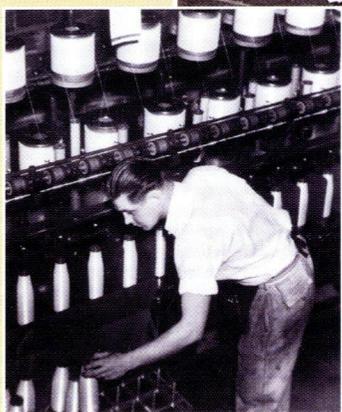
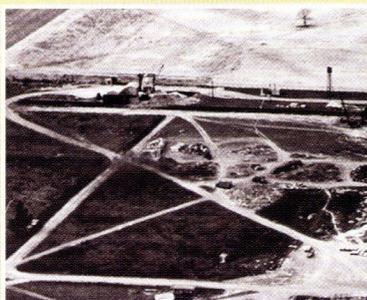


A NATIONAL HISTORIC
CHEMICAL LANDMARK

THE FIRST NYLON PLANT

DUPONT
SEAFORD, DELAWARE

OCTOBER 26, 1995



AMERICAN CHEMICAL SOCIETY

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



DuPont plant, Seaford,
Delaware, 1939.

This booklet commemorates the designation of the DuPont Nylon Plant in Seaford, Delaware, as a National Historic Chemical Landmark. The designation was conferred by the American Chemical Society (ACS), a non-profit scientific and educational organization of 150,000 chemists and chemical engineers.

A plaque marking the ACS designation was presented to the plant on October 26, 1995. The inscription reads: "At this site on December 15, 1939, DuPont began commercial production of nylon. Among the earliest successes of a fundamental research program novel in the American chemical industry, nylon was the first totally synthetic fiber to be fashioned into consumer products. Prepared wholly with materials readily derived from coal, air, and water, nylon has properties superior to its natural counterparts, such as silk. Nylon revolutionized the textile industry and led the way for a variety of synthetic materials that have had enormous social and economic impact on the fabric of everyday life worldwide."

DuPont developed nylon in record time, five years between the creation of the molecule in the laboratory and plant start-up. The process was technically complex, involving new raw materials, new fiber-forming techniques and unfamiliar materials of construction. Plant construction took one year and cost \$8 million. The plant at Seaford initially employed 850 people and had a capacity of 4 million pounds a year; DuPont announced an expansion before the first pound was produced. The Seaford plant is still operating today, employs 1,600 people, and has a capacity of 400 million pounds—100 times greater than in 1939.

Acknowledgments:

The American Chemical Society gratefully acknowledges the assistance of those who helped prepare this booklet, including: Robert D. Lipscomb, retired DuPont scientist and consultant in science education; Joseph X. Labovsky, laboratory assistant to Wallace Carothers; Jeffrey L. Sturchio of Merck & Co., Inc., chairman of the ACS Advisory Committee on National Historic Chemical Landmarks; James J. Bohning of ACS, the Advisory Committee liaison; the staff of the Hagley Museum and Library; and John W. Collette, Director of Scientific Affairs for DuPont, and members of his staff—Patricia Snyder, Marguerite Vavalla and Judy Foraker.

This booklet was written by John F. McAllister and produced by the ACS Office of Public Outreach. Production Supervisor: Vivian Powers. Layout: Dahlman/Middour Design. Photographs courtesy of DuPont and the Hagley Museum and Library.

Copyright © 1995 American Chemical Society

On the Cover: (top, right) DuPont plant, Seaford, Delaware, 1995; (middle) aerial view of Seaford plant, 1939; (bottom, left) "twisters"—bundling nylon yarn filaments.

Background: "Twisters"—bundling nylon yarn filaments.

THE “SUPERPOLYMERS”

While nylon takes many forms, it made its name as a textile fiber and revolutionized the textile industry. According to *Fortune* magazine in 1940, nylon was the fifth basic textile development in 4,000 years; the others were mercerized cotton, mechanical mass production, synthetic dyes, and rayon. In turn, nylon led to a host of other fibers and plastics that are integral to an advanced industrial society.

A “Radical Departure”

In 1926, DuPont’s research head, Dr. Charles M. A. Stine, proposed what he called “a radical departure from previous policy”—a program of “Pure science,” with “the object of establishing or discovering new scientific facts” without foreseeable practical application. Stine proposed research in several areas, including organic synthesis and polymerization. To lead this work, he hired Dr. Wallace Carothers from Harvard University and provided him with a staff of newly minted Ph.D.s from Colorado, Johns Hopkins, Illinois, MIT, and Michigan. Carothers decided to concentrate on polymers, giant molecules that are the building blocks of such familiar substances as rubber and cotton. At that time, most scientists believed polymers were aggregates of small molecules bound by unknown or undefined forces, and not by ordinary chemical bonds. Carothers believed that polymers were molecules hooked together end to end in long chains by ordinary bonds. To test his theory, he proposed to create polymers by using well-known chemical reactions to join together many small molecules. A few days after starting work, he wrote that he intended:

to study the reactions of substances xAx on yBy where A and B are divalent radicals and x and y are functional groups capable of reacting with each other. Where A and B are quite short, such reactions lead to simple rings of which many have been synthesized by this method. Where they are long, formation of small rings is not possible. Hence reaction must lead either to large rings or long chains.

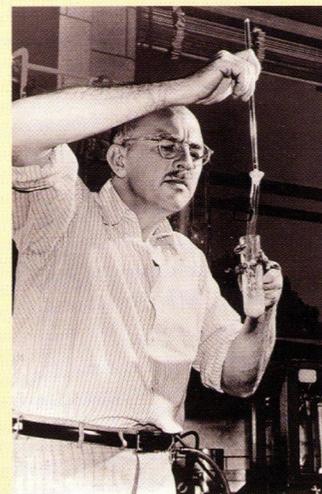
Using dibasic acids and glycols, he was successful in producing polyesters with molecular weights of 2300 to 5000. He then introduced

the molecular still, a laboratory tool that made it possible to produce polyesters with molecular weights as high as 25,000.

Fiber-Forming Polymers

Carothers called these materials “superpolymers.” They were tough, opaque solids which became transparent, viscous liquids when heated. Two important observations were made by his chief associate, Dr. Julian Hill: first, that filaments could be obtained by pulling threads like taffy from the molten polymer; second, that these filaments when cooled could be drawn many times their original length, enhancing their properties. Whether dry or wet, they became strong and elastic — the characteristics of a promising textile fiber. Filaments could also be produced by dissolving the polymer in chloroform and passing the viscous solution through a standard rayon spinneret.

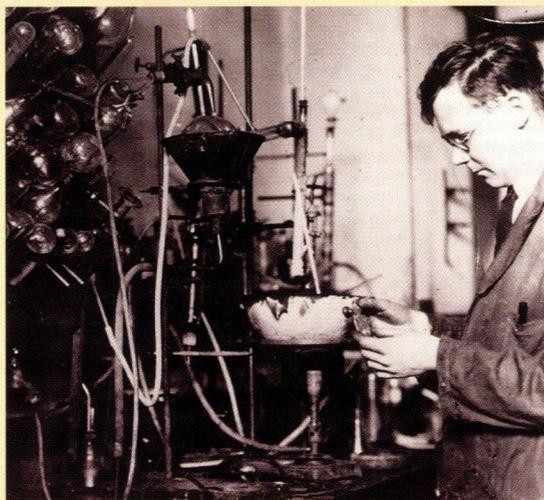
In 1931 the company applied for a patent on linear condensation polymers, and Carothers and Hill presented a paper to the American Chemical Society in which they disclosed superpolyesters that could be extruded and drawn into a fiber with



Julian Hill reenacts the discovery of the first man-made polymer, stretching it into a thin fiber.

properties superior to silk.

Carothers’ group experimented with many compositions, but none was a suitable candidate for a textile fiber. Their melting points were too low, and they were too sensitive to solvents. Though his research continued, by 1933 work on fully synthetic fibers had come to a halt.



Wallace H. Carothers in his laboratory at the DuPont Company’s Experimental Station near Wilmington, Delaware.

THE DEVELOPMENT OF NYLON

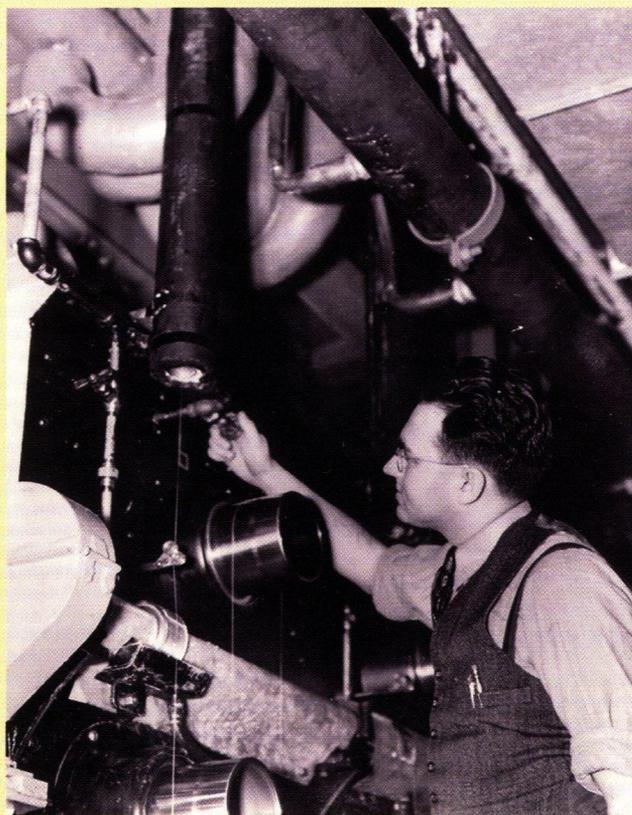
In the early 1930's, Stine was promoted to DuPont's management committee and Elmer K. Bolton succeeded him as chemical research director. Bolton's top research priority was the creation of a new synthetic fiber. Thus began the interplay of science and commerce that marks the development process — the "D" of R&D.

New technology was needed to make the raw materials and to form them into a fiber. The market had to be decided upon, an important choice for a material that could compete with cotton, silk, wool and rayon. The decision to focus on hosiery was crucial. It was a limited, premium market. "When you want to develop a new fiber for fabrics you need thousands of pounds," said Crawford Greenewalt, a research supervisor during nylon development who later became company president and CEO. "All we needed to make was a few grams at a time, enough to knit one stocking." In addition, the technology had to be scaled up and a plant built that required materials of construction that were new at the time. And the time was the Great Depression, not the most propitious moment to take a \$27 million gamble — the cost of nylon from research through the start-up of Seaford.

Back in the Lab

Encouraged by Bolton, in 1934 Carothers began a renewed effort to make a polymer suitable for fibers. He chose an ester of a nine-carbon amino acid as the starting material and produced a polyamide with a high melting point, the first nylon. Carothers' group then looked at 81 polyamide compositions, including on February 28, 1935, the 66 polymer — so called because each of the reacting chemicals, hexamethylene diamine and adipic acid, has six carbon atoms. Polymer 66 was selected for development in part because both of the raw materials could be made from benzene, readily available from coal.

The initial development took place in the laboratory with equipment that could produce 100 pounds of nylon a week. The operation was so temperamental that the technicians actually tip-toed in the spinning room. They cautioned visitors to give the operation only a sidewise glance, for a head-on look would stop the process completely. In 1938, a pilot plant was constructed that could produce 500



Adjusting steam-spinning windup, April 1939.

pounds of nylon a day. The pilot plant was critical to getting Seaford up and running in record time.

The Technical Tasks

The technical tasks were many. Consider these examples:

Intermediate chemicals. New manufacturing processes for both adipic acid and hexamethylene diamine were developed at the Belle, W.Va., plant, and new equipment was designed to keep the ingredients hot during transport over the Appalachians to Delaware.

Melt spinning. Before nylon, spinning — the extrusion of polymer to form filaments (as a spider "spins" its web or a silkworm a cocoon) — was done with a solvent. Nylon could be solution-spun, but it also could be spun by melting the polymer. While this offered advantages, it had never been done. "I had nightmares over melt spinning," said Greenewalt. "The problem was, the melting point of nylon was very close to the decomposition point. We'd get bubbles, because the decomposition products were gases." The solution, simple in

hindsight, was to keep the polymer under high pressure — 4,000 pounds per square inch. Special pumps were designed to operate at these pressures, with small clearances and with no lubricant other than the polymer itself. A new grade of stainless steel had to be used that was abrasion resistant.

The high temperatures, 550° F (285° C), posed other problems. Many types of spinning-cell melting grids were designed to find a candidate that would maintain heated surfaces in spite of the poor thermal conductivity of the polymer. To protect the hot polymer from oxidation, DuPont used a purified grade of nitrogen, which came to be known as “Seaford-grade nitrogen.” In addition, the spinning assembly involved radically new engineering developments to produce fibers of the required uniformity. Before the plant was opened, eight different spinning assemblies were constructed, each one embodying the newest ideas.

High-speed spinning and cold drawing.

Special equipment was designed for this crucial step. Generators were made to run the windup of the yarn at a speed of 2,000 feet per minute with virtually no variation. The draw rolls — between which the yarn was stretched a uniform amount — had to be manufactured to a tolerance of 1/100,000th of an inch.

Sizing. The size, or surface coating, itself proved a major problem. The first choice corroded knitting needles and gummed up the machines. Candidate after candidate was tried and failed. The clock was ticking. DuPont eventually assigned 30 scientists to work on the problem, and they didn't come up with the answer until the structural steel was up at Seaford and much of the other equipment was installed.

Going Public

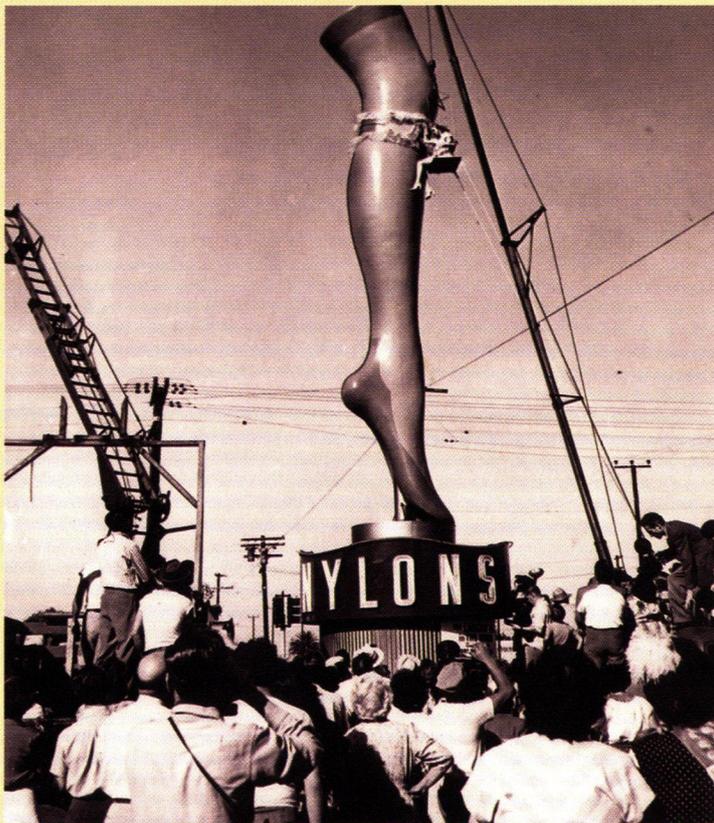
The market development process set off rumors in the textile industry about the new fiber. DuPont kept quiet until the nylon patent was issued in September 1938. The Seaford plant was authorized on October 12, and two weeks later, Stine announced nylon in a nationwide broadcast.

On December 15, 1939, production started on the plant — the first ever to be designed for an operation never before undertaken. It would cost DuPont \$8

million, one-sixth of its 1938 net earnings.

Nylon was a best seller from the outset. Prior to the start-up of Seaford, DuPont had put 4,000 pairs of stockings on sale in Wilmington — they sold out in three hours. Seven months later, the company put 4,000,000 pairs on sale nationally — these sold out in four days. The name “nylon,” intended to be the generic designation of a class of polymers, became another word for stockings.

Today nylon comprises 20 percent of the world's manufactured fiber production, which in turn is almost half the total of all fiber production. Worldwide, 8 billion pounds of nylon are produced each year — 1 1/2 pounds for every person on earth.



To promote nylon, DuPont erected this two-ton, 35-foot-high nylon stocking in Los Angeles. Actress Marie Wilson, whose leg was said to be the model for the display, waves to photographers from an improvised bos'n's chair.

LEADERS AND HEROES



Charles M. A. Stine - A pioneer in industrial research, Stine established the program that led to nylon. A professor of chemistry at 22, he retired from DuPont in 1945 as a vice president and director. Stine was responsible for technical advances in explosives prior to World War I and was an advisor to the atomic energy project during World War II.

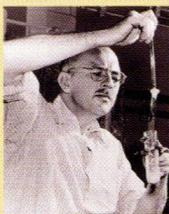


Elmer K. Bolton - Building on Carothers' theories, Bolton provided the direction that led to the development of nylon fiber. He was also instrumental in the preparation of synthetic dyes and the commercialization of neoprene, the first synthetic rubber. He headed DuPont's Chemical Department from 1930 until his retirement in 1951.

Wallace H. Carothers - Rightly celebrated as the one man most responsible for nylon, Carothers revolutionized our understanding of high polymeric chemistry and provided a basis for the development of technically useful synthetic polymeric materials. In 1936, he became the first organic chemist in industry to be elected to the National Academy of Sciences.



George W. Graves - In 1935, he was assigned to assist Carothers in supervising nylon development and became research manager when the nylon division was formed. He retired in 1958 as general director of research for DuPont's Textile Fibers Department.



Julian W. Hill - Carothers' chief associate, Hill was the first to observe the filament and fiber-forming properties of super-polymers. He received his Ph.D. in organic chemistry from the Massachusetts Institute of Technology and later was active in science education, serving as executive secretary of DuPont's Educational Aid Committee.



Emile F. du Pont - Great-great-grandson of the founder of the DuPont Company, he helped to plan the construction of the Seaford plant and in 1938 became its first manager. He later became director of employee relations and a member of the board of directors.

Technical development is like a military campaign. There are leaders and heroes, but it is difficult to single out just who was responsible for victory. Bolton identified 230 chemists and engineers who were engaged at one time or another before the designs were turned over to construction. In addition to the principal players pictured above:

Ernest B. Bengler was assistant director of DuPont's Chemical Department.

E. K. Gladding was the first manager of the nylon division.

G. Preston Hoff was the technical director.

Gerard G. Berchet first synthesized nylon 66.

W. R. Peterson discovered that acetic acid made it possible to produce uniform polymer.

E. Spanagel developed the sizing.

W. W. Heckert designed a dual pump that applied the pressure to eliminate gas bubbles.

Dale F. Babcock developed technology that doubled the rate of production.

W. T. Wood supervised construction of the Seaford plant.

E. G. Ackart was the chief engineer.

John Brentlinger was manager of industrial engineering.

H. W. Oggenfuss was one of the principal design engineers.

Space permitting, the list could continue, to encompass Bolton's 230 chemists and engineers and beyond. It is the nature of the development process that each step towards commercial production involves more and more people, until it becomes an achievement of the organization. Nylon was such an achievement.

REFERENCES FOR FURTHER READING

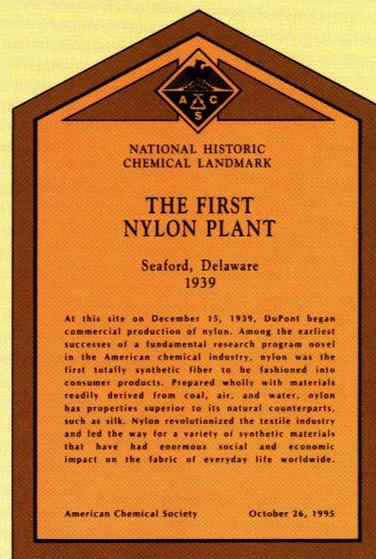
- Roger Adams. "William Hume Carothers." *Biographical Memoirs of the National Academy of Sciences*, Vol. 20, No. 12 (1939): 293-309.
- Elmer K. Bolton. "Development of Nylon." *Industrial and Engineering Chemistry* 34 (January, 1942): 53-58.
- Mary Ellen Bowden and John Kenly Smith Jr. *American Chemical Enterprise*. Philadelphia, Pennsylvania: Chemical Heritage Foundation, 1994.
- Wallace H. Carothers. *Collected Papers of Wallace Hume Carothers on High Polymeric Substances*, ed. by H. Mark and G.S. Whitby. New York: Interscience, 1940.
- William Chambless. "Nylon Is 40." *Context Magazine*, Vol. 1, No. 2 (1978): 24-29.
- Alfred D. Chandler and Stephen Salisbury. *Pierre S. du Pont and the Making of a Modern Corporation*. New York: Harper & Row, 1971.
- DuPont: The Autobiography of an American Enterprise*. New York: Scribners, 1952.
- William S. Dutton. *DuPont — 140 Years*. New York: Scribners, 1949.
- Yasu Furukawa. "Staudinger, Carothers, and the Emergence of Macromolecular Chemistry." Ph.D. thesis, University of Oklahoma, 1983.
- Julian W. Hill. "Wallace Hume Carothers." In *Proceedings of the Robert A. Welch Foundation Conference on Chemical Research*. Vol. 20, *American Chemical Bicentennial*, ed. by W.O. Mulligan (Houston, Texas: Welch Foundation, 1977): 232-251.
- Donald Holmes. *History of the DuPont Company's Textile Fibers Department*. Wilmington, Delaware: DuPont, 1983.
- David A. Hounshell and John Kenly Smith Jr. *Science and Corporate Strategy: DuPont R&D, 1902-1980*. Cambridge: Cambridge University Press, 1988.
- Robert M. Joyce. "Elmer Keiser Bolton, 1886-1969." *Biographical Memoirs of the National Academy of Sciences*, Vol. 54. (1983): 50-72.
- Peter J. T. Morris. *Polymer Pioneers*. Philadelphia, Pennsylvania: Chemical Heritage Foundation, 1986.
- Willard F. Mueller. "DuPont: A Study in Firm Growth." Ph.D. thesis, Vanderbilt University, 1956.
- "Nylon." *Fortune* (July 1940): 53-60.
- Ferdinand Schulze and Roy Soukup. *The Technical Division of the Rayon Department, 1920-51*. Wilmington, Delaware: DuPont, 1952.

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.

An ACS Historic Chemical Milestone designation marks a landmark step in the evolution of 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, 800-ACS-5558, Press 954.



The American Chemical Society

Brian M. Rushton, President
Ronald C. Breslow, President-Elect
Paul H. L. Walter, Board Chairman
John K. Crum, Executive Director
Ann B. Messmore, Director, Public Outreach

ACS Division of the History of Chemistry

Martin D. Saltzman, Chairman
Joseph B. Lambert, Chairman-Elect
Vera Mainz, Secretary-Treasurer
Richard E. Rice, Program Chairman

ACS Delaware Section

Patricia L. Watson, Chairwoman
Prudence Bradley, Chairwoman-Elect
Maria Spinu, Secretary
Helen Hauer, Treasurer

Delaware Section Historical Site Committee

John W. Collette, Co-Chairman
Robert D. Lipscomb, Co-Chairman
Paul Becher
Benjamin D. Herzog
Patricia L. Watson

DuPont

Edgar S. Woolard, Chairman
Joseph A. Miller, Jr., Senior Vice-President,
Technology

**ACS Advisory Committee on
National Historic Chemical Landmarks**

Chairman: Jeffrey L. Sturchio, Merck & Co., Inc.
James J. Bohning, American Chemical Society
Jon B. Eklund, National Museum of
American History
Yasu Furukawa, Tokyo Denki University
Leon Gortler, Brooklyn College
Ned D. Heindel, Lehigh University
Paul R. Jones, University of New Hampshire
James W. Long, University of Oregon
Peter J. T. Morris, National Museum of Science
and Industry, London
Mary Jo Nye, Oregon State University
Stanley I. Proctor, Jr., Proctor Consulting Services
David J. Rhee, Bakken Library and Museum
Ann C. Higgins, ACS Staff Liaison



American Chemical Society
1155 Sixteenth Street, N.W.
Washington, D.C. 20036