Tensions within an Industrial Research Laboratory: The Philips Laboratory's X-Ray Department between the Wars

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Tensions arose in the X-ray department of the Philips research laboratory during the interwar period, caused by the interplay among technological development, organizational culture, and individual behavior. This article traces the efforts of Philips researchers to find a balance between their professional goals and status and the company's strategy. The X-ray research, overseen by Gilles Holst, the laboratory's director, and Albert Bouwers, the group leader for the X-ray department, was a financial failure despite technological successes. Nevertheless, Bouwers was able to continue his X-ray research, having gained the support of company owner Anton Philips. The narrative of the X-ray department allows us to explore not only the personal tensions between Holst and

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Bouwers, but also the interaction between individual goals and company strategy in an industrial research laboratory.

"In the new laboratory of the Philips factories in Eindhoven top researchers are applying their minds—day in, day out—to the task of unraveling the nature of the mysteries of light so as to ensure that the Philips lamp is of the highest quality."[1] This statement, laden with Philips rhetoric, appeared in a 1925 advertisement celebrating the opening of the new Natuurkundig Laboratorium (Physics Laboratory) of the Philips Electric Lamp Factory in Eindhoven, the Netherlands. The advertisement presented the laboratory's scientists as the foremost talent of the day, using their research skills to ensure that Philips products complied with the highest standards.

The Philips company was established in 1891 by Gerard Philips (1858–1942) in Eindhoven. Gerard, a mechanical engineer, was interested in light bulb technology, and he carefully studied the international literature and visited many national and international competitors to improve his knowledge. From the start, he wanted to manufacture light bulbs for export, realizing that the market in the Netherlands would be too small to absorb the firm's output; and indeed, sales to markets abroad quickly exceeded those to the domestic market. Most of the sales success was attributable to Gerard's younger brother, Anton Frederik Philips (1874–1951), who joined the firm in 1895. As Philips historian Andries Heerding writes: ". . . . the differences in make-up between Anton and his older brother were certainly exceptional. The classic rivalry between technology and commerce, and their importance to the ultimate success of an enterprise, personified in the two men, has been reflected in the company ever since."[2] Later in Heerding's book, it becomes clear that this picture is an oversimplification of Philips history: although Anton Philips was a salesman, he took a great interest in technological development.

The Physics Laboratory at Philips was a leading example of an innovation of the twentieth century: the industrial research laboratory.[3] Scientific and technological cross-pollination had been an in-

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[1] Advertisement, Philips Company Archives, Eindhoven, The Netherlands [hereafter, PCA].

[2] Andries Heerding, *The History of N.V. Philips Gloeilampenfabrieken*, vol. 2: *A Company of Many Parts*, trans. Derek S. Jordan (Cambridge, U.K., 1988), 44.

[3] See a comparative article on German industrial companies and Philips by Paul Erker, "The Choice between Competition and Cooperation: Research and Development in the Electrical Industry in Germany and the Netherlands, 1920–

dispensable part of product development since the mid-nineteenth century, but formally organized industrial laboratories constitute one of the striking features of modern science-based industry and innovation.[4] In his study of research and development at General Electric (GE) and Bell, Leonard Reich describes industrial laboratories as "set apart from production facilities, staffed by people trained in science and advanced engineering who work toward deeper understandings of corporate-related science and technology, and who are organized and administered to keep them somewhat insulated from immediate demands yet responsive to long-term company needs."[5] W. Bernard Carlson, in his study of Elihu Thomson's research activities, views industrial innovation as a synthesis of hardware, organization, and strategy articulated within a company; he characterizes it as a social process.[6]

One important element in this social process is the creation of a specific culture in which scientific research becomes possible.[7] The internal organizational culture for research and development is a complex phenomenon; indeed, the definition of "organizational culture" itself is difficult. Scholars have described it most broadly as a pattern of shared assumptions, often produced by top management.[8] In the case of the industrial research laboratory, it is primarily the research director who is responsible for the creation of a research culture in which teamwork and individuality, scientific investigation and product development, can mutually prosper. A description of culture as a set of shared assumptions is, however, an oversimplification. The histories of industrial research laboratories provide us with a far more complex picture, showing that tensions can develop and endure between individual researchers' interests and corporate business goals, and even between research groups with different research agendas.[9] Consequently, individual scientists' activities, in-

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1936," in *Innovations in the European Economy between the Wars*, ed. François Caron, Paul Erker, and Wolfram Fischer (Berlin, 1995), 231–53.

[4] "Science-based" is a term derived from the classification of Keith Pavitt, "Sectoral Patterns of Technical Change: Towards a Taxonomy and a Theory," *Research Policy* 13 (1984): 343–73.

[5] Leonard S. Reich, *The Making of American Industrial Research: Science and Business at GE and Bell, 1876–1926* (New York, 1985), 3.

[6] W. Bernard Carlson, *Innovation as a Social Process: Elihu Thomson and the Rise of General Electric, 1870–1900* (New York, 1991).

[7] Roli Varma, "Changing Research Cultures in U.S. Industry," *Science, Technology, & Human Values* 25, no. 4 (2000): 395–416.

[8] Edgar H. Schein, *Organizational Culture and Leadership* (San Francisco, 1992), 12.

[9] Michael A. Dennis, "Accounting for Research: New Histories of Corporate Laboratories and the Social History of American Science," *Social Studies of Science* 17 (1987): 479–518.

terests, and relations can result in the emergence of subcultures within the research organization. This view is consistent with Joanne Martin's theoretical investigations of organizational cultures in a broader sense. She argues that, because of cognitive and normative diversity within an organization, the attribution of meaning (an important part of the cultural process) is complicated and leads to fragmentation as well as integration, diversity as well as unity.[10] The most difficult task for a research director, then, is to create organizational unity with regard to major company goals while giving individual researchers a feeling of freedom in their scientific work.

A second problem in the analysis of the industrial research laboratory is the relationship between the evolution of a laboratory culture and a company's choices concerning technological innovation. Decisions about whether or not to invest in specific long-term projects are made at both the top management and the local research levels and are part of an evolving business strategy that shapes technological innovation. Both the research director and the company managers have to find a balance between the company's strategy and the priorities and skills of the research staff, who develop their particular bodies of knowledge not only in response to personal and company needs but also in relation to professional networks that transcend the laboratory's boundaries. The laboratory leader must find a balance between an open research culture attuned to the overall scientific concerns of the day and the specific product interests of the company.

In this article, I focus on the development of the X-ray department at the Philips Physics Laboratory and particularly on the role of individuals operating in an industrial research culture. Radiography research was conducted under the leadership of Gilles Holst (the Physics Laboratory's research director) and Albert Bouwers (the X-ray department's group leader). As this investigation will show, the success of these individuals in their scientific and technological fields did not automatically lead to profitable products for the company; the expectation that technological innovation will produce future success is not always fulfilled.[11] Moreover, failure in innovation has consequences for the cultural unity of a research organization. The questions addressed here include the following: How did Holst first become interested in the subject of radiographic technology, and what was the relationship between the X-ray research effort and the

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[10] Joanne Martin, *Cultures in Organizations: Three Perspectives* (New York, 1992).

[11] For this theme see Harro van Lente, *Promising Technology: The Dynamics of Expectations in Technological Developments* (Delft, 1993).

Philips company strategy? What were the products that emanated from the activities of the Physics Laboratory researchers working under Holst and Bouwers, and how did their work relate to X-ray research elsewhere? What problems did they encounter during the innovation process, and what were the consequences for the laboratory's culture?[12]

Radiography in the First Decades of the Twentieth Century

Radiology technology provides a perfect example of accidental laboratory discovery and demonstrates how such a discovery can lead to an entirely new branch of scientific research with practical applications.[13] In 1895 Wilhelm Conrad Röntgen made a chance observation while carrying out electron tube measurements. In a darkened room in his Würzberg University laboratory, Röntgen noticed that a screen coated with barium platinacyanide lit up. He traced the light source to rays derived from a Crookes tube (a type of electron tube devised by the British scientist William Crookes) that he was using for his measurements. He called these unknown rays "X-rays."

Additional research on the phenomenon of material lit up by a bombardment of electrons followed Röntgen's initial discovery. It was soon clear that X-rays were created by electrons hitting metal surfaces at great speed. The first practical applications of X-rays used an X-ray tube, in which a negatively charged electrode (cathode) produced a cluster of electrons that hit a positively charged electrode (anode) that would then emit X-rays. The anode was set at an angle so that the X-rays could escape from the tube. Most of the kinetic energy contained in the electrons hitting the anode became heat rather than X-rays, however, so the anode had to be made of heat-resistant material and kept cool to prevent it from melting.

William Coolidge, an American who had been hired as a researcher by General Electric in 1905, created the device that has been

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[12] The history of internal Physics Laboratory developments raises the notion that actors were proactive as well as reactive toward their environment. Not only corporate interests but also broader social desires and interests influenced, perhaps more indirectly, decisions made in the Physics Laboratory. For this idea, see Philip J. Vergragt, "The Social Shaping of Industrial Innovations," *Social Studies of Science* 18 (1998): 483–513, especially p. 484.

[13] For a study of the phenomenon of serendipity, see Pek van Andel and Bert Andreae, *Serendipiteit: De paradox van de ongezochte vondst* [Serendipity, the Paradox of the Unsought-After Discovery] (Groningen, 1989). See Johannes van Straaten, "Wat zijn röntgenstralen," *De Technische Gids* 2, nr. 15 (1936): 413–15.

the basis for all X-ray tubes manufactured since his groundbreaking work. Coolidge developed his invention at the GE Research Laboratory in Schenectady, New York. GE's laboratory is often cited as an example of "how to do research in industry," and both historians and contemporaries referred to GE as an international trendsetter.[14] GE had a formalized managerial hierarchy and a middle management level for departments such as manufacturing, engineering, and research.[15] The climate at GE allowed Coolidge to become a brilliant experimentalist. Patented and introduced in 1913, the "Coolidge tube" combined the scientist's own tungsten research with his colleague Irving Langmuir's achievements in vacuum technology to create a hot cathode vacuum tube. By 1913 the GE laboratory was manufacturing Coolidge X-ray tubes on a small scale.[16]

Coolidge's findings gain significance in the context of X-ray technology and its potential value. Because they possess a great deal of energy, X-rays can easily penetrate materials composed of light atoms, whereas they are absorbed by substances composed of heavier atoms, such as those found in metals. When rays that have been aimed at an object are projected onto a screen, the parts of the object that have absorbed the rays will become visible as white patches, thus revealing, for instance, the bone structure of a human body: bones absorb X-rays while the softer parts of the body allow the rays to pass through. X-ray tubes were widely used by physicians to examine lungs and to detect bone fractures; there were also myriad applications for the technology in medical therapy. X-rays also had industrial uses: researchers used them, for example, to study the structure of metals.

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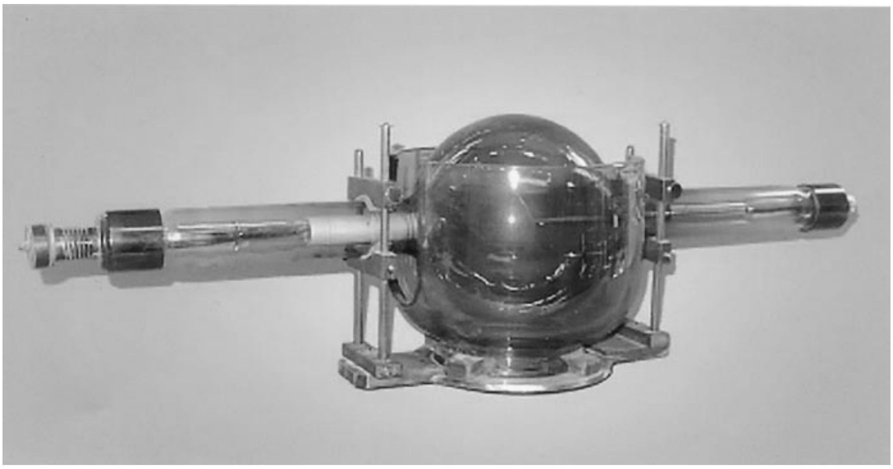
[14] See for example, David A. Hounshell, "The Evolution of Industrial Research in the United States," in *Engines of Innovation: U.S. Industrial Research at the End of an Era*, ed. Richard S. Rosenbloom and William J. Spencer (Boston, 1996), 13–85; and Thomas A. Boyd, *Research: The Pathfinder of Science and Industry* (New York, 1935).

[15] Louis Galambos, "The American Economy and the Reorganization of the Sources of Knowledge," in *The Organization of Knowledge in Modern America, 1880–1920*, ed. Alexandra Oleson and John Voss (Baltimore, Md., 1979), 269–82. See also the Schenectady Museum Archives, Hammond File L 6198; George Wise, *Willis R. Whitney, General Electric, and the Origin of U.S. Industrial Research* (New York, 1985), 72. See also Alfred D. Chandler, Jr., *Scale and Scope: The Dynamics of Industrial Capitalism* (Cambridge, Mass., 1990), especially pp. 220–22 and 537–38, and W. Bernard Carlson, "Competition and Consolidation in the Electrical Manufacturing Industry, 1889–1892," in *Technological Competitiveness: Contemporary and Historical Perspectives on the Electrical, Electronics, and Computer Industries*, ed. William Aspray (New York, 1993), 287–311.

[16] Reich, *Making of American Industrial Research*, chap. 4. The American Institute of Electrical Engineers awarded Coolidge the Edison Medal in 1926 for the origination of ductile tungsten and the fundamental improvement of the X-ray tube.



Coolidge X-ray Tube. Reproduced from the collection of historic instruments in the Department of Physics and Astronomy at the University of Nebraska, Lincoln, with the permission of Eugene Rudd. Original photograph by Tom Hancock.

As scientists worked to develop practical applications of X-ray technology, two specific needs received special attention: sharpening images and protecting users. Not long after Röntgen's initial discovery, it became clear that X-rays were dangerous as well as useful. It was therefore imperative to protect users of X-ray equipment from the damaging effects of rays. In practice, the two objectives—image clarity and user safety—were hard to combine, but designers remained focused on reconciling those two demands. The vacuum technology of the Coolidge tube led to the production of higher-energy X-rays and also permitted operators greater control over energy fluctuations.

The Introduction of X-Ray Technology to the Philips Physics Laboratory

Dutch physicians were among the first in the world to bring X-ray technology into practice, partly as a result of their connections with Wilhelm Röntgen, who had a Dutch mother and spent many years of his youth in the Netherlands. Although he made his scientific career in Germany, he continued to have contacts in the Netherlands.[17] The

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[17] Most of the information in this section is based on Willem A. H. van Wylick's *Röntgen en Nederland: Röntgens betrekkingen tot Nederland en de opkomst der Röntgenologie hier te lande* [Röntgen and the Netherlands: Röntgen's Contacts in the Netherlands and the Rise of X-ray Technology in This Country] (Utrecht, 1966). See also a publication celebrating one hundred years of radiology in the

first academic chair for radiography in Europe was founded in 1899 at the University of Amsterdam, where Johannes Wertheim Salomonson, a Dutch radiologist and neurologist, became the first incumbent. He mobilized Dutch physicians and scientists to work together and to share their knowledge about radiology. In 1901 Wertheim Salomonson founded and became the first head of the Nederlandse Vereeniging voor Electrologie en Röntgenologie (NVER, the Dutch Association for Electrology and Radiology).[18] NVER's annual reports appeared in issues of the *Nederlands Tijdschrift voor Geneeskunde* (the Dutch Journal of Medicine).

Wertheim Salomonson maintained a dominant presence in the journal, writing about X-ray technology, especially the features of the Coolidge tube, as well as about the diagnostic and therapeutic applications of X-rays.[19] Dutch scientists and physicians used imported Coolidge tubes, but Wertheim Salomonson was alarmed that no Dutch industrial company was able to manufacture them. At the beginning of the twentieth century German industrialists, led by C. H. F. Müller AG of Hamburg and by Siemens, established a pioneering position in European X-ray research.[20] As early as 1899 Müller had submitted a request for a patent for an X-ray tube with a water-cooled anode and successfully brought it to market, though that technology was overtaken and the Coolidge principle became the standard.[21] German companies, then, supplied most of the Netherlands' X-ray equipment, and the First World War was cutting off that source of supply. In 1917 Wertheim Salomonson reported at the NVER meeting on his attempts to persuade Dutch industrialists of the promising market opportunities for X-ray equipment, without

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Netherlands: F. M. J. Heijstraten, "G. J. van der Plaats," in *Door het menschelijke vleesch heen: 100 jaar radiodiagnostiek in Nederland, 1895–1995* [Inside the Human Body: 100 Years of Radiotechnology in the Netherlands], ed. A. de Knecht-van Eekelen, J. F. M. Panhuysen, and G. Rosenbusch (Rotterdam, 1995), 259–65.

[18] Algemeen Rijks Archief (The Hague) 2.19.042.34 Ned. Ver. voor Electrologie en Röntgenologie: notulen vergadering 1901–1954. See J. M. Panhuysen, "J. K. A. Wertheim Salomonson," in *Door het menschelijke vleesch heen*, 71–77.

[19] Johannes K. A. Wertheim Salomonson, "De Coolidge-buis," *Nederlands Tijdschrift voor Geneeskunde* 59 (1915): 476–78.

[20] Toward the end of the nineteenth century, C. H. F. Müller was active in German industry as a glass blower, and eventually he set up his own bulb factory. Siemens took an interest in the manufacturing of electro-medical equipment as early as the nineteenth century, and its activities in X-ray technology expanded rapidly after the First World War, when it became Müller's main competitor; see Wilfried Feldenkirchen, *Siemens, 1918–1945* (Columbus, Ohio, 1999), 311–15.

[21] Patent right No. 113430, "Röntgenröhre mit durch Wasser gekühlter Antikathode" [X-ray Tubes with the Water-Cooled Anti-Cathode], 21 May 1899; see also note 13, above.

any result. In fact, however, Philips was developing an interest in the technology.

Many industrial laboratories had sprung up in the Netherlands during the first few decades of the twentieth century, part of the international trend toward specialized industrial research organizations epitomized in the United States by GE, DuPont, and Bell, which began employing physicists and providing them with well-equipped laboratories.[22] The Philips Natuurkundig Laboratorium was the first physics laboratory in the Netherlands and within a short time had made its name as an important center of knowledge.

To discover the origins of the Physics Laboratory we have to go back to 1914, when Gerard and Anton Philips hired Gilles Holst (1886–1968), a Leiden physicist from the Kamerlingh Onnes School, to raise the status of their firm's research efforts.[23] During the laboratory's early years, a small number of researchers had worked on improving the company's main product, the electric light bulb, and on expanding knowledge of electron tube technology in general. It soon became clear that the applied physics research of the scientists employed by Philips was capable of considerably widening Philips's array of products.[24]

Holst's primary task was to support existing Philips technology through testing and troubleshooting to perfect incandescent lamps, and the stream of scientific papers about lamp-related problems emanating from the laboratory indicates that researchers there did focus at first on light bulbs and related phenomena.[25] These scientific articles were the product of Holst's plan to create an academic culture

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[22] Johannes J. Hutter, "Nederlandse laboratoria, 1860–1940" [Dutch Laboratories, 1860–1940, a Quantitative Overview], in *Werkplaatsen van Wetenschap en Techniek: Industriële en Academische Laboratoria in Nederland 1860–1940* [Scientific and Technological Workshops: Industrial and Academic Laboratories in the Netherlands, 1860–1940], ed. R. P. W. Visser and C. Hakfoort (Amsterdam, 1987), 150–74; and see, for example, Hounshell, "The Evolution of Industrial Research in the United States," 13–85, and Reich, *Making of American Industrial Research*, comparing the evolutionary history of the research laboratories at GE and Bell.

[23] Heerding, *A Company of Many Parts*, 314.

[24] Not every new Philips product emanated from the Physics Laboratory, of course. The Dutch historian Hans E. Veldman, in *Innovaties in de lampenfabricage bij Philips 1900–1980* (Eindhoven, 1994), described Philips's innovations in the manufacture of incandescent lamps as characterized by mass production, the pursuit of standardization, and improvements in the production process by engineering work.

[25] B. van Gansewinkel, *Beschrijving van publicaties en verslagen van het Natuurkundig Laboratorium, 1914–1926* [Description of Publications and Reports by the Physics Laboratory, 1914–1926], PCA: internal document, 1989.

for his researchers. Weekly colloquia and encouragement to publish their research findings were important to the industrial scientists.

By improving and further developing incandescent lamps, the Physics Laboratory accomplished its original mission, but a further goal was to obtain more patents and to assist in the company's diversification process. Only after the management decision to diversify its product portfolio did research activities at the Physics Laboratory expand and Holst's scope broaden. In 1923 Philips decided to establish a new laboratory building with modern equipment, plenty of workspace, and a Pilot Factory to facilitate the company's ambitions to expand its product scope. Holst now had the resources at his disposal to carry out the new research activities that Philips demanded. Highly educated Physics Laboratory employees provided Philips with the technical expertise, patents, and new products it required. After 1925, with Philips established in an international lamp cartel, Anton Philips was free to look for new markets.[26]

Radiology technology was only one new area of Philips research, but the X-ray tube was one of the first new products the laboratory researchers had tackled, and the Physics Laboratory's X-ray activities were an important first step in a new direction toward the diversification of Philips. Knowledge and skills developed during electron tube research equipped the Philips staff well for this work, which opened up a completely new market for Philips. The Philips researchers did not spontaneously develop X-ray technology; it found its way into the Physics Laboratory in a roundabout way. In 1917, echoing Wertheim Salomonson, Dutch physicians drew attention to the fact that the war was jeopardizing the supply of X-ray tubes and equipment to the Netherlands.[27] When Germany stopped supplying X-ray equipment, doctors enlisted Philips for repair and maintenance, because X-ray tubes bore many technical similarities to light bulbs. The next year found Wertheim Salomonson expressing relief over Philips's entrance into the radiology market.[28]

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26. Ivo J. Blanken, *The History of Philips Electronics N.V.*, vol. 3: *The Development of N.V. Philips' Gloeilampenfabrieken into a Major Electrical Group* (Zaltbommel, 1999), especially chap. 3, "The Phoebus International Incandescent Lamp Cartel." This Swiss corporation set the rules, controlled prices, regulated sales, implemented policy, and established a testing laboratory to ensure the product quality of its members. See Geoffrey Jones, *The Evolution of International Business: An Introduction* (London, 1996), chap. 4, "National Manufacturing."

27. PCA 815.1 Röntgen; Blanken, *History of Philips Electronics*, 217; and Albert Bouwers, "Natuurwetenschappelijk Onderzoek in de Industrie" [Applied Scientific Research in Industry] *De Ingenieur* 29 (July 1946): A284.

28. Minutes of the 33d Annual Meeting of the NVER, in *Nederlands Tijdschrift voor Geneeskunde* 62 (1918): 1733.

Philips did not stop at repair work, however. Holst became so interested in the phenomenon of X-ray technology that he decided to pursue his own line of research.[29] From the beginning, Holst was aware of the promising aspects of X-ray technology, and he had always tried to carry out development-oriented research. To gain more insight into the Netherlands' uses of X-ray technology, in December 1917 Holst paid a visit to the Antoni van Leeuwenhoek hospital in Amsterdam, where doctors specialized in fighting cancer with the help of X-ray equipment. One of Holst's notebooks contains a report of the visit, describing a conversation with a Mr. G. F. Gaarenstroom, brother of J. H. Gaarenstroom, a submanager and later underdirector of Philips. Holst thus used an informal network to gather information about an unknown technology.[30] During his visit Holst noted how many tubes Gaarenstroom was using, traced the available suppliers, and established that the doctors used X-ray tubes supplied by the German company Müller. Holst also made note of certain scientific and technical matters, such as the solidity of the tubes, the cathode shapes, and the gas used to fill the tube.[31] In the same notebook Holst jotted down several formulas that would later be of use to him when making X-ray-related calculations. It is interesting to see how Holst was interested not only in scientific and technical specifications but also in the sales market. This was typical of Holst, who invariably urged his fellow researchers to ask themselves the question: How can my research benefit Philips in practical terms?[32]

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[29] See PCA/S 657 X-ray miscellaneous.

[30] See PCA 726 NL: the Gilles Holst collection of notebooks, book 5. J. H. Gaarenstroom started working for Philips in 1908, where he would remain until 1940 (PCA 6 A to Z). G. F. Gaarenstroom, his brother, worked at the Antoni van Leeuwenhoek hospital in Amsterdam as a surgeon and radiotherapist until 1922 (PCA 9 UDC A to Z). There was also a third brother, P. Gaarenstroom, who joined the Medical Service at Philips in 1921 in his capacity as a doctor (PCA 6 A to Z).

[31] The first twenty years of X-ray tube development provide an interesting case of a struggle between two dominant technological paradigms (or, to quote Wiebe Bijker, "technological frames"). The study of gases in the X-ray tube was the first dominant technological paradigm. Researchers (for example, Julius Edgar Lilienfeld from Germany) studied and developed gas-filled X-ray tubes. In its simplest form, X-ray tubes of this type consisted of two electrodes in a glass envelope containing gas at low pressure. Coolidge was the researcher who created a hot cathode vacuum tube. The Coolidge vacuum tube that was named after him became the dominant tube in the second paradigm after some years of controversy. For abundant historical details of this complex controversy, see Robert G. Arns, "The High-Vacuum X-Ray Tube: Technological Change in Social Context," *Technology and Culture* 38, no. 4 (1997): 852–90.

[32] Gilles Holst expressed this view in various lectures and articles including *Industrielaboratoria: Rede uitgesproken bij de aanvaarding van het ambt van bijzonder hoogleeraar aan de Rijks-Universiteit te Leiden* [Industrial Laboratories:

Holst responded to the request of the Dutch physicians by starting research and production into X-ray tubes. In addition to satisfying a perceived need, this step was also in line with Philips's diversification policy, and it had important consequences for the research culture of the Physics Laboratory. Holst and the other Philips researchers were hampered, however, because the company had no access to the patented Coolidge tubes for research and manufacturing (although the Physics Laboratory staff were able to repair them). Holst and his colleagues therefore carried out their research activities on the "old-fashioned" Crookes tubes.[33]

One practical problem with gas-filled X-ray tubes was the disappearance of the contents under the influence of electrical discharge. This disappearance made the tube "harder"—that is, it made the tube's resistance greater (for a certain number of milliamperes a higher voltage level was required).[34] A tube could become so hard that electrical transmission was impossible, the cathode evaporated, and the glass sides were coated with metal particles. It was therefore imperative to keep the gas pressure as constant as possible. This process was known as regeneration. A discovery made by Holst and his colleagues resulted in a 1919 patent containing a description of an automatic gas-filling process for X-ray tubes.[35] This innovation enabled Philips to put a new product on the market.

Gradually Holst started producing Crookes-type X-ray tubes on a small scale. The tubes were manufactured at the old Philips Physics Laboratory building in Eindhoven until 1923, when construction began on the new laboratory. Because the demand for Philips X-ray tubes was still small, production continued in the new Pilot Plant,

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Inaugural speech on Becoming Professor at Leiden University] ('s-Gravenhage, 1930), and "Over het Natuurkundig Laboratorium der N.V. Philips' Gloeilampenfabrieken" [On the Applied Science Laboratory at the Philips Electric Light Bulb Factory], *Polytechnisch Weekblad* 19, nr. 50 (1925): 847–51.

[33] Eddy S. Houwaart, "De stabilisering van de röntgenpraktijk, 1914–1940," in *Techniek in Nederland in de Twintigste Eeuw: Deel IV Huishouden, Medische Techniek* [Technology in the Netherlands in the Twentieth Century, Part IV: Household Technology, Medical Technology], ed. Johan Schot (Zutphen, 2001), 197–217, especially p. 206, states that Philips's lack of access to the Coolidge patent could have been the reason for the slow development of radiology technology in the Netherlands. For Holst it was not only the Coolidge patent but also the Physics Laboratory's capacity that was a problem. As soon as the Physics Laboratory's staff grew with Philips's strategy, his organization was able to put more effort into developing new X-ray technology.

[34] Albert Bouwers later described this problem in *Physica en techniek der Röntgenstralen* [The Physics and Technology of X-rays] (Deventer, 1927), 113 ff.

[35] Patent No. 4122, "Inrichting voor het vernieuwen of aanvullen van de gasvulling in ontladingsbuizen" [Installation for Renewing or Supplementing the Gas Contained in Discharge Tubes], 23 July 1919.

rather than in a purpose-built factory (and would remain there until 1930).

A 1919 brochure provides forms for maintenance and repair (for use by doctors who sent their faulty equipment to Philips) and descriptions of the exact types of X-ray tubes Holst and his technicians produced.[36] Two kinds of X-ray tubes are shown: an intake tube without water-cooling with a tungsten anode, and a water-cooled tube for in-depth therapy. By 1920 Holst was able to display Philips-manufactured X-ray tubes at the Eighteenth Dutch Physics and Medical Congress in Utrecht.

Still, the Coolidge tube remained superior to the Crookes tube. Hoping to deepen the Physics Laboratory's theoretical knowledge, Holst hired the gifted physicist Albert Bouwers (1893–1972) in 1920. The 27-year-old Bouwers moved from the Ornstein University Laboratory in Utrecht to the Physics Laboratory to set up a new research program aimed at developing X-ray technology for Philips. He would leave his mark as both a scientist and an individual; until his departure in 1941 Bouwers proved to be the most important person in the X-ray department at the Physics Laboratory.[37]

The First Years under Bouwers's Leadership: The Metalix Tube

Although Bouwers's first task was to find ways to circumvent the Coolidge patent, in his research to develop a new X-ray tube he tried to solve the broader safety problem in the field of radiology. Physicians and scientists had realized the practical potential of X-rays almost at once, but soon after Röntgen's discovery the health risks associated with using X-rays became clear, as radiation claimed many victims among scientists, physicians, and patients.[38]

Although the dangers of overexposure to radiation were known, radiologists continued to injure themselves and their patients, in part because precise guidelines were lacking: no one knew how

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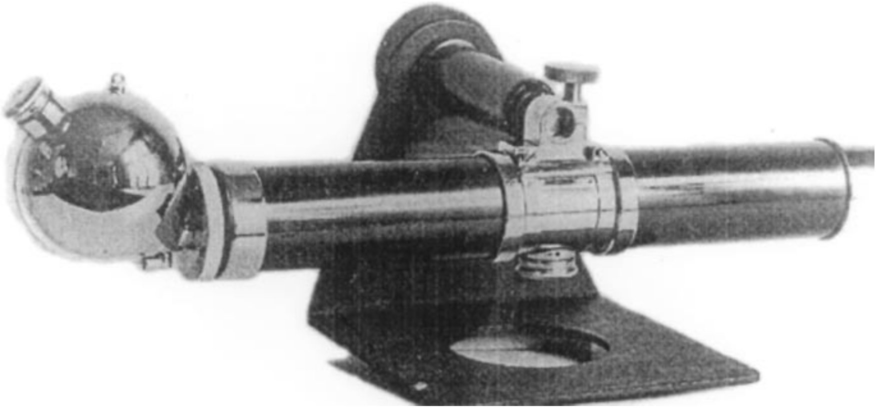
[36] PCA 815.1 X-rays.

[37] See Wybe J. Oosterkamp, "A. Bouwers," in *Door het menschelijke vleesch heen*, 199–210. For a selection of Bouwers's papers, see Albert Bouwers, *Selected Scientific Papers* (Amsterdam, 1969).

[38] This section builds on Catherine Caufield's *Multiple Exposures: Chronicles of the Radiation Age* (London, 1989), chap. 2, and Roelof E. Fokkema's discussion of the dangers of radiation in *Schade door Röntgen- en Radiumstraling: Een hoofdstuk uit de vroege geschiedenis van de radiologie, 1896–1939* [Damage Caused by X-rays: A Chapter in the Early History of Radiology, 1896–1939] (Groningen, 1993).



Philips Metalix X-ray Tube. Reproduced from a photograph by the author.

much radiation was required or the degree of protection needed.[39] Moreover, physicians feared that an obsession with safety would impede further development of a remarkable medical tool and so tended to downplay the dangers. However, the deaths of several German pioneer radiologists and their patients shocked the radiology profession and provided impetus for the development of standards and norms for X-ray protection.[40] International congresses on radiation protection were convened, but committees of the International Congress of Radiology set the first standards only in 1934.

A second path to radiation protection was research to develop safer X-ray tubes. Previously used separate protective screens made of lead rarely provided sufficient protection. Bouwers's first piece of ingenuity at the Physics Laboratory was to develop and patent an X-ray tube with a steel outer covering (the Metalix cylinder), which served to shield people from the dangerous X-rays.[41] In his design for the side of the Metalix tube, Bouwers put a 1922 patent held by

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39. For early uncertainties about the use and interpretation of X-rays, see Bernicke Pasveer, "Kennis van schaduwen: De introductie van de röntgenfotografie in de geneeskunde" [Knowledge through Shadows: The Introduction of X-ray Technology in the Medical Sector], *Kennis en Methode* 12, nr. 4 (1988): 274–94, and "Horen, zien en lezen: Over afbeeldingen in de geneeskunde [To Hear, to See and to Read: About Images in the Medical Sector]," ibid. 17, nr. 1 (1993): 56–77.

40. At the Sankt Georg Hospital in Hamburg, Germany, there is a memorial to radiation martyrs. The central stele, dedicated in 1936, contains the names of 159 physicians, scientists, and others who died as a result of working with X-rays and radium. In the 1920s and 1930s Ed C. Jerman in particular did a great deal to set guidelines. See Richard Terrass, "The Life of Ed C. Jerman: A Historical Perspective," *Radiologic Technology* 66 (1995): 291–98, and the website, http://web.wn.net/~usr/ricter/web/jerman.html.

41. Patent No. 16507, "Röntgenbuis" [X-ray tube], dated 10 May 1927.

Holst to good use. Holst had developed an electrode for discharge tubes with glass sides fused to it, providing the solution to a problem that had bothered technicians during the construction of discharge tubes of all sorts. Discharge tubes were fragile because of tensions arising where various materials that did not expand at equal rates—notably the glass on the side and the metal of the electrodes—came into contact. Tube designers had to make sure that the expansion coefficient of the glass corresponded to that of the materials used in the electrodes.[42] Holst introduced an electrode with a flattened piece of ferrochrome smelted into the glass. Bouwers proved that this combination of materials satisfied the requirements placed upon the Metalix tube. Because the greater part of the tube's side was constructed of metal, a lead layer could be welded directly onto the tube, deflecting the rays through a window designed for that purpose. The technology devised by Bouwers sharply reduced tube users' risk of exposure to dangerous radiation.

Although the metal side of the Metalix tube was a useful innovation, the basic technology still relied on Coolidge's patent. Bouwers cleverly managed to get around the Coolidge patent, which was based on a high-vacuum pressure tube, by filling the Metalix tube with helium gas until it reached a pressure of at least 1/1000 millimeter of mercury. Bouwers also found that the helium filling produced unexpected positive side effects: it avoided electrical charging on the inner side of the gas balloon; it created an effective line focus (that is, the anode of the X-ray tube); and it generated a larger output of X-rays for a given energy input.[43]

In the 1920s GE was aggressively using the courts in trying to protect its Coolidge patents and its monopoly on the American market. When American radiologists, unhappy with the high costs of the Coolidge tubes, began to import the less expensive Metalix tubes, GE claimed patent infringement. Bouwers emphasized the self-protecting qualities of the Metalix, whereas the GE researchers defended the Coolidge patent against European firms like Philips and American firms like Westinghouse by focusing on the extent of

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[42] Wybe Oosterkamp, a scientist in the X-ray department of the Physics Laboratory, gave details in his doctoral thesis of the problems that arose when the tubes were exposed to temperature variations during use; see J. *Problemen bij de constructie van technische röntgenbuizen* [The Problems Encountered during the Construction of Technical X-Ray Tubes] (Delft, 1939).

[43] PCA/NL 560 X-ray. In a letter to C. H. F. Müller, 28 May 1925, Holst gave a clear explanation of the characteristics of the helium-filled tube. Siemens, which held the European rights for the Coolidge patent, was critical of Bouwers's approach. In a highly confidential report, 4 Oct. 1927, Siemens specified its complaints. In the end, this conflict was resolved diplomatically in order to avoid incurring high legal costs.

the vacuum in the tubes.[44] GE lost this battle. As one historian has explained, "GE proved that the Metalix and other such tubes were, in fact, high vacuum tubes, but the courts ultimately judged the degree of vacuum in a tube to be unpatentable."[45]

For Philips and Bouwers the success against GE was important because they could continue the development of the Metalix. For Bouwers, however, the vacuum issue was less important than the evidence of user protection. The discussions in the journal *Radiology* and the positive experiences of users confirmed that the protective properties of the Metalix were greater than those of other tubes. In the years following the invention of the Metalix, Bouwers regularly gave presentations at congresses in order to explain the tube and its characteristics, beginning with the 1924 meeting of the Dutch Physicists Society.[46] The international scientific and industrial world enthusiastically received the Metalix tube. The tube was exhibited to interested industrialists at large international exhibitions, such as the one held in Stockholm in 1928, where reporters viewed the Metalix tube as the only new invention of the show.[47]

Both industrial delegates and doctors reacted positively to the tube's features. A Utrecht physician, B. J. Van der Plaats, described his experiences with the Metalix in a letter. By March 1927 he had purchased eight Metalix tubes that he used for some two thousand radiography transparencies taken for diagnostic purposes. He was particularly impressed by the protection that the tubes provided against escaping rays, and he had exchanged all his Coolidge tubes for Metalix tubes.[48] The tube's merits emerged in technical performance and safety tests carried out by independent experts, who found that the Metalix tube scored highest when compared with other X-ray tubes equipped with radiation protection.[49]

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44. In "The Life of Ed C. Jerman," Terrass analyzes the discussion held in 1929 by Bouwers, Jerman, and others (mostly users of the Metalix) in *Radiology*, the international journal of radiology.

45. Terrass, "The Life of Ed C. Jerman," quotes Zed Atlee, excerpt from letter to E. R. N. Grigg, cited in E. R. N. Grigg, *The Trail of Invisible Light* (Springfield, Ill., 1965), 158.

46. The presentation was published as Albert Bouwers, "Een nieuwe röntgenbuis" [A New Kind of X-ray Tube], *Nederlands Tijdschrift voor Natuurkunde* 4 (1924): 173–79 (a journal for physicists).

47. PCA 882 Germany C. H. F. Müller A.G. See also Alto Brachner, et al., *Röntgenstrahlen. Zum 100: Jubiläum der Entdeckung der X-Strahlen. Entdeckung, Wirkung, Anwendung* [100 Years of X-Rays: Invention, Working, Use] (München, 1995), 87; PCA/NL 560 X-ray.

48. PCA/NL 650 X-ray.

49. PCA/NL 560 X-ray, PCA 882 Germany C. H. F. Müller A.G., and PCA/NL 560 X-ray.

Despite the positive impression made by Bouwers's innovation, the Metalix tube was not without problems, and Philips had received complaints from a number of doctors about the tube's function in practice. In a 1925 letter two Swedish physicians described their experience with the Metalix tube. Their initial achievements with the tube were impressive; it made high-quality photographs and provided sufficient protection against undesirable radiation. Their main criticism concerned the tube's durability: in use, Metalix tubes quickly broke down. Haver Droeze, a Philips employee, lodged a similar complaint during a trip to Indonesia, attributing the tube's failure to the excessively high charge peak.[50] Most of the technical defects arose from faults in the connection between the ferrochrome and the protective shield on the glass side of the tube or from leakage of the helium gas.

These specific concerns presented Holst and Bouwers with a wholly new problem, one that had consequences for the research culture in the X-ray department. Philips personnel, although used to producing large quantities of electric light bulbs, had not previously encountered specific customer demands for product improvement.[51] Although Bouwers was a successful researcher, he could not find a workable resolution to every customer complaint. Medical people were recruited who, with their specific knowledge, were able to support Bouwers and make important contributions to his research. A Dr. Daan, a specialist in radiology, joined the Physics Laboratory in 1928, concentrating on research related to lung examination. Gerardus J. Van der Plaats, the younger brother of B. J. Van der Plaats, replaced him in 1930.[52]

Gerardus Van der Plaats's primary employment was at a hospital in Eindhoven (and from 1936 at a hospital in Maastricht). He worked part time as medical advisor at Philips and did research at the Physics Laboratory, using the results to produce a doctoral thesis in 1938 on the treatment of skin carcinomas with X-ray radiation.[53] Van der Plaats's job at the hospital enabled Bouwers to maintain close contact with the medical sector. Bringing medical specialists into the Physics Laboratory was a new step for Philips, actively involving

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[50] Both in PCA/NL 560 X-ray.

[51] Blanken, *History of Philips Electronics*, chap. 1.

[52] A. Daan, "Over de beteekenis van de Röntgenbuis met draaiende anode voor de Longröntgenographie" [On the Significance of the X-ray Tube with a Revolving Anode for Lung Radiography], *Nederlands Tijdschrift voor Geneeskunde* 74, nr. 15 (1930): 1873–85; Heijstraten, "G. J. van der Plaats." Many years later, in 1955, Van der Plaats became professor of radiology in Groningen.

[53] Gerardus J. van der Plaats, *Over de behandeling van huidcarcinomen met röntgen bestraling volgens de röntgenkaustiekmethode* [about the treatment of skin disease with X-ray technology] (Utrecht, 1938).

users from the medical sector in the innovation process.[54] The Metalix tube first became an integral part of any piece of equipment for use by doctors at the end of 1928, when a portable X-ray appliance was produced, complete with the appropriate cables and a separate transformer. Doctors could literally use it in the field to establish whether or not bones had been broken.[55]

Problems in the X-Ray Department

The years around 1930 proved to be decisive for the Physics Laboratory's innovations in X-ray technology.[56] After the Metalix tube went into production, Bouwers and his assistants received many complaints, most of which were attributable to the tube's inherent technical deficiencies. Dealing with those complaints was time-consuming and expensive. Bouwers could not automatically convert his scientific discoveries into flawless end products. Nor were the problems purely technical: Philips had distribution difficulties as well.

The marketing of Metalix tubes was disappointing. The German company Müller tried to make use of the Philips manufacturing method to produce and market its own "Selbsschutsröhre" (shielded tubes), mounting an aggressive campaign even though the Müller tubes were inferior to the Metalix tubes.[57] Philips sales representatives were unprepared for strong competition and lacked an organizational marketing strategy for X-ray tubes. Müller, by contrast, had an efficient marketing organization. Philips had been locked in patent exchange negotiations with Müller since the early 1920s and had gained a financial stake in the German firm. Despite its sound marketing strategy, Müller fell into financial difficulties, and in 1927 Philips finally took over the German company.[58]

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54. This case supports the idea that the influence of users was essential in the success of the instrument innovation process; see Eric von Hippel, "The Dominant Role of Users in the Scientific Instrument Innovation Process," *Research Policy* 5 (1976): 212–39.

55. From *X-Ray Research and Development: A Selection of the Publications of the Philips X-ray Research Laboratories from 1923–1937* (London, 1937), 107. This combination was commercially available from 1928 onward.

56. PCA/NL 560 X-ray Reports, Overview of the Metalix Situation in 1926.

57. The tension between the two companies emerges clearly from the various relevant archival documents; see PCA 882 Germany C. H. F. Müller A.G. Various tests showed that the Metalix tube was superior to the Müller tube. See P. van Vliet, *De Geschiedenis van Philips' Röntgen deel 3* [The History of Philips X-ray Equipment, part 3] (Eindhoven, 1975), PCA Internal Manuscript and PCA/NL 560 X-ray Reports.

58. PCA 882 Germany C. H. F. Müller A.G. At the time of the takeover, there was another company interest at stake. Philips was also endeavoring to create a

In the years after the acquisition, a structure was set up to streamline the exchange of products and knowledge between the two companies. On June 28, 1928, representatives of Philips and Müller proposed monthly meetings to discuss technical and scientific issues. Bouwers, on behalf of Philips, took part in many of these *Erfarungsaustausch-Konferenzen* (Conferences for the Exchange of Experiences), where researchers from the two firms attempted to resolve differences of opinion on technological and scientific issues, sharing information through a series of subsequent protocols.[59] One of the most striking agreements was that the companies would coordinate technological progress as much as possible, requiring major technological innovations to be discussed first at the meetings. Müller continued to use its own name, advertising Philips's products under the name of C. H. F. Müller AG. Various brochures appeared in which Müller recommended the Metalix tube to its clients and users of the Metalix testified to their positive experiences with the Metalix.[60]

Müller was known worldwide as a "special factory for X-ray tubes," but it had no tradition in industrial research. During an X-ray department meeting, the participants decided to separate the manufacturing and research sides of the business.[61] Shortly after the takeover of Müller, it had been decided that research into X-ray tubes and equipment would be done at the Physics Laboratory in Eindhoven and product manufacturing would be done at the Müller plant in Hamburg. From an overview of the tubes manufactured, however, it becomes clear that Philips was still producing X-ray tubes in Eindhoven as well as in Hamburg.[62] At the same X-ray department meeting, Anton Philips, Holst, and Bouwers, among others attending, decided that, because of Philips's success at X-ray congresses, it was necessary to have separate laboratories with construction and demonstration divisions. It was stipulated that certain of the Eindhoven employees would travel to Hamburg several times a year to share experiences.

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position for itself within the German radio market through Müller's large radio tube factory. See Blanken, *History of Philips Electronics*, 225.

[59] PCA 882 Germany C. H. F. Müller A.G., directors' policy discussions, 1925–1929.

[60] Deutsches Museum, München. Firmenschrift C. H. F. Müller A.G. (internally published): *Die Röntgen-Untersuchungen in der Industrie mit dem Strahlen- und Hochspannungsicheren Makro Metalix Apparat: Die Röntgenmakroskopie in der Materialuntersuchung* (Hamburg, 1933); and *Gutachten-Sammlung über Müller-Media Metalix Röhren* (Hamburg, 1928).

[61] PCA/NL 560 X-ray discussions.

[62] PCA/S 657 X-ray miscellaneous. Overview of the X-ray field carried out by the lawyer, Mr. H. P. Linthorst Homan, of the Secretariat, dated 24 Jan. 1937.

From 1930 onward, X-ray equipment in Eindhoven was manufactured in the Equipment Factory, comprising several buildings that housed various Philips manufacturing departments, including a division for receivers, a chemical group, and the X-ray group.[63] Bouwers and an engineer named Roeterink led the X-ray group. Because of technical problems encountered during manufacturing and in usage, Philips decided in 1937 to reintroduce the Pilot Plant. Roeterink, who was in charge of pilot manufacturing, ambitiously announced that his department would ensure that no product would be mass produced until the company was 100 percent certain that it was ready.[64]

Overseas Markets for Philips X-Ray Technology

Philips's involvement in the X-ray market was not limited to Europe; policy for the United States was frequently debated within the company. In 1928 Bouwers visited the United States, where he made quite an impression.[65] At the Congress of the Radiological Society of North America, held in Chicago, he and the radiologist Arthur Compton of the University of Chicago were awarded medals for their contributions to radiology research.[66] While in the United States Bouwers visited the laboratories of Western Electric, Westinghouse Electric, the Bureau of Standards in Washington, GE, Chicago University, and various hospitals. From his report of the trip, it is evident that there was great interest in the Philips Metalix tube, and five years later, in 1933, the "Philips Metalix Corporation, New York," was established. From then on, Philips also produced X-ray tubes in America. Sales, however, were disappointing. In America Philips faced sharp competition, notably from GE, which used Coolidge's and other important patents aggressively in a defensive strategy.[67] Philips's initiative to enter GE's market with X-ray technology indicates that GE had good reason to keep an eye on Philips, which had expanded its facilities in electric lamps, X-ray technology, and radio during the 1920s and, together with Siemens, became one of GE's biggest overseas competitors.

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63. PCA/NL 322 Equipment.

64. PCA 726 the Pilot Plant, a report of discussions that took place on 20 and 22 July 1937.

65. PCA/NL 560 X-ray.

66. PCA/NL 560 X-ray. Edwin C. Ernst, M.D., president of the Radiological SOC, reported on the event in a letter of 22 Dec. 1929.

67. See Leonard S. Reich, "Lighting the Path to Profit: GE's Control of the Electric Lamp Industry, 1892–1941," *Business History Review* 66 (Summer 1992): 305–34.

Philips was not successful in introducing its X-ray tubes in the United States, partly because the company lacked the necessary sales channels and partly because of the GE strategy. The major problem, however, was that the Metalix tube was simply not compatible with X-ray tubes without a metal shield. Both designers and users of X-ray tube frames were confronted with difficulties with the Metalix that Physics Laboratory researchers were unable to resolve satisfactorily. On November 1, 1938, Philips reorganized its U.S. plant, but even after reorganization, the company results were not promising.[68] Europe remained Philips's most important market for the Metalix tube, and it was only after the Second World War that Philips put more sales effort into its X-ray products for the American market. Philips reorganized its entire company structure and established the Philips Medical Systems Group, which became more successful in the United States.

The Innovation Process and Tensions within the Physics Laboratory

In the prewar years Bouwers developed several new X-ray products. The reactions of certain former Philips and Physics Laboratory employees show that his inventiveness often worked against him. For instance, Frits Philips, the oldest son of Anton Philips and a member of the Board of Directors at the end of the 1930s, once said in an interview:

> Bouwers was, of course, a remarkable figure who had enormous vision and who was able to quickly create things, but there were always problems. For example, he would come up with a new kind of tube that was virtually impossible to reproduce, but whenever a congress came up he did know how to present the product convincingly. However, after that, the factory would be in trouble.[69]

Despite Holst's attempts to create unity through a shared research culture, Bouwers's individual behavior was clearly a source of ten-

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[68] PCA 75:8 Orco. The Orientation Commission (Orco) was created in 1931 to coordinate the various issues and interests of all the different Philips laboratories and factories. Directorate delegates attended the Orco meetings, and members of the commercial divisions represented the patent departments, while Holst or one of his staff members such as Bouwers, or both, would represent the Physics Laboratory. At the Orco meeting of 4 Sept. 1939, the matter of producing Philips equipment in America was raised.

[69] PCA 181.2 A to Z, interview with Frits Philips, 20 Nov. 1973, translation by author. This picture was confirmed and reinforced in an interview: PCA 181.2 A to Z, interview with Wim Hondius Boldingh, 4 Dec. 1962.

Albert Bouwers (1895–1972). Reproduced courtesy of the German Röntgen-Museum, Remscheid, Germany.

sion. Bouwers had considerable independence, but he could at times be rather obstinate in claiming his intellectual freedom.[70] He was convinced, for example, that using oil as an insulation medium for X-ray tubes was useless. In a meeting of July 4, 1938, it emerged that this had given rise to internal conflict at Philips:

> the principle that has continually predominated, i.e. of not using oil, has led to one-sided development which, because of the requirements laid down by the factory, does not seem to be entirely technically warranted. The market is increasingly crying out for

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[70] PCA 181.2 A to Z, interview with J. W. Oosterkamp, 8 Oct. 1973.

> equipment or tubes that are first and foremost reliable: it is not the case that the outward appearance of such equipment is found to be more important than the functioning aspect.[71]

When the factory people complained that Bouwers misused his freedom, Holst had to cope with the problem and try to find a balance between Bouwers's creative impulses and the factory managers' demand for consultation about technical features of X-ray tubes.

A second reason for the tension within the Physics Laboratory was less personal and more structural, caused by the complex nature of industrial research. As the quotation indicating that "the factory would be in trouble" underlines, it was vitally important that the Physics Laboratory and the factories, on the one hand, and technology and the market, on the other hand, be as well attuned to each other as possible in order to put technically and commercially successful products on the market. The period of diversification at the Physics Laboratory required not only technological expertise but also restructuring of the complicated process of innovation. Philips accepted that Physics Laboratory research was sometimes a long-term effort and that there was no guarantee of quickly recouping initial investments. Philips's staff, including Holst (who as the research division's director was responsible for the research part of Philips's innovation process) tried to reduce these risks. Holst constantly reevaluated the scope and nature of the in-house research program. He was always aware of the constraints of the industry concerning product development. He put it thus: "We have always looked at the field in which we found ourselves at the time and have always gradually enlarged this field. It was not possible to devote sufficient attention to making new inventions because all available resources had to be concentrated on the articles we were already manufacturing."[72]

The Physics Laboratory researchers did not operate in scientific isolation. Philips accepted the return of its most gifted scientists to the universities, a price the company paid for the ability to publish in scientific journals, to participate in colloquia, and to join international conferences. Several Physics Laboratory scientists became full-time professors, and in 1930 Holst himself accepted a chair at Leiden University.[73] The contacts he and his other former laboratory researchers maintained in the academy enabled Holst and his re-

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[71] PCA 75: 8 Orco, file 6, translation by author.

[72] Holst in the "Minutes of a meeting of the board of senior managers and company secretaries, of 8 October 1928" PCA. Quoted from Blanken, *History of Philips Electronics*, 291–92.

[73] In his inaugural speech, he reflected on the specific role of an industrial laboratory: Holst, *Industrielaboratoria*.

searchers in the Physics Laboratory to access the universities as a source of knowledge. Moreover, Philips successfully influenced the curriculum of its future employees. The urgent need to combine physics training with practical skills provided the occasion for Philips to insist on the creation of a new Applied Physics curriculum at the Delft University of Technology in 1930.[74] The course proved its value to Philips, which hired nineteen of the seventy-nine physics engineers whom Delft graduated before the Second World War.

Holst expected scientific specialists like Bouwers to understand certain features of modern technology and to find solutions to scientific problems. Holst's organization, with its close relations to the Dutch universities, provided Philips with a source of up-to-date knowledge in X-ray and other complex technologies. On the other hand, Holst did not allow individual Physics Laboratory researchers complete freedom of choice in research topics. The company's leaders reached a consensus on the direction of new invention. Holst maintained that it was not the researchers' but rather the company's task to identify promising new technologies.

Internal Struggles and Business Losses

Bouwers clearly struggled with Holst about research policy, and he was one of the few who succeeded in breaking free from Holst's organizational structure and creating for himself a high degree of autonomy within a department that had grown rapidly over the years. Termed the "grand seigneur" by one of his staff members, Bouwers managed, through his creativity and his obstinacy, to leave his mark on the X-ray department.[75] Bouwers's individuality is illustrated in a comment by a researcher at the X-ray laboratory that "he was the only person at the laboratory who had a secretary": "Holst did not require one. He had two girls . . . to take care of all the administration for him but he really did not like having secretaries. Van der Pol [another Physics Laboratory group leader] didn't have a secretary

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[74] For Philips's role in the history of Applied Physics at the Delft University of Technology see also Adolph F. Kamp, ed., *De Technnische Hogeschool te Delft, 1905–1955* ('s-Gravenhage, 1955), 281–83; R. Kronig, "De opleiding in de technische natuurkunde in Nederland," *Nederlands Tijdschrift voor Natuurkunde* 37, nr. 7 (1971): 186–88; Peter Aarts, Wim Dries, and Fons Spierings, "Apparatenbouwers of wetenschappers: De eerste natuurkundige ingenieurs," *Intermediair* 17, nr. 36 (1981): 55–63.

[75] PCA 181.2 A to Z, interview with H. C. Burgers, 20 April 1973.

Table 1 Investment in the X-Ray Department, Eindhoven, 1923–1930 (in Dutch Guilders, *fl*)

Buildings and laboratory equipment	404,970
Buildings and factory equipment	243,069
Laboratory expenses	1,212,000
X-ray business losses	340,000
Supplies on Dec. 31, 1930	1,600,000
Total (rounded)	3,800,000

Source: PCA 882 Germany C. H. F. Müller A.G., X-ray department investments in Eindhoven, 1923–1930.

either, but Bouwers did, and it seemed that he had also managed to cut loose via Anton Philips."[76]

Bouwers's creativity was undeniable, but the steady barrage of his new ideas and inventions seriously hampered the manufacture and marketing of X-ray equipment at Philips. Moreover, the department was perpetually in financial difficulty.[77] The total investment in the X-ray department between 1923 and 1930 amounted to 3.8 million Dutch guilders (see Table 1). These figures illustrate considerable investment in the X-ray department, even though the department had been running at a loss for years. The overview given in Table 2 confirms the difficult financial situation. The Laboratory's work in the 1930s included five main research areas: light and the production of light (including gas discharges); electrotechnology and radio (including acoustics); chemistry (including metallurgy); X-ray investigation; and mathematics and mathematical physics.[78]

It is difficult to establish the relative value represented by Table 2, because no precise Physics Laboratory expenses and turnover figures remain from this period. From an overview of Physics Laboratory costs, 1931–1941, it is apparent that on average the X-ray department recovered some 10 percent of the Physics Laboratory expenses.[79]

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76. PCA 181.2 A to Z, interview with A. Th. van Urk, Nov. 1973, translation by author. The comment made by Van Urk to the effect that Bouwers had created for himself a special position at the Physics Laboratory and had managed to cut loose from the fixed hierarchy via Anton Philips was something various former employees confirmed in a number of different interviews. See PCA 181.2 A to Z, interview with Wybe Oosterkamp, 8 Oct. 1973; PCA 181.2 A to Z, interview with H. C. Burgers, 20 April 1973; PCA 181.2 A to Z, interview with H. Rinia, 23 May 1973; PCA 181.2 A to Z, interview with Jansen Gration.

77. PCA 882 Germany C. H. F. Müller A.G. X-ray department investments in Eindhoven, 1923–1930.

78. See W. de Groot, "Scientific Research of Philips' Industries from 1891–1951," in *An Anthology of Philips Research* [1891–1966], ed. Hendrik B. G. Casimir and S. Gradstein (Eindhoven, 1967), 15–59.

79. PCA/NL 608.

Table 2 The X-Ray Department's Financial Situation, 1925–1938

Year	Total X-Ray Tubes (*fl*)	Value of X-Ray Tubes (*fl*)	Quantity of Equipment	Value of X-Ray Equipment Turnover (*fl*)	Total Losses (*fl*)
1925	425	—	—	—	—
1926	784	—	—	—	—
1927	967	—	—	—	—
1928	11,280	2,357,853	425	3,963,599	—
1929	12,280	3,009,487	784	5,357,459	—
1930	12,966	3,214,284	967	6,668,691	—
1931	11,103	2,799,480	11,280	6,172,663	—
1932	7,850	1,955,703	12,280	4,824,672	540,000
1933	6,847	1,684,641	12,966	4,771,460	991,119
1934	6,367	1,728,013	11,103	4,722,758	876,999
1935	6,102	1,666,522	7,850	4,909,889	892,184
1935/36[a]	—	—	—	—	891,034
1936/37	—	—	—	—	660,104
1937/38	—	—	—	—	1,253,048

Source: PCA/S 657, miscellaneous X-ray division information. Included with report of H. P. Linthorst Homan, lawyer employed by the Philips Secretariat, 14 Jan. 1937. The turnover figures from 1928 onward include those for Müller.

[a] The total losses of the last three years are taken from: PCA 815.1 X-ray, document from 8 Sept. 1938.

Only scanty details remain in the Philips Archives about the number of personnel and the quantity of tubes manufactured in the early days of the X-ray department. However, some figures provide information concerning the comparative scale of the Physics Laboratory and the X-ray department. In 1931 the Physics Laboratory employed 55 doctors and engineers, 124 assistants, and 135 people in the various workshops. There were 5 doctors and engineers working under Bouwers, 18 assistants, and 24 personnel active in the workshop.[80] These percentages and numbers show that the costs incurred by the X-ray department constituted a substantial portion of total Physics Laboratory expenses.

Despite the lack of financial success of X-ray products, Bouwers was able to defend his position in Holst's organization. It is hard to determine exactly what motives played a part in the decision to continue research into X-ray tubes and equipment. In the early stages, when the X-ray department was still being established, Bouwers, Holst, and Anton Philips would have found it hard to assess the future prospects of a technology new to Philips. But at an X-ray depart-

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[80] PCA/NL 608 Overview of the Physics Laboratory personnel situation, 1 June 1931.

ment meeting held in 1928, at a time when the department was losing money and not contributing anything in financial terms, these three men all defended the necessity of continuing X-ray development.[81] They were all much more interested in the technology than in the department's financial predicament. Anton Philips himself attached great importance to X-ray technology because of its importance for lung research. He even had his own personnel examined with the help of X-ray equipment.[82]

One might conclude that the opportunity given to researchers in the X-ray department to pursue their research activities—despite the financially difficult situation—was due to Anton Philips's personal involvement and support for Bouwers's activities.[83] Certainly Anton was interested in the long-term prospects of X-ray technology for his company, and he realized that losses in the early phase might generate profits in the future. However, because of limited knowledge about the new market for X-ray technology, planning was almost impossible for Philips in this area. The progress of X-ray investigations depended on the ability of individuals like Anton Philips to command resources and to direct them in unconventional and surprising directions.[84]

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[81] PCA/NL radiology discussions.

[82] See the highly romanticized Anton Philips biography by Piet J. Bouwman, *Anton Philips, De mens de ondernemer* [Anton Philips, the Man and the Entrepreneur] (Utrecht, 1966) and Blanken, *History of Philips Electronics*, 228. Anton's interest in the subject was evident, for example, in a letter of 27 Nov. 1934, which stated the following: "In connection with the gathering of statistical material relating to the results of medical research being conducted with radiation, Dr. A. F. Philips has requested the cooperation of all staff members. Dr. G. C. E. Burger, head of the Health Service, therefore requests that each of the scientific researchers at the Physics Laboratory consent to having X-rays done." PCA/NL 560 X-ray work, translation by author.

[83] Opinions are divided on the reasons that ultimately persuaded Anton Philips to take this step. Blanken, in *History of Philips Electronics*, praises Anton Philips for his strategic insight. Wim Wennekes, who refers to Anton as a cool and calculating rationalist in his publication on the founders of Dutch industry, *De aartsvaders: Grondleggers van het Nederlandse Bedrijfsleven* [The Patriarchs: Founders of Dutch Industry] (Amsterdam, 1993), was, it would seem from the following quotation (p. 319, translation by author), not so convinced of Anton's humanitarian motives: "To create propaganda for X-ray research A. F. Philips used his own company as a *showcase*. He had the entire staff X-rayed and in his results, he made it known that all the tuberculosis cases within the organization had been identified; that the contamination risks had been reduced to the minimum and that the numbers of lost working days had also been drastically reduced. Public opinion, the government and the country's armed forces thus warmed to the idea of national X-ray screening."

[84] As Joseph A. Schumpeter wrote in *Socialism, Capitalism, and Democracy* (London, 1943), entrepreneurship (bringing new technology into the economic system) has been the province of bold individuals, because in a world of limited knowledge it is necessarily an unpredictable and extrarational activity.

Bouwers's scientific and technological success was insufficient; over the course of time he was expected to resolve organizational and financial problems as well as technological ones. This caused tensions in the Physics Laboratory, as Holst tried to reduce risks. Bouwers, however, insisted on his intellectual freedom and sought the support of Anton Philips, even if this involved going behind the back of Holst, his immediate superior.[85] Anton turned out to be fully prepared to offer the support Bouwers needed. Together they managed to push through this loss-making activity, basing their outlook on the usefulness of X-ray technology on personal expectations.

With this support, Bouwers's X-ray work at Philips continued and, over the years, gained a certain momentum. Aided by the Metalix principle, Bouwers's researchers developed further X-ray appliances in the 1920s for specific uses, for instance by dentists, and several new kinds of X-ray tubes in the 1930s.[86] Bouwers's creativity was reflected in a new discovery in early 1930, when he applied for a patent for an X-ray tube with a metal discharge space constructed along the lines of the Metalix tube but with a rotating anode with bearings and known as the Rotalix. As early as 1898 a researcher named Breton had described the notion of a rotating anode, but no one had ever successfully commercialized the principle.[87] Combining the principles of the Metalix tube and the revolving anode represented a major step forward.[88] The rotating anode lessened potential for damage by excessive heat, because newly cooled sections of the anode kept moving under the beam of electrodes. The new system also made sharper images possible.[89]

The Rotalix was well received by customers, including doctors who used it for lung X-rays. Van der Plaats used this tube for his

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[85] Blanken, in *History of Philips Electronics*, maintains that these reasons for pursuing research probably became known only in the early 1930s. Until then, Anton Philips had not expressed these reasons in so many words.

[86] Wim Hondius Boldingh, *De Geschiedenis van Philips' Röntgen* [The History of Philips X-ray Research] (Eindhoven, 1975), PCA internal manuscript.

[87] J. H. van der Tuuk, "De Rotalix-buis voor Röntgendiagnostiek" [The Rotalix tube in Radiological Diagnosis], in *Philips Technisch Tijdschrift* 3, nr. 10 (1938): 297.

[88] Like the Metalix, the Rotalix became known worldwide; see Brachner, et al., *Röntgenstrahlen Zum 100*, 70; J. H. van der Tuuk, "Röntgenbuizen met draaiende anode" [X-ray tubes with revolving anodes], in *Philips Technisch Tijdschrift* 8, nr. 2 (1946).

[89] A. Daan, affiliated with the Physics Laboratory for a number of years in his capacity as doctor, elucidated this in an article published in 1929 entitled "Over de betekenis van de röntgenbuis met draaiend anode voor de longröntgenographie" [The Significance of the X-ray Tube with a Revolving Anode for Lung Radiography], a lecture given to the Dutch Society of Physicians Specialised in Tuberculosis.

Ph.D. research. However, once again there were a number of technical problems, notably difficulties in carrying away heat through the bearings. Using fine lead powder to "grease" the bearings did not totally resolve the problem. Better designs for ball-bearing construction occurred soon after, but were not actually introduced until 1937.

Most of the new tubes were incremental improvements on the Metalix technology, such as attempts to answer the technical requirements of dentists. Bouwers and his researchers did not restrict themselves to the development of X-ray tubes, however. They also constructed cascade generators for very high tensions, for which Bouwers made use of the latest insights in valve technology. At the Fifth International Congress of Radiology at Chicago in 1937, Philips exhibited a 400 kilovolt generator with an X-ray therapy tube. In 1939, Bouwers developed a million-volt unit for the Antoni van Leeuwenhoek hospital in Amsterdam.[90]

Production of X-ray tubes and equipment continued as usual (as much as was possible) after the outbreak of the Second World War. The Physics Laboratory, like all other Philips departments, fell under the supervision of a German director, a *Verwalter*. The Germans decided to export X-ray tubes via Hamburg through Müller. After the bombing of the Philips factory in Eindhoven by the British Royal Air Force on December 6, 1942, the destruction of much of the X-ray department brought production and development of X-ray tubes and equipment to a halt.[91] Bouwers had left Philips earlier that year to join an optical firm in Delft, where he became research director.[92] As soon as Bouwers left the Philips company, the X-ray department again became an integral part of the Physics Laboratory organization.

After the Second World War, Philips shared the popular vision of the promise of industrial research for both the company and society as a whole.[93] Philips reflected the general feeling that the basic sciences could play an important part in the postwar development of industry, and this view was to influence the Physics Laboratory's research program. In this culture, Philips's X-ray research developed into Philips Medical Systems, a world leader in diagnostic imaging

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[90] See Wim Hondius Boldingh, "Technical Evolution of Roentgenology," *MedicaMundi* 16, nr. 1 (1972): 9–17; J. H. van der Tuuk, "Een röntgenbuis voor 1 millioen volt" [A 1-Million-Volt X-ray Tube], in *Philips Technisch Tijdschrift* 4, nr. 6 (1939): 161–70.

[91] Hondius Boldingh, *De Geschiedenis van Philips' Röntgen.*

[92] In 1949 Bouwers became Extraordinary Professor at the Delft Engineering School. He titled his inauguration speech "Instruments of this Century."

[93] In the United States, Vannevar Bush promoted basic or pure (scientific) research in his famous 1945 essay, *Science the Endless Frontier: A Report to the President* (Washington, D.C., 1945).

and patient monitoring. In this part of the Philips company, Physics Laboratory research and development continues to support products. Researchers are working on X-ray diagnostic technologies and several digital imaging technologies.[94]

Epilogue and Reflections

I have shown that Philips's original interest in X-ray technology stemmed not from the company's researchers, but rather from Dutch physicians and X-ray technology users in the medical field, who were eager for a Dutch presence in radiology products. Subsequently Holst initiated his own research. The most important X-ray product developed by the Physics Laboratory was the Metalix tube, a discovery made by Bouwers. Although Bouwers built upon existing X-ray technology (Coolidge tube principles), the Metalix tube represented a genuine innovation in radiation protection. However, it is unclear if the X-ray department was successful under Bouwers. Bouwers had some scientific and technological success, but he needed the personal support of Anton Philips's own expectations of X-ray technology—based on personal intuition—to overcome Holst's caution and to support unprofitable research ventures.

Holst maintained his opinion that the Physics Laboratory was first a servant of the company, and he tried to balance scientific research and the company's strategic goal of being a mass producer of consumer products. An examination of the history of the X-ray department also shows that the ideas of the leading individual industrial researcher were not always in line with those of his research director. At the time, the Philips research laboratory lacked a clear structure to define the relative powers of Holst and Bouwers. Instead, their struggles led to an ad hoc structure, which allowed Bouwers's X-ray research to prosper.

Ultimately, however, it was the entrepreneur Anton Philips himself who was willing to invest in the X-ray project for the long term. We can conclude that Philips's X-ray research activities were not so much about transforming scientific and technological knowledge into concrete products as about a complex coordination of scientific research, product development, and organizational and cultural elements.

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[94] Hans M. Barella, "ATL and Philips Medical Systems," *MedicaMundi* 43, nr. 3 (1999): 3–5; Paul, H. Smit, "Philips Medical Systems: A New Force in the Healthcare World," ibid. 45, nr. 3 (2001): 2–6.

In retrospect, we can attribute Bouwers's and Philips's apparently noncommercial decision to continue X-ray research to strategic insight. At the moment of decision they based their predictions on developments taking place in the Physics Laboratory and elsewhere, with the direction of these developments not always clear, guided only by the perception that X-ray technology was a promising field. From the melting pot of science, technology, business, and the market they tried to distill products whose commercial value was not immediately apparent.[95] It was not until after the Second World War that X-ray technology would finally produce positive financial results for Philips.

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95. This borrows a metaphor used by Andries Sarlemijn in "Designs Are Cultural Alloys: STeMPJE Approach in Design Methodology," in *Design Methodology and Relationships with Science*, ed. Marc J. de Vries, Nigel Cross, and Donald P. Grant (Dordrecht, 1993) to indicate that various factors may influence product design.

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