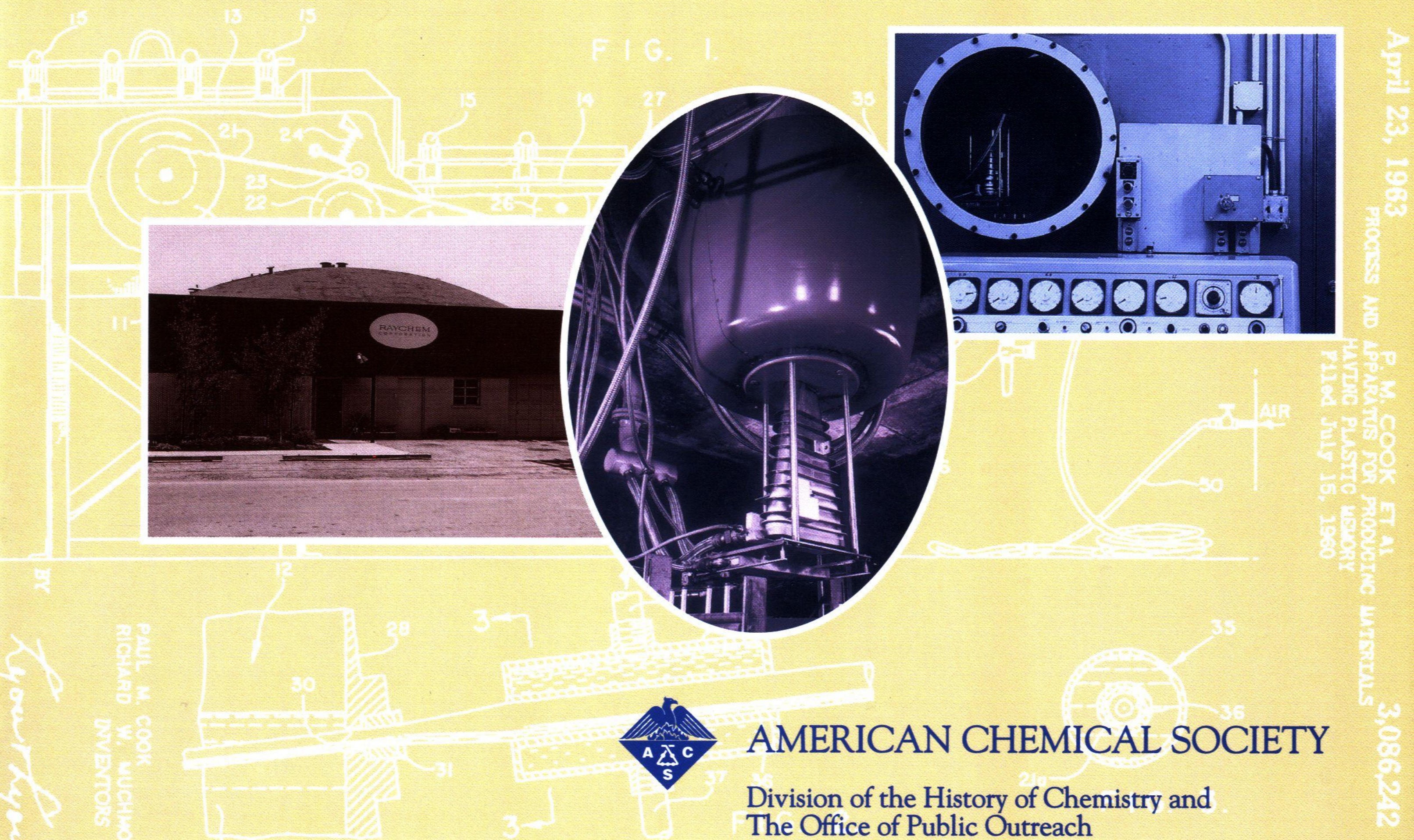
A NATIONAL HISTORIC CHEMICAL LANDMARK

FIRST SUCCESSFUL COMMERCIALIZATION OF RADIATION CHEMISTRY

RAYCHEM CORPORATION
REDWOOD CITY, CALIFORNIA

APRIL 9, 1997



AMERICAN CHEMICAL SOCIETY

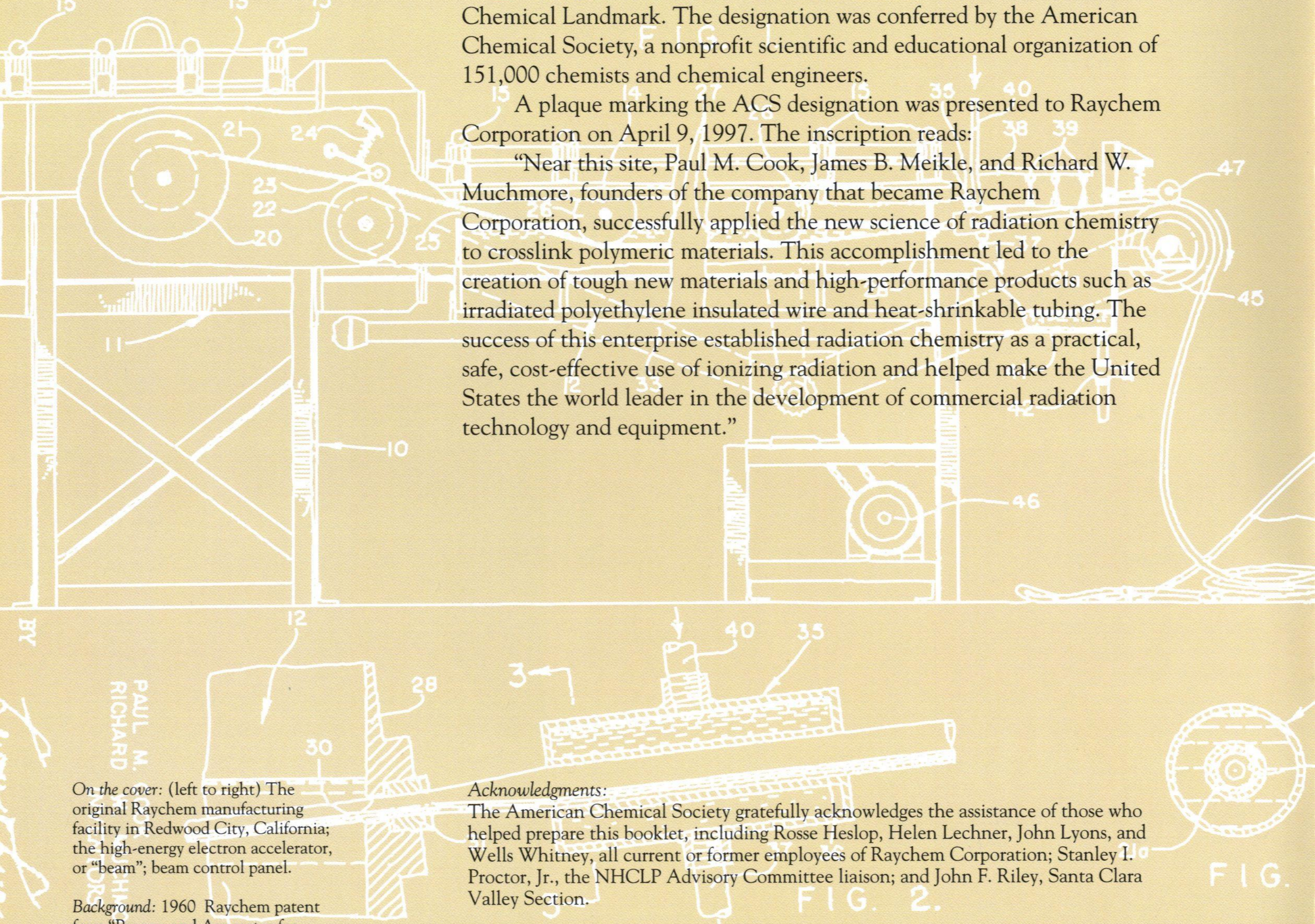
Division of the History of Chemistry and
The Office of Public Outreach

The first Raychem site at 2821 Fair Oaks Avenue in Redwood City, California. The small rectangular building at left houses the original electron beam.

This booklet commemorates the designation of the first successful commercialization of radiation chemistry at Raychem Corporation in Redwood City, California, as a National Historic Chemical Landmark. The designation was conferred by the American Chemical Society, a nonprofit scientific and educational organization of 151,000 chemists and chemical engineers.

A plaque marking the ACS designation was presented to Raychem Corporation on April 9, 1997. The inscription reads:

"Near this site, Paul M. Cook, James B. Meikle, and Richard W. Muchmore, founders of the company that became Raychem Corporation, successfully applied the new science of radiation chemistry to crosslink polymeric materials. This accomplishment led to the creation of tough new materials and high-performance products such as irradiated polyethylene insulated wire and heat-shrinkable tubing. The success of this enterprise established radiation chemistry as a practical, safe, cost-effective use of ionizing radiation and helped make the United States the world leader in the development of commercial radiation technology and equipment."



On the cover: (left to right) The original Raychem manufacturing facility in Redwood City, California; the high-energy electron accelerator, or "beam"; beam control panel.

Background: 1960 Raychem patent for a "Process and Apparatus for Producing Materials Having Plastic Memory."

Acknowledgments:
The American Chemical Society gratefully acknowledges the assistance of those who helped prepare this booklet, including Rosse Heslop, Helen Lechner, John Lyons, and Wells Whitney, all current or former employees of Raychem Corporation; Stanley I. Proctor, Jr., the NHCLP Advisory Committee liaison; and John F. Riley, Santa Clara Valley Section.

The booklet was produced by the Raychem Communications and Design Center and was written by Eric Ahrendt. Photographs courtesy of Raychem Corporation.

CREATING A NEW INDUSTRY

In 1950, the United States government embarked on a search for peacetime applications for atomic energy. The most promising application was the nuclear power reactor, seen as an abundant source of clean energy. To extend the value of reactors to the commercial sector, the government funded research on uses for the radioactive by-products of reactor operations.

As part of that research, the Reactor Development Division of the Atomic Energy Commission sponsored a study at the newly created Stanford Research Institute (SRI) in Palo Alto, California. The purpose of the study, supervised by 25-year-old chemical engineer Paul Cook, was to determine the potential industrial uses of waste fission products—alpha emitters, beta emitters, and gamma ray producers.

The study concluded that there were limited industrial uses for waste fission products. However, as a result of these studies and subsequent experiments conducted by Cook at SRI and elsewhere, he became convinced that radiation could be used to develop new materials for industrial applications. When a reliable, low-cost source of ionizing radiation became available, Cook—with James B. Meikle and Richard W. Muchmore—founded the first company based on *radiation chemistry*, the field of knowledge concerned with the chemical effects of radiation on different materials. Cook and the employees of the company that became Raychem Corporation proved the commercial value of treating and altering the chemical structure of polymeric products in their final form, giving them special properties and characteristics that could not be easily created using any other method.

By successfully commercializing radiation chemistry, Cook achieved three things. First, primarily as a result of the demand for particle accelerators from Raychem and others, the United States took a clear lead in the development of commercial radiation technology and equipment. Second, he developed products that greatly improved the performance of electronics components, electrical insulation, and the world's industrial and telecommunications infrastructure. Third, he created a new industry that today provides jobs to thousands of people all over the world and generates revenues of more than $10 billion annually.

Applying Radiation Chemistry

The beginnings of radiation chemistry can be traced to the discovery of X-rays by Wilhelm Roentgen in 1895 and of radioactivity by Antoine Henri Becquerel the following year. In 1898 Pierre and Marie Curie discovered polonium and radium. By isolating radium in appreciable amounts, they made available a relatively powerful source of high-energy radiation, permitting the study of the chemical effects of radiation on materials.

For decades after these early discoveries, experimenters were limited by the lack of a machine for producing high-energy ionizing radiation. With the advent of particle accelerators in the early 1930s, that limitation was removed, and radiation chemists began examining the effects of radiation on a range of materials.

The Manhattan Project, started in the 1940s as a wartime effort by an international group of scientists led by the United States, greatly stimulated such research. These researchers were motivated by this project to find materials—needed for electrical cables and construction materials used in nuclear reactors—that would resist the effects of atomic radiation. Thus, along with studying wartime uses of nuclear energy, scientists during World War II studied the effects of radiation on the electrical and mechanical properties of plastics.

After the war, significant work with irradiated plastics was done in the early 1950s by Arthur M. Bueche and Elliott J. Lawton at General Electric (GE), who used radiation to crosslink polyethylene in a tape form. Reading about this pioneering work, Paul Cook became convinced that a business based on radiation chemistry could succeed.

From his work on the SRI study in 1950, Cook knew that waste fission products would not work as a source of ionizing radiation for commercial applications. They are an impractical source because the radiation cannot be turned off and on and because it is emitted in all directions, increasing concerns about radiation exposure. Instead of waste fission products, the study recommended using a machine powered by electricity that would generate a readily controlled, unidirectional beam of radiation.

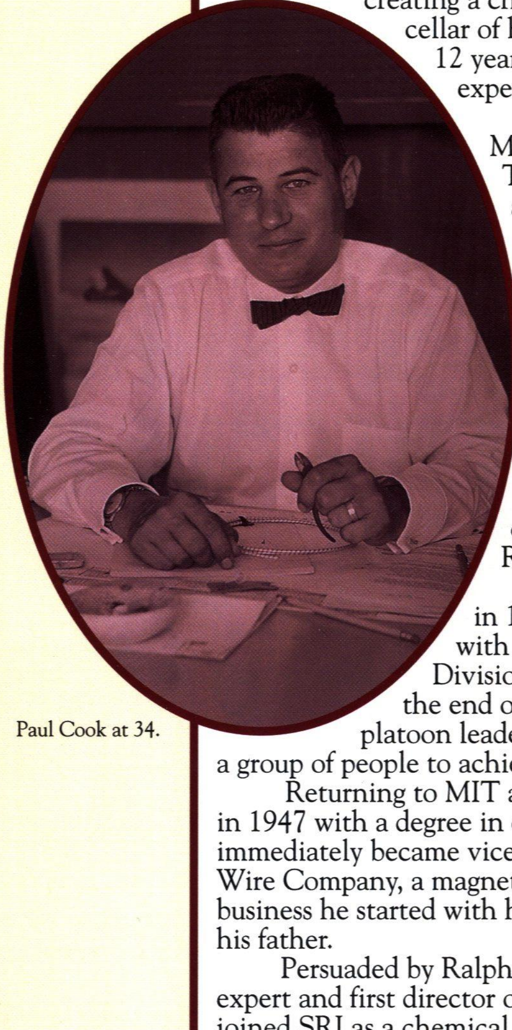
Recognizing a business opportunity in applying radiation chemistry, Cook promoted the establishment of a laboratory at SRI. The Radiation Engineering Laboratory was established in 1952, and Cook became its first head. To begin operations, the lab acquired a large cobalt-60 source to conduct chemical experiments and to sterilize food.

THE MAKING OF AN INNOVATOR

The education and experiences of Paul Cook's youth and early adulthood gave him the knowledge, skills, and personality to pioneer the application of a new technology and make it the foundation of a successful company.

Paul M. Cook was born in Ridgewood, New Jersey, on April 25, 1924. His father was president and chief mechanical engineer for a company he had founded, the Cornish Wire Company. His mother was an energetic woman who encouraged her children's interests in music and art as well as science and technology.

Cook showed an early interest in technology, creating a chemistry laboratory in the cellar of his house when he was 12 years old and conducting experiments.



Paul Cook at 34.

He enrolled at the Massachusetts Institute of Technology (MIT) in 1941, spent two years there, then enlisted in the Army. He was placed in the Army Specialized Training Program and was sent to Stanford University for six months, where he studied mechanical engineering—an added specialty that helped him solve engineering challenges confronting Raychem in its early days.

Cook was sent to Italy in 1944 as a second lieutenant with the 10th Mountain Division and fought there until the end of the war. He became a platoon leader at 20 and learned to lead a group of people to achieve specific results.

Returning to MIT after the war, he graduated in 1947 with a degree in chemical engineering. He immediately became vice president of the Warren Wire Company, a magnet wire manufacturing business he started with his brother, supported by his father.

Persuaded by Ralph M. Krause, a radiation expert and first director of research at SRI, Cook joined SRI as a chemical engineer in 1948. It was there he began the work that led to the first successful commercialization of radiation chemistry.

Paul Cook is active today as chairman of the board of SRI International; chairman of the board of the David Sarnoff Research Center (formerly RCA Laboratories); chairman of the board of CellNet Data Systems; and founder, chairman of the board, and CEO of Diva Systems Corporation, developers of an interactive video-on-demand system.

Giving Polymers New Properties

It has been known since early in the 20th century that various forms of radiation can cause chemical change. By the 1930s, for example, researchers knew that ionizing radiation could be used to sterilize food and pharmaceuticals. However, commercial exploitation of the field was slow because of the lack of a low-cost source of radiation. When GE and others during the 1950s developed reliable and relatively low-cost high-energy electron accelerators, industrial radiation chemistry became economically feasible. Raychem combined the technology with expertise in materials science to develop new products, such as aircraft wire and heat-shrinkable tubing, with new properties for uses in high-temperature and other extreme environments.

The key to the success of Raychem's first products was *radiation crosslinking*, which became the cornerstone technology supporting a worldwide industry. When certain polymers are exposed to radiation, they crosslink and acquire many desirable characteristics, including strength and toughness, abrasion resistance, cut-through resistance, solvent and chemical resistance, improved high-temperature performance, and elastic memory.

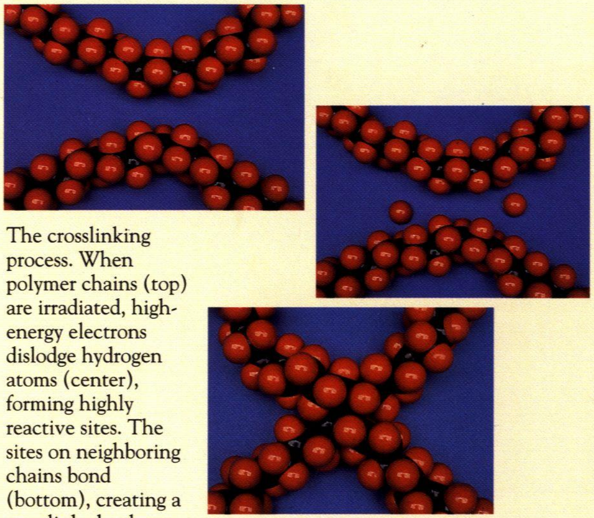
Radiation crosslinking was performed at Raychem's first facility with a rented GE resonant-transformer electron generator, which produces a beam of high-energy electrons. High-energy electron accelerators are used because the beam they generate can be focused very precisely, has a high energy level, and penetrates materials well.

Raychem co-founder Richard W. Muchmore at controls of GE resonant-beam generator.

The structure of a polymer, such as a thermoplastic material, consists primarily of extremely long, very thin molecules in a random arrangement. The molecules are composed of hydrocarbon units strung together in a linear chain, like beads on a string. Crystals form where the molecules come close to each other in an ordered fashion.

During irradiation, electrons from the beam strike and dislodge hydrogen atoms. These dislodged hydrogen atoms eventually form molecules of hydrogen gas, which escape. They leave behind highly chemically reactive (free-radical) sites on the polymer chain.

Free-radical sites on neighboring polymer chains can migrate close together, react, and join to create *crosslinks*—bonds from a chemical reaction between pairs of free radicals on neighboring polymer chains. When crosslinking occurs in multiple sites along and between polymer chains, the polymer material is said to be crosslinked. Control of the radiation dose allows control of the extent of crosslinking.



The crosslinking process. When polymer chains (top) are irradiated, high-energy electrons dislodge hydrogen atoms (center), forming highly reactive sites. The sites on neighboring chains bond (bottom), creating a crosslinked polymer.

The Founding of Raychem

While still at SRI, Cook received permission to start an off-hours business operation to make electronic hook-up wire, which is used to connect electronic components. The business was the Sequoia Process Corporation, a wire and cable manufacturer. When that business became moderately successful, Cook left SRI in 1953 to become its CEO full time. While Cook was at Sequoia, the first attempt was made to produce an irradiated polyethylene hook-up wire, intended to fill a niche for a temperature-resistant aircraft wire.

Cook's tenure at Sequoia was short. He saw a future for using high-energy radiation to develop unique products and wanted Sequoia to pursue it. The man who had a controlling interest in the company didn't agree, and Cook left in 1956.

He remained enthusiastic about the future of irradiated products, and developments in related technology supplied new tools. He learned that GE's X-ray department had just introduced a one-million-electron-volt, five-milliamp (1 MeV, 5 mA) high-energy electron accelerator. Previous one-milliamp generators permitted only experimental work, but the new beam was powerful and sturdy enough for industrial use.

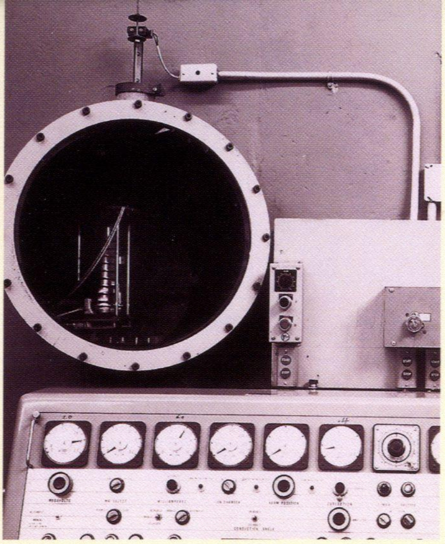
Cook mortgaged his house and scraped together $50,000 in equity capital to rent the very first high-energy electron accelerator GE produced, which was delivered in March 1957 to the facilities for Cook's new company, Irradiated Products, Inc. The new company began in a leased 4800-square-foot building in Redwood City at 2821 Fair Oaks Avenue on January 1, 1957. After two months the company name was changed to Raytherm. In 1960 the company name was changed to Raychem to avoid confusion with the established Raytheon Corporation.

In January 1957, Richard Muchmore and James Meikle joined Cook as co-founders. A manufacturing executive, Muchmore devised equipment and processes to ensure that products to be irradiated could be passed continuously under the high-energy electron accelerator and receive the calculated dose of radiation. His work in manufacturing processing helped turn radiation chemistry into a viable industrial operation. Meikle, an engineer, performed the critical experiments that yielded the compounds, complete with additives, that Raychem irradiated. He determined which materials would respond in desired ways to measured radiation doses and acquire enhanced properties.

To house and shield the high-energy electron accelerator, Cook and associates built an innovative, effective and—at $7000—very inexpensive radiation shell, consisting of hollow wooden walls joined by steel reinforcing rods and filled with sand. Today a radiation shell costs approximately $1.5 million; adjusted for inflation, the cost for the original shell was about $39,000.

By successfully using a high-energy electron accelerator in a production setting for the first time, Raychem proved two things: (1) beams could be rugged and reliable enough for constant industrial use and (2) high-energy radiation could be safe enough for an industrial environment. Raychem's mechanical engineers also made the irradiation process cost-effective for industrial applications by developing innovative production processes, such as high-speed, reel-to-reel, multipass transport systems, to enable very long lengths of wire or tubing to be processed through the radiation zone of a beam.

In the late 1950s, other companies, among them Radiation Materials, Inc., Surprenant Wire and Cable, and Electronized Chemicals Corporation, followed Raychem's pioneering work to develop their own businesses based on radiation chemistry.



Beam tube and control panel for GE resonant-beam generator.

Every new technology has kinks, and Raychem encountered a major one in its first year. Soon after processes had been scaled up for commercial production, the tube in the beam, which generates and accelerates the electrons, failed. Without radiation capacity for 11 weeks, the company had to lay off many employees. Those left took drastic pay cuts, and Raychem nearly went bankrupt. Operations resumed only after a new, working tube—the fifth one GE sent—was installed on Christmas Eve 1957. The company won back its customers and immediately ordered replacement tubes to keep on hand for future emergencies.

In its first year Raychem introduced several products, including:

- A flame-retardant, irradiated polyethylene-insulated hook-up wire.
- A foamed, irradiated, linear polyethylene subminiature coaxial cable.
- A heat-shrinkable, flame-retardant polyethylene tubing—the progenitor of heat-shrinkable tubings and molded shapes.

The light weight and superior performance characteristics of Raychem's irradiated products made them ideal for military applications, because of the severe environmental demands placed on military equipment compared with those placed on commercial equipment. Military contractors were therefore the initial customers for the first products developed through radiation chemistry.

Creating New Products with Elastic Memory

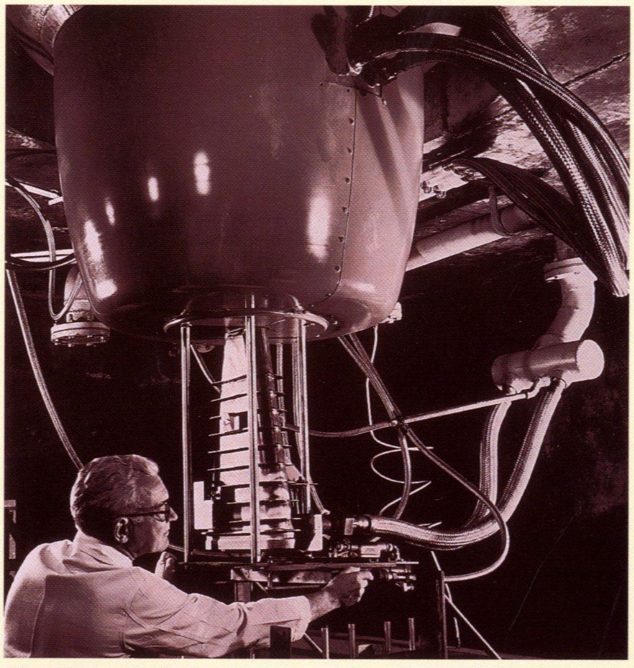
Raychem's work with radiation crosslinking enabled the company to crosslink products continuously in their final form at room temperature, which other methods of crosslinking, such as chemical crosslinking, do not permit. Radiation crosslinking also made possible the commercialization of another important new technology—*elastic memory* for polymer materials. Elastic memory refers to the ability of crosslinked, expanded materials to revert to their original dimensions when subjected to heat.

To create a product with elastic memory, technicians heat a crosslinked polymer compound just enough to melt the polymer crystals. The molten polymer still has structural integrity because its molecules are tied together by the crosslinks, but it has become elastic. Still hot, the polymer is deformed (stretched) by the application of pressure. While in this deformed position, the polymer product, such as heat-shrinkable tubing, is cooled. Crystals reform, thereby locking the structure in its deformed condition. The product is supplied to customers in this form.

To install a product such as heat-shrinkable tubing, the user heats it, melting the locking crystals and enabling the material to return to its original shape. After cooling, the crystals reform and the material is locked in its final form. Even if subsequently reheated, no further change in shape will take place.

This new technology enabled Raychem engineers to design a whole array of new polymer products that were easy to install with heat and that tightly covered a variety of equipment sizes and shapes, thereby protecting materials from moisture, corrosion, solvents, and other harmful environmental elements and processes.

From a start-up venture that opened its doors with three employees in 1957, Raychem has grown into a company with 8500 employees in more than 45 countries. Raychem today produces hundreds of products based on radiation chemistry that in 1996 earned revenues of $1.67 billion in electronics, industrial, and telecommunications markets worldwide.



The GE resonant-beam generator used to produce the first irradiated products.

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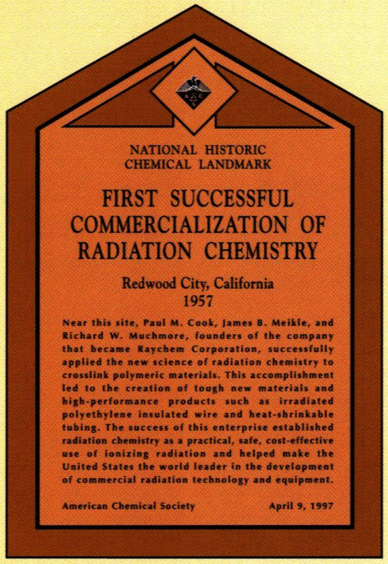
THE NATIONAL HISTORIC CHEMICAL LANDMARKS PROGRAM OF THE AMERICAN CHEMICAL SOCIETY

The ACS National Historic Chemical Landmarks Program recognizes our scientific and technical heritage and encourages the preservation of historically important achievements and artifacts in chemistry, chemical engineering, and the chemical process industries. It provides an annotated roster to remind chemists, chemical engineers, students, educators, historians, and travelers of an inspiring heritage that illuminates both where we have been and where we might go when traveling the diverse paths to discovery.

ACS Historic Chemical Landmarks represent or are closely linked to seminal achievements in the chemical sciences and technologies. A site designation marks the location of an artifact, event, or other development of clear historical importance to chemists and chemical engineers. An historic collection designation marks the contributions of a number of objects with special significance to the historical development of chemistry and chemical engineering.

This program began in 1992, when the Division of the History of Chemistry of the ACS formed an international Advisory Committee. The committee, composed of chemists, chemical engineers, and historians of science and technology, works with the ACS Office of Public Outreach and is assisted by the Chemical Heritage Foundation. Together, these organizations provide a public service by examining, noting, recording, and acknowledging particularly significant achievements in chemistry and chemical engineering. For further information, please contact the ACS Office of Public Outreach, 1155 Sixteenth Street, N.W., Washington, D.C. 20036; 1-800-227-5558, Ext. 6293.



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American Chemical Society April 9, 1997

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