difficult to say where certain pieces of information came from. I have therefore chosen/been forced to omit references and instead refer to the interview material in the author's possession.
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X-ray filter
X-ray institute
X-ray spectrograph
X-ray therapy
X-ray therapy, X-ray treatment
X-ray examination
Samuelsson, Yngve
Sandberg, Ingrid
Sandler, Rikard
secondary radiation
Serafimer Hospital
Siegbahn, Manne
Sievert, Astrid (née Östergren)
Sievert, Bengt
Sievert, Bo
Sievert, Ernst
Sievert, Georg
Sievert, Heinrich Theodor
Sievert, Kerstin
Sievert, Lisa
Sievert, Max
Sievert, Max
Sievert, Rolf
Sievert's cable works
Sjögren, Iwar
Slettenmark, Gustaf
Solomon, I.
Sowby, David
Spiers, Frederick
Swedish Radiation Protection Institute, SSI
Stenbeck, Thor
Stenvinkel, Gösta
Sterky, Håkan
Strand, Axel
Strassmann, Fritz
radiation dose
radiation injuries
Swedin, Bertil
Taylor, Lauriston
Royal Institute of Technology in Stockholm, KTH
Swedish Telegraph Administration
Tesla
Thomson, J. J.
Thoræus, Robert
Tvartorp
Tvartorp
UNSCEAR
Wahlbäck, Martin
Walstam, Rune
Wickham
Windscale
Wyckoff
Åberg, Bertil
Åkerblom, Filip
Ångström anders
Åslund, Sven
Östman, Johan