# CHAPTER FOUR

## A DURABLE DIRECTOR (July 1975–March 1989)

The *NBS Standard,* official employee bulletin of the Bureau, printed on July 16, 1975, the letter of resignation written to President Gerald Ford at the end of June by Director Roberts.[1] On the same page was printed Ford's letter of acceptance and a message from Roberts to the staff explaining his reason for leaving NBS.

The front page of that issue was given to an account of the designation of Ernest Ambler to the post of Acting Director of NBS:

> On June 30, 1975, Betsy Ancker-Johnson, Assistant Secretary of Commerce for Science and Technology, designated Ernest Ambler Acting Director of the National Bureau of Standards. Ambler fills the vacancy left by Richard W. Roberts, who has joined the Energy Research and Development Administration as Assistant Administrator for Nuclear Energy.

The account continued with the news that Robert S. Walleigh, former NBS Associate Director Emeritus, would serve as Acting Deputy Director. After Walleigh, the succession in case of Ambler's absence was given as John D. Hoffman, Director of the Institute for Materials Research; Ruth M. Davis, Director of the Institute for Computer Science and Technology; F. Karl Willenbrock, Director of the Institute for Applied Technology; and Arthur O. McCoubrey, Director, Institute for Basic Standards.

Ambler was reluctant to accept the directorship of the Bureau, but he proved to be one of its most durable directors. Nothing shows this durability more than the surprising fact that Ambler served as the leader of NBS under four U.S. presidents: he was named Acting Director in 1975 by Gerald Ford; he was nominated and installed as director in 1978 by Jimmy Carter; he served through the two terms of Ronald Reagan's presidency; and his retirement notice was received in 1989 by George Bush. For nearly 14 years, Ambler provided the continuity of leadership that had been lacking at NBS under his two predecessors.

In view of his background as a renowned physicist, Ambler might well have resisted the trend towards applied technical work that had begun for NBS during the tenure of Lewis Branscomb. But in fact Ambler embraced the trend even as it threatened the agency's traditional roles in physical and chemical standards and fundamental scientific research. Clearly, he endorsed the notion that change was as important for the future of the Bureau as it was for the future of American industry.

In the record of Ambler's lengthy tenure, we note the growth in NBS programs intended to improve the lot of American industry. By the end of his tour as director, substantial modification of the Bureau's charter was not at all surprising.

[1] *NBS Standard,* Vol. 20, No. 15, July 16, 1975, p. 2.

## A Presidency in Transition

If the departure of Richard Roberts was barely noticed by the Executive Branch of the United States Government, it was because the President and his staff had a lot on their minds.

Along with the Presidency, Gerald Ford had inherited "stagflation" in August of 1974. Stagflation was the name given to an economically unhealthy combination of rising inflation and falling consumer demand for goods. Other problems—a difficult, ignoble disengagement from Vietnam; a substantial and growing foreign-trade deficit; a falling stock market; and increasing unemployment—added to his woes. He was "the man who pardoned Nixon," the nominal head of a political party that could not gain control of Congress and might lose the White House as well in the 1976 elections.

At the time he received the resignation of NBS Director Richard Roberts, Ford had just completed a difficult quarter-year. April 1975 had seen the evacuation of all Americans and many South Vietnamese from Saigon while the capital was under fire from North Vietnamese troops. On May 12, the *S. S. Mayaguez,* an American merchant ship, had been seized off the Coast of Cambodia and its crew kidnapped by Cambodian forces. In an angry but controversial reaction, Ford had ordered the Marines to retake the ship and free the crew. The recovery was completed successfully, but with the sobering loss of nearly 40 U.S. fighting men. At home, Ford had to face a request from New York City for $1 billion to stave off bankruptcy; Ford refused, demanding that the city first reform its spendthrift policies before expecting U.S. help.

As if all these problems were not enough, Ford found that he had to veto many Congressional spending bills that were pushing the national debt to unprecedented heights. Only a sturdy self-confidence and the discipline born of years of dealing with today's problems—never mind yesterday's or tomorrow's—enabled the embattled President to maintain a steady grip on the office left him by the first Presidential resignation in U.S. history.

Ford had promised his wife after the 1972 elections that the 1974 Congressional campaign would be his last. Still young enough to practice law privately and earn the "big money" which had not been his lot as a Congressman,[2] yet a veteran politician with no real hope of realizing his personal ambition to become Speaker of the House, Ford had been prepared to leave government service. Completing Agnew's term as Vice President, he had opined, "would be a nice cap to my career."[3] But now he was President of the United States, a whole new ballgame for the former Michigan linebacker.

Within 10 days after his inauguration as the 38th President of the United States, Ford had nominated Nelson A. Rockefeller to be Vice President. This action was dictated by the 25th Amendment, just as his own nomination by Nixon had been ordained by the necessity to maintain the Constitutional line of succession to the

[2] In 1968, Congressional pay was $30,000 per year—an amount easily spent by a family of six.

[3] James Cannon, *Time and Chance: Gerald Ford's Appointment With History* (New York: Harper Collins, Publishers, 1994) p. 206.

Presidency. Rockefeller, the second non-elected Vice President of the United States, was subjected to the same detailed scrutiny of his patriotism and integrity that Ford himself had endured. Found satisfactorily blameless, Rockefeller was easily confirmed by both houses of Congress and sworn to the office on December 19, 1974.

Somewhat to his own surprise, Ford found that he liked being President. He shared with Harry Truman more than the fact that each had suddenly been thrust into the Oval Office; like Truman, he faced each day's multitude of crises with vigor. He was used to hard work, he knew the Congress well from long years as a powerful insider, and he was on good terms with nearly all of his colleagues. Although Ford was a friendly man by nature, he could say "No" to friend and foe alike without second thoughts where he saw the country's welfare at stake; he vetoed 66 bills—mostly spending bills that he regarded as profligate—during his truncated tenure (fewer than 900 days) as President.[4]

Despite his early statements that he would not seek further public office after serving out the balance of Agnew's term as Vice President, Ford decided to run for the presidency in 1976.

A possible tipoff to the date of Ford's decision can be found in his appointment of Rogers C. B. Morton as Secretary of Commerce. Ford left in place Nixon's Secretary of Commerce, Frederick B. Dent, until February, 1975; then Ford asked Dent to serve as chief U.S. trade negotiator. After Dent's departure from Commerce, Ford nominated Morton on March 27, 1975. It was supposed that Morton would be heavily involved in any race for the presidency, and indeed that proved to be the case.

Much of the day-to-day interaction between the Director of the Bureau and the Department of Commerce during this period involved the office of Assistant Secretary of Commerce for Science and Technology. Betsy Ancker-Johnson, appointed by President Nixon, held that post from 1973 until the end of Ford's term as President in 1977.

Late in 1975, the post of Under Secretary of Commerce, with supervision over technical matters, was created in the department. Its first incumbent was James A. Baker, III, a Texas lawyer. He became the immediate supervisor of Betsy Ancker-Johnson. After only a few months as Under Secretary, however, he moved on to work on Ford's re-election campaign.

In January 1976, President Ford asked Rogers Morton to leave his post as Secretary of Commerce to take a position as White House counselor on economic and domestic policy, as well as "incidental duties of liaison with the President's re-election committee and the Republican National Committee."[5] To replace Morton and Baker, Ford nominated Elliot Richardson and Edward O. Vetter. Richardson was an unusually capable leader who had previously served as Secretary of Health, Education, and Welfare; Secretary of Defense; Attorney General; and, most recently, Ambassador to Britain. Vetter, a graduate of the Massachusetts Institute of Technology, was a veteran

[4] Ibid., p. 404. "I know of no friend I lost in Congress because I told them they were wrong," he said. "The truth is that usually after a veto, Congress came back with more realistic legislation that I could sign." Only 12 of his vetoes were overturned.

[5] James M. Naughton, *New York Times*, January 14, 1976, p. 16.

of a decade of work in oil engineering and two decades as an executive in the Texas Instruments Company. Ancker-Johnson, as noted, remained at her post until replaced by President Carter.

Fallout from the Watergate disaster continued throughout the presidency of Gerald Ford. Controversy over his quick pardon of Richard Nixon, with its consequent frustration of the investigative and prosecutorial work of the Select Senate Committee, dogged the President. To counter the unfavorable publicity, Ford ordered investigations of the Central Intelligence Agency and the Federal Bureau of Investigation in order to restore their public images, which had been tarnished by his predecessor. He cut taxes by some $16 billion and reduced Federal spending in a determined effort to decrease the unusually high (more than 9 %) level of unemployment that he confronted in 1975. But nothing Ford was able to do could erase the image of government gone bad.

Although Ford entrusted Vice President Rockefeller with important domestic responsibilities, including leadership of his Domestic Council and of the Presidential Commission on the CIA, Rockefeller decided in November, 1975, that he would leave the political scene at the end of Ford's term in 1977.

Ford's bid for re-election in 1976 was vigorously contested by Ronald Reagan, former Governor of California. Ford won the Republican nomination, but he and his running mate, Senator Robert Dole of Kansas, were narrowly defeated by the slate of Jimmy Carter, former Governor of Georgia, and Walter Mondale, former Senator from Minnesota. After Ford relinquished the presidency to Carter, he made good on his promise to his wife; they retired to private life in California, to be seen thereafter only rarely in the news.

## JAMES EARL CARTER, JR.

"Jimmy" Carter came to Washington as an outsider. In the 1976 elections, the Republican leadership expected serious trouble because the American public was deeply offended by the spectacle of Watergate and the distressing view it offered of a lawless and mendacious President.

Carter identified himself as independent of the machinations of Washington and he promised honesty in government. He delivered on both claims, but only at the expense of an often-discouraging unfamiliarity with the reins of Federal management that helped make him a one-term President.

Carter graduated from the United States Naval Academy in 1946. He finished in the top 10 % of his class, and was rewarded with a choice assignment in Admiral Rickover's nuclear navy. He was appointed an officer on the submarine Sea Wolf and served in that capacity for several years. Eventually he decided not to make a career of service in the Navy. He resigned his commission in 1953 to return to farming in Georgia.

After a successful decade as a farmer, Carter took an interest in politics. He sought and won two terms as a Georgia State Senator in 1962 and 1964, and he won the Georgia governorship in 1970. As Governor, Carter undertook a vigorous reformation of the Georgia government: he issued a public call for an end to racial discrimination in the state; and he reorganized the government, calling for zero-based budgeting and so-called "sunshine" legislation. Zero-base budgeting, in Carter's view, was the answer to outmoded government bodies and commissions. Under this principle, each agency would be required to begin each year with a defense of its entire budget, in effect annually justifying its own existence. The National Bureau of Standards management was to find this process burdensome when Carter attained the office of President. "Sunshine" laws were similarly simple in concept; with few exceptions—such as discussions of personnel—all agency meetings were to be announced in advance and open to the public. Logical enough to the public that it lives on throughout government today, the idea was radical and unwelcome to many a bureaucrat.

Having succeeded in his forays into state government, Carter set his sights on the national scene. He recognized the antipathy of the American people to the wretched record of the Nixon administration, so he undertook a campaign for President in 1976 that promised, as an "outsider," to return honesty and good government to Washington. A quiet, sincere, yet forceful speaker, Carter entered some 30 state primary elections and accumulated sufficient electoral backing to win the Democratic nomination on the first ballot. He defeated such Democratic competitors—all "insiders"—as Senator Henry M. Jackson, former Director of the Peace Corps Sargent Shriver, and Representative Morris Udall. With Senator Walter F. Mondale helping cement support in the mid-West and East, and buttressed by his own popularity in the South, Carter narrowly defeated Ford in the 1976 presidential race.

Carter immediately emphasized his desire to break with the past by walking, rather than riding in a limousine as was customary, from the U.S. Capitol to the White House during his inaugural proceedings. He also quickly sold the presidential yacht.

Juanita M. Kreps, a Professor of Economics, was selected by Carter as his Secretary of Commerce. She was the first woman to occupy that post. She was confirmed by the Senate on January 20, 1977, and sworn in on January 23rd. Sidney Harman was named Under Secretary, and Jordan J. Baruch—like Vetter, an MIT graduate—was appointed Assistant Secretary for Science and Technology.

As president, Jimmy Carter continued to practice the economy and openness in government that had served him well in Georgia. He promised to place a ceiling on the number of Federal workers, and he proposed a comprehensive reform of the Civil Service system. He met the crisis in energy with a plan he called "the moral equivalent of war." He established a Department of Energy in October of 1977 and obtained a large increase in funding for energy research. In 1979, he separated the Department of Health, Education, and Welfare into two—a Department of Education and a Department of Health and Human Services.

In mid-1979, Carter replaced Under Secretary Harman with Luther H. Hodges, Jr., a professor of business at Duke University. A year later, Kreps left her post, to be succeeded by Philip M. Klutznick. At the same time, the title of Baruch's position was changed to reflect a new emphasis on industrial competitiveness: Baruch became the Assistant Secretary for Productivity, Technology, and Innovation.

Carter's efforts as President often seemed tinged with naiveté. His attempts to improve respect for human rights—especially in the Soviet Union—were seen by the Soviets as interference by a nation that still had plenty of human rights violations of its own. His efforts to heal the economic ravages brought by inflation and imported oil left the country in 1980 with worse inflation—from 4.8 % in 1976 to 12 % in 1980—and high unemployment—at 7.7 %, only a slight improvement over the Ford presidency.

When Iranian "students" entered the U.S. embassy in Teheran and took some 63 U.S. citizens as hostages in November 1979, Carter's effectiveness as a national leader was questioned. For more than a year the United States was unable, by force or by diplomacy, to liberate the hostages.

During a speech carried on national television, Carter graded his administration harshly; C+ to B on foreign policy, C on domestic policy, A on energy, C on the economy, and B on leadership.[6] Little wonder that the ticket of Carter and Mondale received only 42 % of the popular vote in the 1980 presidential race against Ronald Reagan and George Bush.[7]

### RONALD WILSON REAGAN

Without doubt, Ronald Reagan was a man of his times. Sportscaster, movie star, television-show host, video-advertising icon, Governor of California—Reagan embodied the full gamut of the era of communications. He also covered the political spectrum, changing his philosophy from liberal Democrat to conservative Republican as he shed his acting career for a new life in government.

Reagan was as self-assured as Jimmy Carter had been self-questioning. Trained from his youth in mass communication, he projected confidence even when discussing issues that were much in doubt. Joining with George H. W. Bush to campaign for a conservative America, Reagan easily defeated incumbent President Jimmy Carter and his running mate, Vice President Walter F. Mondale.

Nearly 70 years of age when he took office, Reagan's stamina and outlook were the envy of men decades younger. He rejoiced in the opportunities that the presidency offered—glittering parties, banquets with heads of state, speeches on the greatness of America and the evils of Communism, thoughtful discussions with captains of industry, horseback-riding vacations at Camp David and at his beloved ranch in California, political debates with Democrats. No one, seemingly, could find a fault in Reagan—especially Democrats, who always seemed tongue-tied by comparison with the "Great Communicator."

In fact, from all points of view save one—that of fiscal responsibility—Reagan's two terms as President were successful.

[6] James M. Burns, *The Crosswinds of Freedom,* (New York: Vintage Books, 1990) p. 530.

[7] Hedrick Smith, *The Power Game: How Washington Works* (New York: Random House, 1988), p. 674.

Reagan's presidency suffered a rocky start. Only 3 months into his presidency, Reagan was shot by John W. Hinckley, Jr., not a political assassin but a dangerous psychopath. Reagan proved to have been very lucky to have survived the attack (Hinckley's bullet lodged very near his heart, and he lost nearly half his blood before emergency physicians could stop the flow). His doctors reported amazement at Reagan's strong physical condition and the speed of his recovery from the attack.

Reagan's second year as president, 1982, was marred by a recession which slowed his progress in implementing his campaign promise of a strongly conservative, strongly nationalistic government.

Reagan's presidential policy was made to order for counteracting an economic slump. Confront the "evil empire" at every opportunity, increase defense spending, decrease non-defense spending, reduce taxes—these were the simple tenets by which the Reagan administration prospered. America's defense industry quickly led the way to economic well-being.

On December 11, 1980, Reagan named Malcolm Baldrige, Jr., as his choice for Secretary of Commerce. Six other Department heads were revealed on that day. Baldrige, 58, was a successful businessman, most recently as Chairman of the Board of Scoville Manufacturing Company of Waterbury, Connecticut. Long active in Connecticut and national politics, Baldrige had the distinction among Reagan's nominees of being the only member of the Rodeo Cowboys Association.

Reagan abandoned the posts of Under Secretary for Science and Assistant Secretary for Science and Technology. NBS Director Ernest Ambler thus found himself more closely involved with the office of the Secretary of Commerce, a situation that pleased Ambler.[8]

In the 1984 presidential campaign, the Reagan-Bush team defeated the challenge presented by Walter Mondale and his running mate, Geraldine Ferraro, with only modest effort. Questions regarding his advanced age, as always, were dismissed by Reagan with a jaunty smile and a ready quip.[9]

Secretary of Commerce Baldrige remained at his post until his untimely death on July 25, 1987, while riding in a rodeo. He was succeeded in August 1987 by Acting Secretary Clarence J. Brown. In turn, Brown was replaced in October 1987 by C. William Verity, Jr., retired chairman of Armco Steel Company.

Reagan demonstrated his self-confidence and his devotion to conservative government early in his presidency. During his first year in office, 1981, he ordered a freeze on the hiring of Federal employees and fired the nation's air-traffic controllers when they struck for better working conditions.

With Vice President Bush as point man and a Republican majority in the Senate, Reagan pushed a tax-reduction program to reduce the maximum Federal income tax rate from 70 % to 50 % and the maximum capital-gains rate from 28 % to 20 %.

[8] Ernest Ambler, Oral History, September 22, 1988.

[9] During a televised presidential debate, Reagan pre-empted the age question. He stated that he knew that age was considered a factor in the election but, although he was well aware that Mr. Mondale was "young and inexperienced" by comparison to himself, he promised that he would not dwell on that fact during the campaign.

These tax cuts were to be funded at the expense of social programs, but not defense expenditures; among the first cuts was the synthetic fuels program. America would increasingly be strong in the face of Communism, and Americans at the top of the economic heap would be happy.

A Strategic Defense Initiative—called "Star Wars" by skeptical critics—was begun in 1983. The SDI program was intended to prevent attack on the United States mainland by mid- or long-range missiles. It was to feature defensive weapons that incorporated the latest in technology, including high-powered lasers. All government agencies, including the National Bureau of Standards, worked feverishly to configure technical projects as helping to create, to detect, or to shoot down space-based weapons.

In the same year, the United States invaded the tiny island of Grenada in response to a request by the Organization of Eastern Caribbean States. It took only a few days for U.S. Marines and Rangers, aided by troops from six Caribbean nations, to eliminate the Marxist threat from that source.[10]

President Reagan generally showed little interest in the mechanics of Executive Branch agencies, many of which he regarded as unnecessary. An exception occurred in 1987 when he paid a surprise visit to a federal meeting on high-temperature superconductors and proposed a new project (see A Presidential Initiative later in this chapter).

The U.S. economy, buoyed by what was essentially a war effort against Communism, boomed as it always has during a war. The principle involved in war-economy boom times is simple, though slightly flawed: American industry is heavily employed in the manufacture of goods that are bought by the American government and disposed of in the process of conducting foreign policy; wages are reliable, employment stays low, and the standard of living is good.

The flaws in Reagan's policies, skyrocketing national debt and trade deficits—the budget deficit alone reached $180 billion during 1984—were unfortunate but virtually unavoidable companions to the defense-based economic boom.

Let this important truth be stated clearly, however: not only did Reagan's militaristic foreign policy send the U.S. government deeply into debt, but it also sent the "evil empire" into bankruptcy. The Soviet Union, out-spent and eventually kopeck-less, was forced to call off the Cold War. The Union itself was dissolved by vote of its people and, on November 9, 1989, the Berlin Wall began to be dismantled. This was Reagan's greatest legacy, in the view of many historians.

By 1988, Reagan was 77 years old but still vigorous. Had he not been limited to two terms by law, he might have run again. However, under the circumstances he happily supported his Vice President's campaign to succeed him. George Bush chose Senator Danforth Quayle of Indiana as his running mate. The two easily defeated Massachusetts Governor Michael Dukakis and Texas Senator Lloyd Bentsen, although the Democratic Party retained control of both houses of Congress.

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[10] Mark S. Hoffman, editor, *The World Almanac and Book of Facts,* (New York: Pharos Books, 1988) p. 454.

## Ernest Ambler, Temporarily an Acting Director

Ernest Ambler became the first naturalized citizen to head NBS. Born in Bradford, Yorkshire, England in 1923, he was educated at Oxford University, receiving the D. Phil. degree in 1953. Immediately upon graduation, he was recruited by NBS to assist in physics research at extremely low temperatures, using the method of adiabatic demagnetization of paramagnetic samples. Ambler became a U.S. citizen in 1958.

The ability of NBS to undertake experiments at temperatures below one kelvin eventually won world-wide recognition for Ambler and for his Bureau colleagues; their work proved vital to the success of an experiment demonstrating the failure of the physical principle of conservation of parity in weak interactions. The "parity experiment," suggested by physicists Tsung-dao Lee and Chen Ning Yang of Columbia University, won for them the 1957 Nobel Prize in physics.

Ralph P. Hudson shared with Ambler the responsibility for the cryogenic aspects of the parity experiment. Hudson, instrumental in bringing Ambler to NBS,[11] was Chief of the Cryogenic Physics Section of the Heat and Power Division when the parity experiment got under way. Raymond W. Hayward and Dale D. Hoppes, both members of the Radioactivity Section of the Atomic and Radiation Physics Division, were responsible for the radiation physics portion of the experiment.

In 1961, Director Allen Astin appointed Hudson Chief of the Heat Division and Ambler Chief of the division's Cryogenic Physics Section. In 1965, Ambler became Chief of the Inorganic Materials Division. In 1968, Astin made Ambler Director of the Institute for Basic Standards. When Lawrence Kushner left NBS in May 1973 for the post of Commissioner of the Consumer Products Safety Commission, Director Richard Roberts appointed Ambler Deputy Director of NBS.

By nature, Ambler was inclined to speak plainly, not always a recipe for successful management. He later recalled his years as a working scientist as among his happiest and most exciting times, but noted that, as his management responsibilities continued to grow, he came to enjoy as well his administrative role.[12]

Even as he was named Acting Director of NBS following the abrupt resignation of Richard Roberts in June 1975, Ambler questioned his own suitability to deal successfully with the Congress. Asked if he would be interested in the position of Director on a permanent basis, his surprising answer was, "No." His logic was simply put in a later memoir:[13]

> The prospects facing any new Director were not very attractive, especially with the justification of Federal budgets getting ever more difficult. Besides, one had the feeling that the scientific and technical community thought that if a real

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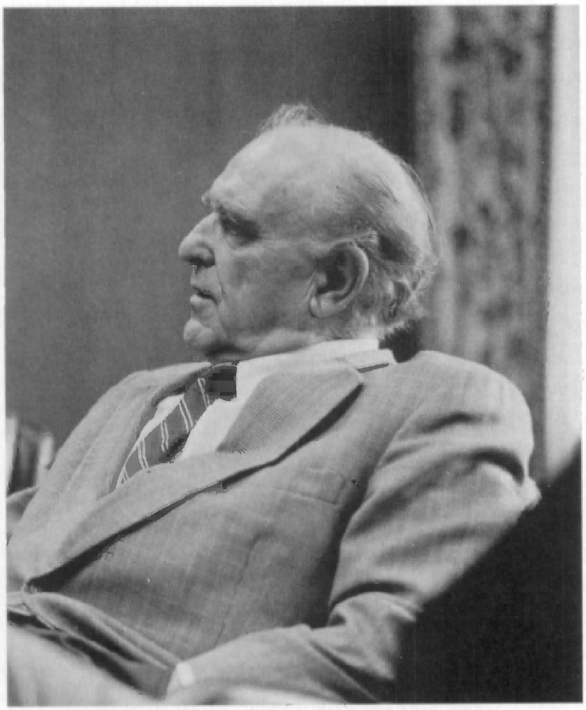
[11] Ernest Ambler, Oral History, July 7, 1988.

[12] Ernest Ambler, Oral History, July 27, 1988. See also Ernest Ambler, "Historical Perspective: 1973-1989," in *NBS/NIST, a Historical Perspective: A Symposium in Celebration of NIST's Ninetieth Anniversary, March 4, 1991*, Karma A. Beal, Editor, *NIST Special Publication 825*, April 1992, p. 38.

[13] Ibid., p. 32.



Ernest Ambler was the eighth director of NBS. Only Samuel Stratton and Allen Astin exceeded his tenure as head of the agency.

> "mover and shaker" were appointed, the forces arrayed against agencies like the Bureau could be overcome. Well, I was not convinced that the "great man" theory was correct, and in any case I knew I was not such a person.

Despite his personal ambivalence towards the job, Ambler agreed in 1975 to serve as the acting Director of NBS, a post he held from July 1975 to February 1978.

**A New Administrative Structure for NBS**

During an ad hoc meeting with NBS managers on September 12, 1977, Ernest Ambler proposed the first major reorganization of NBS since 1964, and only the second top-to-bottom change in agency history. In creating the "institute" structure in 1964, Allen Astin recognized the difficulty of managing many division chiefs—their number having grown substantially by the creation of various "applied" units. Ambler stated that his principal motivation was to focus the engineering units of the Bureau on the traditional engineering disciplines and to help them meet the demands of modern technology.[14] But Ambler's proposal was not limited to the NBS engineering units—virtually every employee was affected by the change.

[14] Ambler, *SP 825*, p. 34.

On its face, it seems remarkable that an Acting Director—one who was uncertain whether he wanted the job on a permanent basis—would propose to remake his agency. Such a sweeping reorganization might be expected from a director with considerable experience in the position. It is instructive to probe a bit to seek an explanation for Ambler's move.

### *A Director-In-Waiting*

An important first step in understanding Ambler's 1977 proposal for reorganization is to notice a substantial change in his own status during 1976.

When Elliot Richardson became Secretary of Commerce on February 2, 1976, he took an immediate interest in the leadership of NBS. Ernest Ambler later recalled a visit from Richardson at the Bureau on March 1, 1976, only a month after Richardson had been confirmed as Secretary.

As mentioned earlier, Ambler had hesitated to seek permanent status as Director because of the increasing budget difficulties facing NBS, feeling that only a "hero" could bring home sufficient funding to properly support the Bureau. He stated his concerns to Richardson. Richardson urged Ambler to reconsider, pointing out that integrity and a high level of understanding of NBS were of paramount importance to success as head of a technical agency.

Ambler found Richardson's argument convincing, and he agreed to accept permanent status as director.[15] President Ford submitted the nomination of Ambler for director of the Bureau in June of 1976.

Once the nomination process had begun, Ernest Ambler no longer was a temporary leader of NBS with only temporary thoughts about its management. By 1977, Ambler was an appointee, awaiting formal proceedings that most likely would make him permanent director of the Bureau.

As it happened, nearly two years—until February 3, 1978— passed before Ambler's appointment was completed. The delay implied no lack of confidence by the President or the Congress in Ambler's ability to perform as director, but only a coincidental hiatus occasioned by the national election of 1976.

Upon receiving Ford's nomination of Ambler, the leadership of the responsible Senate committee initially scheduled hearings for July, 1976. The unavoidable activity accompanying an election year, however, pushed the hearings into the background.

The election of Jimmy Carter, very much an outsider in Washington, resulted in yet further delay as the new president struggled to grasp the reins of government. On November 10, 1977, Carter announced his intention to nominate Ambler to the post of NBS director. Ambler's nomination hearing took place at last on December 14, 1977. As expected, confirmation came smoothly on February 1, 1978. President Carter gave Ernest Ambler his "Commission of Office" on February 3, 1978; NBS had its eighth director.[16]

[15] Ambler, *NIST Special Publication 825*, p. 32.

[16] "Senate confirms Ambler as NBS Director," *NBS Standard* **23**, No. 3, February 8, 1978, p. 1.

## *A Push For Change*

The second step in understanding Ambler's reorganization of NBS in 1977-78 involves an appreciation of his determination to perform his duties as he saw them.

As director of the Institute of Basic Standards a decade earlier, Ambler had made substantial organizational changes in order to modernize the scientific bases for certain of the divisions.[17] This had been his first experience with the interpersonal problems that accompany management decisions everywhere. In 1977, perceiving a need to revise the Bureau's response to current problems in technology—particularly those in engineering—Ambler did not hesitate to act.

## *Reorganizing to Deliver Technology*

In an article in the NBS Standard of September 21, 1977, Ambler stated:

> I have been thinking about reorganization for some time, because of difficulties I have experienced working with the present organization. Also, I have been studying the proposal made by Dr. Baruch in July that the Bureau undertake programs to foster the delivery of technology to the industrial, intergovernmental and international sectors. What I shall propose will allow for the strengthening of the scientific and technical competences at NBS as well as responding more quickly and effectively to the expectations of those who use our services.

In Ambler's proposal, the four NBS institutes would be eliminated, to be replaced by "more streamlined" units. Ambler reassured the anxious staff that, although nearly all employees would be affected by the coming changes, every effort would be made to avoid loss of jobs.

A steering committee and five task forces were created by Ambler to accomplish the transition. Leading the task forces were:

- National Engineering Laboratory: John W. Lyons.
- National Measurement Laboratory: John D. Hoffman.
- Technology Programs: Howard E. Sorrows.
- Associate Directorate for Administration / Associate Directorate for Information Programs: Richard P. Bartlett, Jr.
- Financial Management, Budget, and Programs: Raymond G. Kammer.

The target date for completion of the reorganization was set as mid-October 1977. Ambler urged all employees to submit ideas and comments on the reorganization directly to the task forces.[18]

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[17] Ernest Ambler, Oral History, September 22, 1988.

[18] *NBS Standard*, Vol. 22, No. 19, Sept 21, 1977, p. 1.

Over the following 9 months, some 20 bulletins were issued to the Bureau staff describing progress toward the new organization.[19]

As approved by Assistant Secretary of Commerce Baruch in November 1977, major elements of the new organization were:[20]

- National Engineering Laboratory.
- National Measurement Laboratory.
- Institute for Computer Sciences and Technology.
- NBS/Boulder Laboratories.
- Two National Centers for Cooperative Technology.
- Administrative and Information Systems.

In separating the portions of NBS that primarily supplied engineering work from those primarily devoted to measurement, Ambler's task groups generally left standards and calibration activities untouched in their respective divisions. As a result, standards and calibration efforts were divided nearly equally between NEL and NML.

### *Creating a National Engineering Laboratory*

Assembling a strong engineering activity at NBS was one of Ambler's principal objectives for the 1978 reorganization. Several components that could become useful parts of the National Engineering Laboratory, to be headed by John W. Lyons, already existed within the Bureau; others, in Ambler's opinion, had to be coaxed into being. Certain programs within the former Institute for Applied Technology had been quite successful, but were not suitable for the new structure simply because their functions had been taken over by private firms. Others, not based on traditional engineering disciplines, did not fit Ambler's view of NBS.

One of the most successful of all the IAT programs was the Fire Research program (see A Hectic Decade for Fire Science later in this chapter). As directed in the *Federal Fire Prevention and Control Act of 1974,*[21] the Bureau had created a Center for Fire Research, placing in it all NBS resources devoted to fire research and fire safety. John Lyons had been brought to the Bureau to head the new Center. When he was selected in 1978 to head the National Engineering Laboratory, Frederick B. Clarke was named Acting Director of CFR. The center included but two divisions, Fire Science, headed by Robert L. Levine, and Fire Safety Engineering, headed by Irwin A. Benjamin.

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[19] NBS Admin. Bull. 77-46, September 23, 1977; 77-49, October 6, 1977; 77-55, October 12, 1977; 77-62, November 2, 1977; 77-64, November 7, 1977; 77-66, November 22, 1977; 77-68, November 29, 1977; 77-69, December 6, 1977; 77-72, December 15, 1977; 77-73, December 16, 1977; 78-2, January 16, 1978; 78-3, January 24, 1978; 78-5, February 6, 1978; 78-7, February 13, 1978; 78-10, March 9, 1978; 78-13, March 22, 1978; 78-14, March 28, 1978; 78-15, April 6, 1978; 78-20, May 1978; and 78-21, May 18, 1978.

[20] NBS Admin. Bull. 78-21, May 18, 1978.

[21] Public Law PL93-498, 88 Stat. 1535-1549, enacted October 29, 1974.

A Center for Electronics and Electrical Engineering, to be headed by Judson C. French, was readily formed from existing divisions and sections:

- A new Electron Devices Division, placed under the management of W. Murray Bullis, was created by renaming the former Electronic Technology Division.
- A new Electrosystems Division was formed by reassigning part of the staff of the former Electricity Division. Oskars Peterson was chosen to lead the new division.
- A new Electromagnetic Fields Division, located in Boulder under the direction of Harold S. Boyne, was created by reassigning part of the staff of the former Electromagnetics Division.
- A new Electromagnetic Technology Division, a Boulder unit under Robert A. Kamper, was formed from the remaining personnel of the former Electromagnetics Division.

A Center for Mechanical Engineering and Process Technology (CMEPT) was created from personnel from several former IBS divisions and placed under the leadership of John A. Simpson. The new units were the Mechanical Processes Division, under Russell D. Young; the Fluid Engineering Division, under George E. Mattingly; the Thermal Processes Division, under Kenneth G. Kreider; the Acoustical Engineering Division, under David S. Pallett; and the Boulder-based Thermophysical Properties Division, under Richard H. Kropschot.

Realizing later the value of separate centers for mechanical engineering and chemical engineering, Ambler in 1981 divided CMEPT into a Center for Manufacturing Engineering and a Center for Chemical Engineering.

The IAT Center for Building Technology, headed by Richard N. Wright, was essentially transferred *in toto* to the new NEL, although the new center structure was modified to include these four divisions: a Structure and Materials Division, under Edward O. Pfrang; a Building Thermal and Service Systems Division, under Preston E. McNall; an Environmental Design Research Division, under Francis T. Ventre; and a Building Economics and Regulatory Technology Division, under James G. Gross.

The IAT Center for Consumer Product Technology, headed by Stanley I. Warshaw, was transferred into the new NEL with the divisions of Consumer Sciences, under Harold P. Van Cott; Product Performance Engineering, under Andrew J. Fowell; and Product Safety Technology, under Walter G. Leight.

The IBS Applied Mathematics Division became NEL's Center for Applied Mathematics, Burton H. Colvin, Director, with divisions for Mathematical Analysis, under Frederick C. Johnson; Operations Research, under Alan J. Goldman; Statistical Engineering, under Harry H. Ku; and Scientific Computing, temporarily under Colvin.

## *Creating a National Measurement Laboratory*

Formation of a National Measurement Laboratory, to be directed by John D. Hoffman, was considerably easier. It was to contain all of the portions of the former Institute for Basic Standards and the Institute for Materials Research that had not been commandeered to form the NEL, providing the heart of the Bureau's traditional measurement standards, physics, and chemistry activities.

A Center for Absolute Physical Quantities, to be directed by Karl G. Kessler, included divisions for Electrical Measurements and Standards, under Barry N. Taylor; Temperature Measurements and Standards, under James F. Schooley; Length and Mass Measurements and Standards, under Ralph P. Hudson; and Boulder's Time and Frequency, under James A. Barnes, and Quantum Physics (JILA), under Gordon H. Dunn.

A Center for Radiation Research, under James E. Leiss, incorporated the following divisions: Atomic and Plasma Radiation, under Wolfgang L. Wiese; Nuclear Radiation, under Randall S. Caswell; Radiation Physics, under Christopher E. Kuyatt; Radiometric Physics, under Jack L. Tech; and Radiation Source and Instrumentation, under Samuel Penner.

A Center for Thermodynamics and Molecular Science, headed by Milton D. Scheer, included five divisions. These were Surface Science, under Cedric J. Powell; Chemical Kinetics, under Wing Tsang; Chemical Thermodynamics, under David Garvin; Thermophysics, under Harold J. Raveche; and Molecular Spectroscopy, under Merrill M. Hessel. During 1981, CTMS was re-named the Center for Chemical Physics.

A Center for Analytical Chemistry, Philip D. LaFleur, Director, incorporated divisions for Inorganic Analytical Research, under I. Lynus Barnes; Organic Analytical Research, under Harry S. Hertz; and Gas and Particulate Science, under John K. Taylor.

A Center for Materials Science was formed, to be directed by John B. Wachtman, Jr. Its component divisions were Chemical Stability and Corrosion, under Thomas D. Coyle; Fracture and Deformation, under Sheldon M. Wiederhorn; Polymer Science and Standards, under Ronald K. Eby; Metal Science and Standards, under Arthur W. Ruff; Ceramics, Glass, and Solid State, under Hans P. R. Frederikse; and Reactor Radiation, under Robert S. Carter.

The Institute for Computer Science and Technology, directed by M. Zane Thornton after the departure of Ruth M. Davis, was transferred into the new organization without change.

## *Fine Tuning the New Organization*

As might be expected, the sweeping changes wrought during the 1978 reorganization received additional modification as the new units began to fulfill their intended purposes. Notable among these was the loss of Ambler's choice as his deputy director, Thomas A. Dillon. Dillon, completing his doctoral work as a chemical physicist in 1969, quickly became an itinerant manager; he joined the NBS Program Office in 1974, the Department of Energy in 1976, NBS again (as Ambler's deputy) in 1978, and the Department of Energy again in 1980. Ambler chose Raymond G. Kammer to replace Dillon as Deputy Director.

Most changes wrought by the original reorganization plan were mentioned in the descriptions given above. Later changes included the following:

- Incorporation of the Gaithersburg instrument shop into NEL as part of the Center for Manufacturing Engineering, taking advantage of progress in computer-based machine tools. Other changes in this center left it with—besides the new Fabrication Technology Division—a Mechanical Production Technology division, under Daniel Flynn; an Automated Production Technology Division, under Robert Hocken; and an Industrial Systems Division, under James Albus.
- Re-orienting and renaming of the Center for Thermodynamics and Molecular Science as the Center for Chemical Physics, Peter L. M. Heydemann, Director.
- Appointment of James H. Burrows, a mathematician who formerly supervised data processing for the U.S. Air Force, as permanent Director of the Institute for Computer Sciences and Technology.
- Incorporation of the Computer Services Division, Martin R. Shaver, Chief, into NEL as part of the Center for Applied Mathematics.
- Addition of a Building Equipment Division to the NEL Center for Building Technology.
- Addition of a Fire Performance Evaluation Division to the NEL Center for Fire Research.
- Creation of a Center for Chemical Engineering within the NEL. This new center, filling a much-needed void in the NEL roster of engineering disciplines, was headed by Jesse L. Hord. It encompassed the Fluid Mechanics, Thermal Processes, and Thermophysical Properties divisions, earlier included in the Center for Mechanical Engineering and Process Technology.

### *An Expanded Role for the Institute for Computer Sciences and Technology*

The Center for Computer Sciences and Technology, established in NBS in 1966 in response to the "Brooks Act" (PL 89-306, 1965), was made a separate organizational entity late in 1968 and given institute status in 1973. Its purpose was to prepare standards and guidelines for the purchase and effective utilization of computers by government agencies. Ruth Davis had seen the advantage of adding to that duty a substantial dose of computer science.

Unfortunately, when the "lead agency" concept took hold in the Federal government in the early 1980s, the Office of Management and Budget suggested that ICST should be transferred bodily to the General Services Administration, the agency in charge of government procurement.

Fate intervened, however; nearly intractable problems arose in the business and industrial sectors as they tried connecting computer components obtained from different sources. Inundated by the magnitude of the interfacing problem, they turned to NBS and to ICST for help. ICST scientists and engineers were ready with assistance based upon the creation of voluntary standards, much of it through research done at the Bureau. The Institute initiated the use of testbeds such as the Network Protocol Testing Facility, materially shortening the time and effort needed by the private sector to utilize computers as versatile business tools.

No longer did Bureau management hear suggestions that ICST was not a legitimate component of NBS.

The new organization lasted a decade. Under John Lyons, the National Engineering Laboratory sought to establish for the Department of Commerce a leadership position in industrial technology. The effort fit very well into the growing mood of Congress that there should be more that the Federal Government could do to foster competitiveness in the international arena for American firms. The consumer movement characteristic of earlier days was dying; it was being replaced by an emphasis on technology.

As noted above, Ernest Ambler's appointment as permanent director of NBS took place during the time that the last details of the 1977-78 Bureau reorganization were being decided.[22]

### *Reorganization Brings Stress*

The first major reorganization in 13 years brought peace to some NBS staff members, but upset and uncertainty to many more.

Responding to frequent calls from distraught employees, David Lesage, an employee development specialist in the Personnel Division, collaborated with psychologist Craig Wasserman of the University of Maryland to cope with employee uncertainty and stress that was connected to the re-arrangement of most operating divisions. The result was a lecture entitled "Organizational Change—Dilemma or Opportunity."[23]

The approach taken by Lesage and Wasserman was rooted in the notion that crisis embodied both danger and opportunity. Employees who enrolled in the course were reminded of the ways in which major change could be faced while minimizing destructive thoughts brought on by disturbances in their daily routine. Three major problems surfaced; loss of contact with accustomed co-workers; loss of "hard" information; and fear of re-assignment to less desirable projects.

Employees re-located into new situations—and there were many of these—were encouraged to discuss problems—both in new duties and in personal fears—with their new supervisors.

The 1977-78 reorganization was a nerve-wracking experience for many Bureau employees. Its real significance, however, was as a harbinger of change to come. With the reorganization, Ernest Ambler created a structure that he felt could more readily serve as a resource for the engines of America's technology.

[22] *NBS Standard,* Vol. 23, No. 3, February 8, 1978, p. 1.

[23] "Exploiting opportunities of change," *NBS Standard,* Vol 23, No. 5, p. 2.

## Other Administrative Activities During Ambler's Directorship

### *More Work for the Congressional Liaison*

Esther Cassidy continued in her position of Assistant to the Director for Congressional Affairs throughout Ambler's tenure as director. In 1973, she had left the laboratory for a Commerce Science Fellowship in Congress;[24] at the end of 1974, Director Richard Roberts had appointed her to the position of Assistant to the Director for Congressional Affairs. Ambler declared that appointment of such an assistant had been one of Director Roberts' most useful steps, providing NBS with a constant and informed contact for the ever-increasing communications with Congress. He noted that in one year alone—1984—some 120 Congressional staff members came to NBS for briefings.[25]

### *NBS/ERDA Energy Agreement*

Throughout the period when Ernest Ambler was director, the nation endured shortages of energy or rising energy costs. Frequently, both maladies were in evidence. As a result, energy conservation and alternative sources of energy to augment U.S. oil and coal supplies were continuing items in the Bureau's technical menu.

In November 1975, officials of NBS and the Energy Research and Development Administration—new home to former director Richard Roberts—signed a memorandum of understanding relating to ways that the Bureau could assist ERDA with its assigned duties. The memo provided for the transfer of funds to NBS for work in the areas of energy research and technology, including such alternative sources of energy as solar power. The agreement also embodied Bureau efforts in standards, measurement methods, and data acquisition, as well as technical consultations by NBS staff members. Considerable work was accomplished under the aegis of the agreement.

### *NBS Celebrates Its 75th Birthday*

During 1976, NBS staged a year-long celebration of its 75th year of service to the Nation with open houses at both its Gaithersburg and Boulder campuses, exhibits, symposia, workshops, and films. The party began on March 1, with a ceremonial visit to the Gaithersburg campus by Secretary of Commerce Elliot Richardson and the opening of a 4-day symposium staged by the Institute for Basic Standards. The symposium was titled *Measurements for the Safe Use of Radiation.*

March 3, 1976, the 75th anniversary of the creation of NBS, was marked by an address by Director Ambler and by the dedication of new exhibit areas in the Gaithersburg Administration building.

Lectures by distinguished scientists—Edward Teller of the University of California, Norman Ramsey of Harvard, William O. Baker of Bell Laboratories, Henry Eyring of the University of Utah, Garrett Birkhoff of Harvard, Alan Perlis of Yale,

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[24] *NBS Standard,* Vol. 20, No. 16, July 30, 1975, p. 3.

[25] Ernest Ambler, *SP 825,* p. 31.

In November 1975, during a period when the Nation's energy crisis seemed to demand action, Deputy Administrator of the Energy Research and Development Administration (ERDA) Robert W. Fri (left) and NBS Director Ernest Ambler signed a memorandum of understanding that Bureau scientists would assist ERDA in various technical capacities.

Robert C. Seamans of the Energy Research and Development Administration, and Simon Ramo of TRW Corporation—were given at Gaithersburg during March and April. A similar series at the Boulder laboratories opened with Arthur Schawlow of Stanford University, who spoke on February 11.

On April 5, the Institute for Applied Technology sponsored a symposium on Fire Standards and Safety.

A 3-day symposium on Computers in a Democratic Society was presented by the Institute for Computer Science and Technology during July. Also in July, the National Conference on Weights and Measures met in celebratory session on the Gaithersburg campus.

From September 20-24, a symposium on Methods and Standards for Environmental Measurement was presented by the Institute for Materials Research.

Open houses were held on the Gaithersburg campus from May 6-8 and on the Boulder grounds from October 14-16.[26] An estimated 50,000 people—many of them schoolchildren—visited the laboratories and grounds of the Gaithersburg site over the 3-day period. Dozens of selected tour stops featured imaginative presentations that described arcane projects in simplified terms.

[26] *NBS Standard,* Vol 21, No. 4, pp. 1, 8, February 25, 1976; ibid., No. 5, pp. 1-8, March 10, 1976; ibid., No. 10, pp. 4,5,8, May 19, 1976. Further details were given in other 1976 issues of the periodical.

At a former NIKE missile base adjacent to its Gaithersburg site, NBS engineers tested solar collectors in a project sponsored by the Energy Research and Development Administration. A key part of solar heating and cooling systems, the collectors were lowered into the former missile silos when not under test.

NBS scientist Freddy A. Khoury explained research in synthetic surgical implants to school children at an NBS Open House held in 1976.

### *The Fiscal Year Moves to September 30th*

During 1976, the fiscal year of the Federal government was delayed by a quarter-year to give the Congress more time to appropriate funds for government activity for another 12 months. The end of Fiscal Year 1976 took place on June 30, 1976; then a short, quarter-year funding cycle carried all the agencies through to September 30, 1976, whereupon Fiscal Year 1977 began.

The gambit could hardly be called a success, if judged by the need—which periodically recurred long after the change—for "continuing resolutions" to carry the government into a new fiscal year when the appropriations bills had not been passed in a timely fashion.[27]

[27] See, for example, Eric Pianin and Juliet Eilperin, "Hill Passes Temporary Spending Measure," *The Washington Post*, September 29, 1999, p. 1. In its lead paragraph, the authors explain, "The [Congress] voted yesterday for a temporary spending measure that would keep the government open for another three weeks as it tries to resolve internal differences . . ."

### *NBS/EPRI Agreement*

The Electric Power Research Institute, a nonprofit organization funded by all sectors of America's electric utility industry, was created to advance electric-power technology by means that were sound not only from a technical viewpoint, but on environmental and energy-conservation grounds as well.

During 1976, Director Ernest Ambler of NBS signed a Memorandum of Understanding (MoU) with Chauncey Starr, President of EPRI, which involved the Bureau directly in EPRI projects. As might be expected, the NBS contribution was to be heavily slanted towards measurement technology—on equipment, power generation, power distribution, and methods of power usage.

Five areas where EPRI expected the most help from NBS, according the MoU, were the measurement of electrical and electromagnetic quantities, physical-properties data, evaluation of devices and control systems, mathematical and computer-aided design, and energy conservation methods at all stages of power generation, distribution, and use.

### *A Distinguished Federal Servant*

On Jan 12, 1977, Ambler received the President's Award for Distinguished Federal Service in the East Room of the White House. The award was presented by Vice President Nelson A. Rockefeller. Ambler was the first NBS employee and only the second Commerce employee to receive the award. Secretary of Commerce Elliot L. Richardson and former NBS directors Roberts, Branscomb, and Astin also attended.[28] The citation read in part:

> His extraordinary accomplishments in the fields of low temperature and nuclear physics, his brilliant work which invalidated a previously accepted fundamental law of physics, and his leadership as Acting Director of the National Bureau of Standards, have been of great importance to the Nation and the world.

The President's Award was only the latest of many for Ambler. His experimental work with Ralph Hudson, Raymond Hayward, and Dale Hoppes, performed in conjunction with C. S. Wu of Columbia University, demonstrated the non-conservation of parity in weak nuclear interactions and earned him and his colleagues several major awards. Over the years, Ambler received the Department of Commerce Gold Medal, the Arthur S. Flemming Award, the John Price Wetherill Medal of the Franklin Institute, the NBS Stratton Award, a 1-year John Simon Guggenheim Memorial Foundation Fellowship, the Washington Academy of Sciences Award, and the William A. Wildhack Award.

[28] *NBS Standard,* Vol. 22, No. 2, January 26, 1977, p. 1.

*Oversight Hearings*

During the tenure of Lewis Branscomb as director, the Bureau was the subject of oversight hearings by the Subcommittee on Science, Research, and Development of the House Committee on Science and Astronautics. On October 25, 1977, another day of hearings began, this time by the Subcommittee on Science, Research, and Technology of the House Committee on Science and Technology. Remarkably, the House hearings were followed a few months later by Senate oversight hearings, the first anyone could remember.

As might have been expected, the testimony of Ernest Ambler dominated the hearings on October 25. His testimony was heavily buttressed, however, by statements from Jordan J. Baruch, the Commerce Department Assistant Secretary for Science and Technology; from Charles E. Peck of Owens-Corning Fiberglass Corporation, representing the NBS statutory Visiting Committee; and from William O. Baker of the Bell Telephone Laboratories, representing the views of the evaluation panels chosen by the National Academy of Sciences and the National Research Council to review the work of the NBS technical divisions.

Jordan Baruch, who opened the session, testified to his respect for NBS. "NBS," he said, "is in many ways a unique institution." Baruch enumerated the wide range of Bureau activities and its worldwide reputation for excellence and objectivity, praising the agency for providing the Nation with measurement know-how that spanned the scientific, technical, and commercial sectors. Significantly, Baruch pointed to NBS as a potentially powerful ally of the fading U.S. industrial prowess in the arena of international commerce.

Ambler, in the midst of staff discussions regarding the major reorganization of 1977-78 (discussed previously in this chapter), described the facilities of NBS, its staff, its budget,[29] its congressional mandates,[30] its major activities, and its problems. In discussing the last category, Ambler sounded a warning that all was not well with the Bureau. His message noted unfunded Congressional assignments, a staff too often called upon to solve short-term problems at the expense of long-term competence, and an effort to design a more effective management structure.

Peck, at that time Chair of the statutory Visiting Committee, continued the somber theme. Peck quoted from a recent report of the five-member committee:

> NBS is on the brink of serious trouble. The persistent retrenchment that has taken place threatens to bring NBS to a mediocrity that is unacceptable. Shocking gaps exist in NBS' ability to carry out its basic assignment, even without supplemental assignments. New assignments thrust on the Bureau

[29] In Fiscal Year 1977, $70 million of direct appropriations, $48 million from other government agencies for consultations on their problems, and $6 million in calibrations and fees.

[30] These included the recent additions of the *Brooks Act of 1965; the Federal Non-Nuclear Research and Development Act of 1974; the Fire Prevention and Control Act of 1974; the Energy Policy and Conservation Act of 1975;* and the *Resource Conservation and Recovery Act of 1976.*

without funding or personnel have forced NBS leadership into defensive management, whereby long-range programs are sacrificed to salvage short-term objectives.

One study indicates that basic research in constant dollars may have dwindled to half the level of 10 years ago. Fifteen new laws since 1965 have given NBS assignments, yet the NBS overall budget in constant dollars has not increased.

NBS has had four different directors in 10 years. The present head has been in an "acting" status for two years. "Temporary" management cannot do a strong job.

The Visiting Committee had pulled no punches in its condemnation of the poor care given NBS by the Office of Management and Budget, the Department of Commerce, and the Congress. Peck was glad for the opportunity to testify on behalf of the beleaguered scientists.

Speaking for the many divisional evaluation panels, Baker expressed his admiration for NBS support of the Nation's science and technology. He reviewed the existing organization of the Bureau and threw the weight of the panels behind the dire assessment given by the NBS Visiting Committee.

The hearings gave the House subcommittee some things to think about.

Senator Adlai E. Stevenson, III, chaired oversight hearings on NBS held by the Senate Committee on Commerce, Science, and Transportation, Subcommittee on Science, Technology, and Space during February and April of 1978. Stevenson confessed uncertainty regarding the precedent for Senate oversight:

> This is the first congressional oversight hearing for the Bureau in memory. We haven't been able to figure out when the last one was, if ever, in the Senate. We aim to remedy that neglect. Our objective is a strong NBS which continues to contribute to the scientific and technical capabilities of the United States.

The February Senate hearings were short. The Congress was in recess, so that only Stevenson was present. Nevertheless, four leading Bureau managers presented testimony—Ambler; John Hoffman, director of the Institute for Materials Research; John Lyons, recently appointed director of the Institute for Applied Technology; and Zane Thornton, acting director of the Institute for Computer Science and Technology. The topics discussed included the proposed NBS reorganization, which received final approval on March 8, 1978; a program in cooperative technology, included in the Fiscal 1979 budget; and overviews of the NBS institutes.

On April 6, 1978, the Senate oversight hearings continued. Jordan Baruch once again testified to the quality of work done at NBS, cautioning, however, that the Bureau was "stretched thin" by its variety of new assignments. Baruch was followed by W. Dale Compton of Ford Motor Company, William Baker of the Bell Laboratories, and George E. Brown, Jr., congressman from the 36th district of California. Once again, the nascent cooperative technology program came under discussion, along with the question of periodic oversight hearings. Ambler suggested that reviews on a 2-year or 3-year cycle might be appropriate.

Later, Congress decided that it should review the authorization of NBS funding on a 1- or 2-year cycle, in place of the continuing authorization used for so many years. Olin Teague, chair of the House Science and Technology Committee, suggested that periodic review would "assure that the Bureau of Standards will indeed be able to make its maximum contribution" to the Nation. In fact, hearings on the NBS authorization became an annual ritual.

On February 1, 1980, George Brown, chair of the House Subcommittee on Science, Research, and Technology, opened a 6-day hearing on the NBS FY 1981 budget authorization. The hearings were historic in that they were held at NBS, in the Red Auditorium.

Ernest Ambler, Thomas Dillon, John Hoffman, James Burrows, John Lyons, and Ray Kammer presented their views of the Bureau, either in prepared statements or in answer to the many questions posed by the committee members. Joining Rep. Brown were Reps. Don Fuqua and Alan Ertel. In questions and comments, the committee members expressed respect for NBS and support for its mission and needs.

Following the presentations and question-and-answer sessions, the Congressional delegation toured the Gaithersburg site.

### *Remaking the Civil Service*

As part of his plan to streamline the Federal government, President Jimmy Carter proposed on March 2, 1978, that the Civil Service should be reformed. If accepted by the Congress, the changes would affect 2.1 million Federal employees.

Carter's proposal was intended to affect all aspects of government service—hiring and firing, pay, grievances, transfers, and retirement.

After some debate, the Senate Governmental Operations Committee voted on July 24, 1978, to support the major features of Carter's proposal, and the Civil Service Reform Act was signed by the president on October 13, 1978.

The principal provisions of the 116-page law established new job performance standards. It also established a new type of government employment, the Senior Executive Service, composed of nearly 11,000 high-level managers who were subject to re-assignment from agency to agency. The Civil Service Commission was abolished, to be replaced by an Office of Personnel Management, a Merit Systems Protection Board, and a Federal Labor Relations Authority.

It would take some time before the changes wrought by the new act would be fully assimilated by the nation's Federal civil servants.

### *Scrutiny From a Conservative Administration*

President Reagan's avowed goal of reducing the reach of the Federal Government in areas that could possibly be served by private-sector efforts, coupled with the ever-growing budget deficit, forced NBS to justify many of its programs over and over again throughout the 1980s. Two government-wide surveys and continued scrutiny from the Administration's Office of Management and Budget kept the Bureau on constant alert.

The President's Private Sector Survey on Cost Control, chaired by J. Peter Grace and consequently known as the Grace Commission, undertook a monumental survey of the entire federal government during 1982 and 1983, looking for ways to economize. A total of 47 volumes eventually made up the report of the Commission—one of them devoted entirely to the Department of Commerce.

The 45-member Commerce Task Force spent, by their own count, 80 person-months studying the department. They suggested that substantial cost savings (some $45 million over 3 years) could be realized within NBS alone. The savings could result, they said, by eliminating certain activities that could be accomplished by the private sector and certain other activities that showed high cost/benefit ratios. Still other savings could be realized by generating more financial support for certain projects from the using public. Six of the NBS centers—Chemical Engineering, Manufacturing Engineering, Fire Research, Building Technology, Analytical Chemistry, and Materials Science—were cited as potential sources for the savings.

Fortunately for the Bureau, the "using public," which depended heavily upon NBS scientific and engineering expertise, became vocal in defense of the Bureau. Largely through their efforts, damage to NBS programs from the Grace Commission recommendations was minimal.

The White House Science Council Federal Laboratory Review Panel visited NBS on November 28, 1982. The panel was chaired by David Packard, Chairman of the Board of Hewlett-Packard Company; members included John Bardeen of the University of Illinois, D. Allan Bromley of Yale University, Donald S. Fredrickson of the Howard Hughes Medical Institute, Arthur K. Kerman of MIT, Edward Teller of Stanford University, and Albert D. Wheelon of Hughes Aircraft. The Bureau was one of 16 laboratories visited, surrogates for some 700 laboratories operated either for or by the Federal government.

The panel had been asked by George A. Keyworth, Science Advisor to the President, to review the operations of the laboratories with an eye to improving their use and performance. In contrast to the suffocating recommendations offered by the Grace Commission, NBS Director Ernest Ambler found in the *Packard Report*[31] valuable guidance for the future of the Bureau.[32]

The panel focused on five features regarded as crucial to the success of the laboratories. The features and brief synopses of panel recommendations follow:

- Mission—must be clearly defined and consistent with Federal goals.
- Personnel policies—should be changed to operate outside of normal civil service restrictions, in order to attract high-quality staff.
- Funding—should be multi-year, with 5 %-10 % devoted to independent research.
- Management—should include outside peer review of laboratory management and operations.
- Interaction with universities, industry, and users of laboratory outputs—access to Federal facilities, collaboration, and contracting should be encouraged.

[31] *Report of the White House Science Council Federal Laboratory Review Panel,* Office of Science and Technology Policy,Washington, DC, 20500, May 1983.

[32] Ernest Ambler, *SP 825,* pp. 33-34.

After meeting with Packard to discuss details of the report, Ambler was determined to follow its recommendations. He gave particular significance to refining the NBS mission with regard to assisting U.S. industrial prowess, to strengthening ties with outside organizations, and placing more emphasis on outside review of NBS work. Ambler noted several ways in which NBS improved its record during the following years:

- By 1986, the number of Industrial Research Associates at NBS reached 255, three times the number in 1980.
- By 1987, the number of cost-sharing projects with industry reached 244, with 174 different companies involved. Gifts and loans of equipment similarly increased.
- Other-agency funding and earned income both increased markedly during the 1980s.
- NBS was the scene of a 5-year *Personnel Management and Demonstration* project, beginning in 1988.

During the Reagan administration, the Office of Management and Budget, pursuing the cost-cutting effort that drove the Grace Commission, viewed several programs at NBS as candidates for elimination or privatization. The National Academy of Science-National Research Council postdoctoral research associate program, a primary source of scientific talent for NBS, was earmarked for elimination at one point. The NBS library became a candidate for privatization. The OMB questioned NBS expenses for travel, even to scientific meetings, and Bureau costs for printing and reproduction. Even funds spent for scientific consulting were challenged in a serious effort to reduce the cost of government.

All of these efforts to truncate the work of the Bureau required detailed justification, both from within and outside NBS. Most of the NBS responses came from the staff of the Bureau's Office of Programs, Budget, and Finance. The PBF staff spent the decade of the 1980s in continual motion to minimize the cost to NBS of a strong national defense.

Complicating Ambler's management during 1982 was the loss of Deputy Director Raymond G. Kammer. Kammer left on a temporary assignment to the Department of Commerce to assist the National Oceanic and Atmospheric Administration in its efforts to procure a new radar system. In Kammer's absence, John W. Lyons served as Deputy Director of NBS. As part of his new duties, Lyons utilized the opportunity to broaden his knowledge of Bureau programs and personnel.

### *Updating NBS Computers*

NBS scientists, mathematicians, and engineers were heavily involved in computer development even before the first ENIAC (Electronic Numerical Integrator and Automatic Computer) was built at the University of Pennsylvania in 1947. At the request of the Bureau of the Census and the Office of Naval Research, NBS prepared computer design specifications for those agencies just after the close of World War II.

To test computer components, train operators, and provide computations for its own staff, the Bureau built the Standards Eastern Automatic Computer (SEAC) at the same time. It went into service during June, 1950. SEAC was the first general-purpose, stored-program computer in the U.S. It was used for 14 years; for a remarkable 4000 hours, it performed without a malfunction.

Keeping the Bureau abreast of the revolution in computers turned into a complicated problem while Ernest Ambler was still director of the Bureau's Institute for Basic Standards. The initial problem for NBS was difficult enough—to replace its badly outdated central computer. The large expense involved in the replacement had to be justified in terms of large need. As time went on, however, the issue of central main-frame vs minicomputers and even smaller units became an equally thorny one.

The situation was complicated by the rationale used to support the central computer—running time on the machine was charged to individual project funds. Machine time was sufficiently expensive that the computer was idle for a substantial portion of each day. Some staff members argued for reduced-cost or free use of the computer so that it would be utilized more fully.

During the late 1960s, minicomputers with relatively high capacity became available. As early as 1970, Harvey A. Alperin and Edward Prince of the Reactor Radiation Division reported the installation of a "medium-sized" computer that was used in a time-share mode to control data acquisition by a group of eight instruments at the NBS reactor and to perform computations in real time.[33] The most "computer literate" of the scientific and engineering staff foresaw the use of small, dedicated computers both for off-line calculations and direct interactive support of laboratory data-taking.[34] Some scientists argued that the purchase of several "mini-computers" might eliminate the need for a central facility. In fact, the Bureau administration was reluctant to allow the purchase of smaller machines for fear of weakening its case for a new central mainframe computer.

Faced with a virtual ban on minicomputers, scientists with more need for computer use than they had project funds to pay for machine time sought out colleagues in other organizations who could share time on minicomputers which, once purchased, could be used full-time with nearly no further expense.

As director of NBS, Ambler found the problem still alive and troublesome; there was still no new central computer. By 1975, the lack of computational facilities was damaging the Bureau's ability to attract top-ranking scientists to its laboratories.

Like his predecessors, Ambler saw a continuing need for a central NBS computing facility which could be used for scientific calculations and data reduction by the technical staff as well as for record-keeping and secretarial functions by the administration. His advisors envisioned a network linking individual laboratories to a central

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[33] H. A. Alperin and E. Prince, "A time-shared computer system for diffractometer control," *J. Res. NBS* **74C**, Nos. 3, 4, 89-95 (1970).

[34] This viewpoint was supported by a "Statement of ADP Policy for NBS," *NBS Standard,* Vol XV, No. 8, August 1970, pp. 4-5.

"supercomputer." To this end, he continued attempts to justify and fund a new, high-capacity main-frame machine. However, requests to the technical staff for information on their present and foreseeable computer needs met with resistance; already saddled with heavy costs for computation on the outdated central computer, some staff members feared that their project funds would be hit with still larger bills if their true needs were known. Also, Ambler found himself in the unenviable position of discouraging acquisition of laboratory-size computers—ever smaller and ever more powerful—in order to maintain demand for a central computer.

Eventually NBS, largely through the personal efforts of Ambler and a substantial group of advisors including Eleazer Bromberg, Burton H. Colvin, Glenn R. Ingram, Stephen White, Richard T. Penn, John W. Lyons, and Guy W. Chamberlin, Jr., obtained both departmental permission and the money to buy a new central computer. It was delivered in 1985 and became operational in 1986.

By the time the new central computer was in place, the question of main-frame *vs* individual computer was moot. Hundreds of relatively inexpensive, powerful desk-top computers were in use to run experiments, record and process data on-line, and function as private secretaries as well. Similar stand-alone units quickly came into use in secretarial offices throughout NBS. Because the secretarial staff had no experience in word-processing, NBS provided assistance in several forms: a computer-assistance office was formed under the leadership of Patsy Saunders to create standard procedures for office computing; and a newsletter was created to take some of the "magic" out of the computerized office.

The availability of computers to run laboratory experiments at NBS, to acquire and process data, and to facilitate the communication of results constituted an enormous gain in the efficiency and productivity of Bureau scientists and engineers. Similar advantages accrued to administrative workers. But the development was a painful one.

### *New Legislation for NBS*

During the tenure of Ernest Ambler, a raft of new legislation brought new duties to NBS. Among the new congressional acts were the following:

- *Energy Policy and Conservation Act* (PL 94-163), 1975. This act called upon the Federal Energy Administration to direct NBS in the development of appropriate test procedures relating to energy conservation, including recycled oil. At NBS, the mission of the Center for Consumer Product Technology was altered: the Appliance Labeling Section was re-named the Product Standards Development Section; the Consumer Behavior and Information Section was abolished; the Electronics and Instrumentation Section and the Electrical and Mechanical Engineering Section were combined into an Advanced Measurement Technology Section; and the Product Systems Section was re-named the Product Safety Engineering Section.

- *Metric Conversion Act of 1975* (PL 94-168). This act instructed NBS to help the National Conference on Weights and Measures with its project on metric education for state governments.

• *National Science and Technology Policy, Organization, and Priorities Act of 1976* (PL 94-282). This act established an Office of Science and Technology Policy for the White House. It also instructed the President to form a President's Committee on Science and Technology. The legislation reflected congressional disappointment over the loss of direct science advice during the Nixon and Ford administrations.

• *Energy Conservation and Production Act* (PL 94-385), 1976. In this act, the Federal Energy Administration was instructed to direct NBS in the development of energy-efficiency-improvement targets for major household appliances. The Department of Housing and Urban Development was called upon to promulgate performance standards for commercial and residential buildings.

• *Resource Conservation and Recovery Act of 1976* (PL 94-580). Provisions of this act instructed NBS to assist the Office of Solid Waste of the Environmental Protection Agency on a reimbursable basis.

• *Clean Air Act, Amendments of 1977* (PL 95-95) and Clean Water Act of 1977 (PL 95-217). In these acts, NBS was assigned to assist the EPA as requested.

• *Earthquake Hazards Reduction Act of 1977* (PL 95-124). NBS was called upon for analysis and testing as part of this Act.

• *Federal Mine Safety and Health Amendments Act of 1977* (PL 95-164). Among other provisions, this act placed the NBS Director on a mine-safety advisory committee.

• *Federal Fire Prevention and Control Act of 1974,* amendment (PL 96-121), 1979. This act updated the NBS Organic Act with respect to the 1974 law.

• *Trade Agreements Act of 1979* (PL 96-39). This act resulted in NBS becoming the inquiry point for the provision of the General Agreement on Tariffs and Trade that pertained to technical barriers to trade. It also led to the establishment at NBS of a National Center for Standards and Certification Information and to a technical office for non-agricultural products.

During October 1980, President Carter signed into law five more bills of interest to NBS:

• *The NBS Authorization Act for Fiscal Years 1981 and 1982* (PL 96-461) authorized the expenditure of $107. 6 million during Fiscal Year 1981 and $142.4 million during fiscal 1982. The act also contained two amendments to the NBS Organic Act; it increased the amount of appropriated funds available for refurbishing buildings, and it provided new authority for international activities. NBS was allowed to provide financial assistance to foreign scientists to work at NBS, and NBS employees working at foreign institutions were allowed to receive financial assistance, fellowships, and lectureships. It also allowed the Secretary of Commerce to support foreign scientists studying at NBS.

• *The Federal Emergency Management Act* (PL 96-472) authorized NBS to spend $425,000 for earthquake hazard work during fiscal 1981. It also authorized FEMA $1 million for use by NBS earthquake scientists and $4.3 million for use by the NBS fire research program (see A Hectic Decade for NBS Fire Science later in this chapter).

• *The National Materials and Minerals Policy, Research, and Development Act of 1980* (PL 96-479) required the Commerce Department to provide by January 1981 a case study identifying specific materials needed for national security, economic well-being, and industrial production. The act also required the department to provide by October 1981 an assessment and recommendation for programs to meet the identified needs.

• *The Used Oil Recycling Act of 1980* (PL 96-463) updated provisions of PL 94-163. NBS was instructed to continue its oil recycling program, but the act forbade identifying oil as recycled until the study was complete and the Federal Trade Commission had promulgated suitable labeling rules. The act also mandated assessment of environmental problems caused by improper disposal or reuse of recycled oil, analysis of the supply and demand for used oil, and comparison of the energy savings associated with refined used oil.

• *The Stevenson-Wydler Technology Innovation Act of 1980* (PL 96-480) authorized the Secretary of Commerce to create Centers for Industrial Technology, jointly financed by industry and government, and affiliated with universities or other nonprofit corporations; and to develop and transfer new technologies through a Research and Technical Applications Office to industry, to state governments, and to local governments. Beginning in FY 1982, the department, along with other Federal departments with in-house research laboratories, was to set aside 0.5 % of its research and development budget for the support of technology transfer functions. Within NBS, an Office of Research and Technology Applications was established to carry out the Wydler-Stevenson activities.

• In 1981, amendments were added to the *Earthquake Hazards Reduction Act of 1977 and to the Federal Fire Prevention and Control Act of 1974.* These amendments mainly affected the NBS Fire Research Center.

• *The Federal Technology Transfer Act of 1986* (PL 99-502) established within NBS a Federal Laboratory Consortium for Technology Transfer.

• *The Computer Security Act of 1987* (PL 100-235) established within NBS a computer standards program to provide for government-wide computer security and training in computer security.

• By the end of 1987, there could be no doubt of the view of many in Congress that NBS was ideally suited to the task of transferring technology to American industry. As it had in the past, the Bureau provided quick and effective responses to congressional requests. It was time to build the new mission into the NBS Organic Act. This change was accomplished by the last legislation to be mentioned in this section: the *Omnibus Trade and Competitiveness Act of 1988* (PL 100-418), which renamed NBS as the National Institute of Standards and Technology and amended the agency's Organic Act. This act is the principal subject of the next chapter.

### *Foreign Guest Workers*

NBS always welcomed visits by scientists from foreign countries. The numbers of foreign visitors and guest workers increased as the effect of the *NBS Authorization Act for Fiscal Years 1981 and 1982* (PL 96-461), which changed the ground-rules for foreign scientists, was felt throughout the Bureau. Visitors continued to come from the "usual" places—England, France, Germany, Australia, Japan, and the other industrialized nations— but increasing numbers arrived from countries with less industrial development. Korea, Mexico, China, and Brazil, among many others, sought to find the key to economic progress in the Bureau's activities in science and technology.

Under the Protocol for Cooperation between NBS and the State Bureau of Metrology of the People's Republic of China, for example, three guest workers—all women—reached NBS during the summer of 1980. The three, chemists interested in learning some of the newest measurement techniques, represented the Chinese National Institute of Metrology:

- Pan Xiurong, Chief of the Institute Chemistry Laboratory, was responsible for a project in standard reference materials. She came to study the Bureau's Standard Reference Materials program.
- He Xiheng, a thermodynamicist, participated in the work of the Chemical Thermodynamics Division project in refuse-derived fuels.
- Feng Fengdi, interested particularly in instrumental analytical chemistry, worked with Robert Watters on computerized trace analysis.

The three scientists were typical of a growing number of foreign visitors to NBS.

### *Reagan's RIF*

In April 1981, nearly 3 years had passed since the 1978 oversight hearings had featured plain warnings by observers of NBS that the Bureau was seriously understaffed and underfunded. If President Reagan was aware of those alarms as his 2-term tenure began, he was indifferent to them. Reagan announced a plan to decrease the size of the Federal work force in non-defense agencies. For NBS, the edict amounted to a loss of about 300 of its employees (10 %) by the end of Fiscal Year 1982.

In the *NBS Standard* for April 29, 1981, Director Ambler noted that NBS was already over its personnel ceiling at the end of the Carter administration, having expected relief in the Fiscal 1981 budget but receiving none.

Ambler expected about 100 employees to leave via attrition and reprogramming during the 18-month period of the downsizing; the rest would be released through a Reduction in Force (RIF) action. A table was offered to identify the numbers of employees to be separated from the Bureau—by one means or another—during Fiscal 1981.

John Hoffman and John Lyons, heads of the two major NBS units, each proposed to use programmatic criteria in enacting the RIFs. A "Job Search Assistance Program" was initiated by the Bureau Personnel Division to assist employees affected by the RIF to find other work, either at NBS or elsewhere. The JSAP augmented the long-existing Employee Assistance Program.

The RIF was begun immediately after it was announced, to minimize the inevitable impact on employee morale. So-called "bumping rights," allowing employees who received RIF notices to displace other employees with similar duties but less job security, affected many Bureau staffers who were not initially touched by the RIF actions. It was an unhappy time for NBS.

### *NBS Voice Grows Weaker*

Another of President Reagan's economies throttled the Bureau's voice. The employee newsletter, The *NBS Standard,* for a quarter-century the prime means by which employees received news of each other and a significant mechanism used by management to communicate news of administrative changes, was abolished in the name of cost efficiency after publication of the July 22, 1981, issue. It was to be replaced by "regular features or columns from each Commerce agency" in a department publication, *World of Commerce.*

Three months after losing its internal voice, NBS lost *Dimensions/NBS,* the monthly magazine by which the Bureau had communicated with two generations of technical readers worldwide. Begun in 1917 as the *NBS Technical News Bulletin* and continued in 1976 as *Dimensions/NBS,* the magazine offered news of scientific projects written in understandable prose, schedules of meetings of scientific and technical groups, and availability of NBS reports and standards, including Standard Reference Materials. Cessation of the publication was "in line with reduced government spending."

As it did with other economies practiced by the Reagan and other presidential administrations, NBS management played the good soldier with no complaint as two of its communications lines went down. There was no choice in the matter.[35]

### *Organic-Act Hearings, 1981*

The House Subcommittee on Science, Research, and Technology held hearings on the NBS Organic Act on June 16-19, 1981. It was the intention of subcommittee members to review the adequacy of the act that created the Bureau in 1901; drafts of proposed amendments to the 1901 legislation were at hand. Subcommittee member Don Fuqua urged his fellows to take care that any revisions of the Organic Act not deter NBS from useful work on behalf of America. Rep. Douglas Walgren, subcommittee chair, suggested that the relevant question was, "What should the Bureau be doing for the country 5, 10, and 20 years from now?"

[35] John W. Lyons, suffering under the same communications ban during his term as Director, recalled instituting a monthly newsletter to the staff. The size of the newsletter gradually expanded to contain information on activities throughout NIST, thus mitigating the effect of the ban.

During the hearings, Secretary of Commerce Malcolm Baldrige, only months into his new position, gave a ringing endorsement to NBS:

> I view it as one of the best in the world.
> It would be a mistake to alter the mission of the Bureau or otherwise affect its operations by legislation until we have seen what develops from its new relationship to the rest of DoC.

At issue in the hearings were several proposed modifications to the Bureau's environment: a possible new Under Secretary of Commerce for Economic Affairs, who might influence NBS programs; Bureau participation in the work of the International Trade Administration; possible return to NBS of the National Technical Information Service and the Office of Product Standards Policy; and the proper Bureau role in industrial technology development, especially including automation research.

Baldrige stressed his view that NBS should remain primarily a research laboratory, despite its involvement in America's industrial development.

### *The Malcolm Baldrige National Quality Award*

Secretary of Commerce Malcolm Baldrige died in 1987, a victim of his love for riding in rodeos. Friends of Baldrige in Congress, seeking an apt memorial, gave his name to a new suggestion—an award for industrial excellence. Such an award, named for W. Edwards Deming,[36] was given periodically in Japan.

New Commerce Secretary C. William Verity asked NBS to manage the competition for the award.[37] Ambler in turn assigned Curt Reimann to the task. Reimann was a good man for the job, since he had a long-standing interest in quality control and was familiar with the quality-control community in the United States and abroad.

Operating without any special funding, Reimann quickly raised money from the private sector for the project and recruited industrial representatives to develop criteria for the award and to spearhead the selection process.

So effective was Reimann that it became possible to present the first awards on November 14, 1988. President Reagan showed his interest in the concept by his personal participation; Vice President George Bush and several of the Reagan cabinet members also attended the ceremony.

The success of the project led to awards for both Reimann and Ambler—cash for the former, the Secretary of Commerce Medal for the latter.[38]

Management of the Baldrige Quality Award became a continuing function for NIST. Competition for the award became keen among U.S. industrial firms, and NBS

[36] Andrea Gabor, *The man who discovered quality: how W. Edwards Deming brought the quality revolution to America: the stories of Ford, Xerox, and GM* (New York: Times Books/Random House, 1990).

[37] Ambler, *SP 825*, pp. 38-39.

[38] This was the first award of the Secretary's Medal to a government official.

became more secure in the role given it by Congress to "assist industry in the development of technologies and procedures needed to improve quality and modernize manufacturing processes." By 1991 NBS publicists could write:

> The Malcolm Baldrige National Quality Award has quickly become both the U.S. standard of quality achievement in industry and a comprehensive guide to quality improvement. Tens of thousands of U.S. companies are using the application guidelines to evaluate their operations in seven key areas of quality management and performance—leadership, information and analysis, planning, human resource use, quality assurance of products and services, quality results, and customer satisfaction.[39]

### *Civil Servants by Day, Public Servants by Night*

A variety of motives prompted many NBS employees to become active in civic affairs. Some sought an outlet for extra energy, but many more simply saw a need that they could fill on a part-time basis. Both Gaithersburg and its environs and Boulder and its environs offered plenty of opportunity for public service.

It would be very difficult to record all of the instances of public service among Bureau staffers over the years, but it would be unkind to omit some mention of the activity.

Examples of public service during Ernest Ambler's tenure as director included, in Montgomery County, Maryland, home of NBS/Gaithersburg:

- John Menke, Center for Radiation Research, who served on the Montgomery County Council.
- Larry Fischer, Product Performance Engineering Division, who served as a consumer representative for the Washington Suburban Sanitary Commission.
- David Hogben, Statistical Engineering Division, President of the Greater Glen Mill Community Association.
- Donald R. Johnson, Deputy Director, National Measurement Laboratory, member of the Gaithersburg Planning Commission.
- Julius Persensky, Center for Consumer Product Technology, member of the Gaithersburg City Council.
- Gene Rowland, Deputy Director, Center for Mechanical Engineering and Process Technology, member of the Maryland State Advisory Commission for Industrialized Buildings and Mobile Homes.

[39] "Malcolm Baldrige National Quality Award," p. 6 in "Research, Services, Facilities: National Institute of Standards and Technology," *NIST SP 817*, August 1991, 88 pp.

In 1988, exemplars of American industrial excellence began to receive the Malcolm Baldridge National Quality Award, named for deceased Secretary of Commerce Malcolm Baldridge, Jr.

In Boulder County, Colorado, home of the NBS/Boulder Laboratories:

- William L. Gans, Electromagnetic Technology Division, member of the Boulder County Housing Authority.
- John L. Workman, Electromagnetic Fields Division, Mayor of Nederland, Colorado.

## Ambler's Impact on NBS

Ernest Ambler was an important figure in the history of NBS. His scientific work gained international renown for himself and the Bureau. He served as chief of the Cryogenic Physics Section and the Inorganic Materials Division, as director of the Institute for Basic Standards, and as Richard Roberts' deputy before commencing a long tenure as Acting Director and Director of NBS. His leadership of the Bureau was instrumental in the transition from NBS to NIST.

### *Win Some, Lose Some, But Keep On Leaning*

Ernest Ambler directed the work of the National Bureau of Standards for nearly 14 years, longer than any save Samuel Stratton and Allen Astin. It can be argued that Stratton's administration of the Bureau was the most tumultuous—he personally carried the nascent agency through its infancy, successfully and continually marshalling new congressional support in order that NBS could undertake new and needed projects. It can also be argued that Astin personally brought the Bureau through a perilous time, overseeing the dispersal of one-third of its war-time staff to other agencies, seeing his agency pilloried as unfair to American enterprise, and finding himself called upon to resign, only to leave his post years later of his own volition with the reputation of NBS at an all-time high. But one can make a case that Ambler, too, brought his agency through a decisive period of its existence.

Heavy pressure on NBS during Ambler's tenure as director came from two sources. From the administrations of Presidents Carter and Reagan—both innately suspicious of big government and both determined to prune it—came calls for the privatization of the national standards of measurement; for abandonment of the postdoctoral research associate program; for disposal of the NBS fire program, its building-technology program, its library, its Personnel Division, its Instrument Shops, its NBS procurement group; and for an end to publication of the *Journal of Research*, the *NBS Dimensions* magazine, and the *NBS Standard*. From the Congress came ever-louder urging for the Bureau to do more for cooperative technology, industrial productivity, technology transfer, international competitiveness—many names for the same idea.

Ambler intuitively resisted administration attempts to weaken NBS; the threat to its postdoctoral program he found especially dangerous. Some of those battles he won, some he lost. But Ambler had learned one lesson well during a decade of management at the Bureau—"keep on leaning." He recalled the lesson during a 1991 retrospective speech:[40]

> I did not relish the thought of working with the government machinery outside NBS, but I was prepared to be patient and take it on.
> Above all, you kept coming back and improving your presentation and your own sense of conviction and commitment. "Keep on leaning" became my motto.

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[40] E. Ambler, *NBS Special Publication 825*, April 1992, p. 32.

On the other hand, Congressional calls for NBS to assist American industry struck a responsive chord in Ambler early in his tour as director. Here was a niche that offered an expanding future for the Bureau.

### *Leaning Towards Industrial Productivity*

In a revealing preface to a report on progress at NBS during 1979 and 1980, Ernest Ambler wrote:[41]

> I would like to focus for a moment on the future, and on how NBS research can help find solutions to this country's most important and complex problems. Energy, environment, health, public safety are quite familiar. Relatively new challenges with equally important consequences for our standard of living and general economic strength are the needs for improved industrial innovation and productivity.

In the introduction to that report, the following statement appeared:

> During 1980 every effort has been made to tailor the research programs of (NBS) to the technology needs of the coming decade.

The text continued with a brief discussion of the effort to maintain and enhance both the NBS facilities and its staff in the fundamental areas of science and engineering that were seen as vital to coming national needs. Then it directed the reader's attention to projects intended to "bolster industrial productivity while encouraging energy conservation"—electronics, automation, chemical processing, and advanced materials. These new watchwords began to dominate the language of Bureau management during the decade of the 1980s.

In a 1991 discussion of his administration, Ambler dwelt at length on his personal reaction to the 1982 *Packard Report*.[42] He was much taken with the recommendations of the report, particularly the first, calling for a "well-defined agency mission," and the fifth, calling for "stronger interactions with academia and industry." These, he felt, fit well with the mandates continually pressed on the Bureau by members of congress. He gave particular significance to refining the NBS mission with regard to assisting U.S. industrial prowess, to strengthening ties with outside organizations, and placing more emphasis on outside review of NBS work. During the 1980s, that approach was successful in attracting increasing financial support from other government agencies and from users of NBS services.

As time went on, Ambler saw more and more clearly the significance of the push toward industrial productivity that was manifest in both the Congress and in Reagan's Commerce Department.

[41] "National Bureau of Standards 1980," *NBS Special Publication 600*, January 1981, 40 pp.

[42] Ambler, *NBS Special Publication 825*, pp. 33-34.

By 1988, Ambler saw the transformation of the National Bureau of Standards into the National Institute of Standards and Technology not as a threat, but as an opportunity. He was convinced that intimate involvement by a strong technical agency in solving America's trade deficit would happen—if not by NBS, then by another agency taking its place. Shortly after his retirement, Ambler described the Congressional attitude on passage of the 1988 Competitiveness Act:[43]

> The intent was clear to have NIST "assist industry." Also implicit [was that] this new function should receive equal if not greater emphasis than that of providing basic standards and measurements.
>
> Congress wanted to expand our vision, our influence, and our funding and help us achieve our full potential in the way we worked with industry, small as well as large. To duck such a challenge, even if we could, would not only be faint-hearted, but foolish; we would have become the mother of yet another agency by starving ourselves.

Ambler's attitude towards the place of scientific excellence at NBS was reminiscent of the often-expressed philosophy of Lewis Branscomb. Both men felt that a good scientific atmosphere brought good people to the Bureau, and that good people did good work. Branscomb especially decried the distinction between basic and applied science, preferring to speak of high intellectual content and productivity as the hallmarks of a good staff.

Despite the continuous efforts of the Reagan administration to cut non-military government spending, Ambler left NBS with a substantially larger budget than it had when he took office as director.

## TECHNICAL WORK OF THE BUREAU, 1975-1989

### Research in Chemistry

Only a few of the many chemistry research projects undertaken by the NBS staff during this period are mentioned in the following pages. However, the accounts serve to underscore the breadth of the Bureau program in chemical science.

#### *Isotopic Enrichment With Lasers*

A recurring problem in fields as diverse as clinical medicine and nuclear power was finding ways to obtain chemicals that were enriched in certain isotopes. In medicine and biological research, particular isotopes could be used as tracers to follow the course of chemicals added to living matter. In nuclear power, the radioactive properties of certain uranium isotopes made them especially suitable for use in reactors.

Over the years, various methods were used to achieve isotopic enrichment. A particularly interesting method perfected during this period involved the use of photochemistry. A group of Bureau scientists employed electronic excitation to produce stable, enriched compounds containing chlorine or boron isotopes.

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[43] Ibid., p. 39.

Taking advantage of support from the NBS Laser Chemistry Program, Joseph J. Ritter of the Inorganic Materials Division and Richard A. Keller of the Physical Chemistry Division, along with their colleagues Harry J. Dewey, a postdoctoral research associate in the Optical Physics Division and Michel Lamotte, a visiting scientist from the Faculty of Sciences of Bordeaux, France were able to markedly affect the isotopic composition of $^{35}Cl$ using a photochemical method.[44]

The authors noted that earlier attempts at enrichment involving laser irradiation had failed to produce stable molecules. One of these attempts had involved Stephen R. Leone, prior to his joining NBS; along with his mentor at the University of California at Berkeley, C. Bradley Moore, Leone had irradiated bromine molecules, using the 558 nm and 532 nm lines from an yttrium-aluminum-garnet laser. The laser irradiation selectively excited the diatomic bromine molecules until they dissociated into atoms that reacted with hydrogen iodide. They found indications that marked isotopic enrichments (from the normal 1:1 ratio of $^{79}Br$:$^{81}Br$ to 4:1 $H^{81}Br$:$H^{79}Br$) occurred, prior to "scrambling"—atomic rearrangement of the HBr molecules through collisions, with loss of the enrichment.[45]

Ritter and his colleagues sought to produce stable end-products in their experiments. To this end, they chose to excite $^{35}Cl$ or $^{37}Cl$ electrons in thiophosgene ($C^{32}S^{35}Cl_2$ or $C^{32}S^{37}Cl_2$) to a particular state by the choice of the irradiating wavelength of a nitrogen-pumped, tunable dye laser, then to retain the isotopic enrichment by taking advantage of an enhanced chemical reaction rate between the excited molecule and diethoxyethylene. The concentration of $^{35}Cl$ in thiophosgene was changed from 75 % in the naturally occurring material to 64 % (about one-third the theoretical limit for the concentration change) when $^{35}Cl$ was selectively irradiated, and from 75 % to 80 % when $^{37}Cl$ was irradiated.

A similar experiment was performed on boron isotopes by Keller and Samuel M. Freund of the Optical Physics Division, using radiation from a carbon dioxide laser. In this case, boron trichloride was reacted with hydrogen sulfide. After excitation of the $^{11}B$–Cl stretching vibration in the $BCl_3$ molecule for periods as long as 10 hours, the abundance of $^{11}B$ fell from its usual value of 80.5 % to 70.8 %; correspondingly, the $^{10}B$ abundance rose from 19.5 % to 29.2 %. Excitation of the $^{10}B$–Cl stretching mode, on the other hand, resulted in an isotopic enrichment of $^{11}B$.[46]

These experiments led to the issuance of two patents—one for the laser-induced photochemical enrichment of boron isotopes[47] and a second for photochemical enrichment of chlorine isotopes.[48]

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[44] Michel Lamotte, Harry J. Dewey, Richard A. Keller, and Joseph J. Ritter, "Laser induced photochemical enrichment of chlorine isotopes," *Chemical Physics Letters* **30**, No. 2, 165-170 (1975).

[45] Stephen R. Leone and C. Bradley Moore, "Isotopically selective photochemistry of bromine," *Phys. Rev. Lett.*, **33**, No. 5, 269-272 (1974).

[46] "Laser-induced photochemical enrichment of isotopes," *Dimensions/NBS*, April 1975, pp. 80-82.

[47] U.S. Patent 3,996,120, issued December 7, 1976, to S. M. Freund and J. J. Ritter.

[48] U.S. Patent 4,025,406, issued on May 24, 1977, to M. Lamotte, H. J. Dewey, R. A. Keller, and J. J. Ritter.

Later, Ritter made use of the technique to study chemical reactions of the molecules $Cl_2CF_2$ and $Br_2CF_2$ with several olefins, finding that he could establish the presence of certain intermediary molecules, as well as determining the levels of enrichment occurring in the isotopes of carbon. Ritter used a carbon dioxide transverse excitation laser in the experiments, which appeared to involve unexpectedly complex free-radical reactions.[49]

### *Atomic Weights*

Lura J. Powell, Thomas J. Murphy, and John W. Gramlich used the technique of mass spectrometry to determine the atomic weight of silver with unprecedented accuracy. The value, 107.868 15±0.000 11, was obtained for the natural isotopic abundance of the element, which contained nearly equal parts $^{107}Ag$ and $^{109}Ag$. The uncertainty of the new determination was smaller than the previous best by a factor of five. To obtain the result for the reference sample, carefully measured quantities of the two isotopes were mixed to calibrate the mass spectrometer.[50]

In their experiments, Powell, Murphy, and Gramlich used the same isotopic samples of silver that had been employed earlier by Richard S. Davis and Vincent E. Bower to improve coulometric measurements of the electrochemical equivalent of silver.[51] Davis and Bower discovered a means of reducing the measurement error arising from impurities in the silver; they dissolved the silver from the residue in the coulometer and plated the silver onto a cathode held at constant potential with respect to a reference electrode, integrating the electrolysis current electronically.[52]

A fundamental units task force of the (international group) CODATA immediately undertook to use the new value for a recalculation of the Faraday, historically evaluated by electrodeposition of silver. The new Faraday uncertainty, reflecting the improved accuracy of the silver atomic weight, improved by a factor of five.

A discussion of progress in the evaluation of atomic weights and of the use of tables of atomic weights prepared under the auspices of the International Union of Pure and Applied Chemistry was presented by I. Lynus Barnes and H. Steffen Peiser for the National Conference of Standards Laboratories during its 1986 meeting. The authors pointed out the ubiquity of atomic weight data in science, technology and commerce, the usefulness of the IUPAC tables in unifying world-wide data on atomic weights, and the process by which the tabular values were derived.[53]

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[49] J. J. Ritter, "Isotopically selective $CO_2$ transverse excitation laser induced chemical reactions of $Cl_2CF_2$ and $Br_2CF_2$ with olefins," *J. Am. Chem. Soc.* **100**, No. 8, 2441-2444 (1978).

[50] L. J. Powell, T. J. Murphy, and J. W. Gramlich, "The absolute isotopic abundance and atomic weight of a reference sample of silver," *J. Res. NBS* **87**, No. 1, 9-19 (1982).

[51] R. S. Davis and V. E. Bower, "Corrections to the Faraday as determined by means of the silver coulometer," *Atomic Masses and Fundamental Constants*, J. A. Nolen, Jr. and W. Benenson, editors (New York: Plenum Press, 1980), pp. 161-165.

[52] R. S. Davis and V. E. Bower, "A novel method for analyzing silver sediment with high precision," *J. Res. NBS* **84**, No. 2, 157-160 (1979).

[53] I. L. Barnes and H. S. Peiser, "Twenty five years of accuracy assessment of the atomic weights," pp. 22/1-22/10 in *Proc. Natl. Conf. of Stds. Labs., October 6-9, 1986, Gaithersburg, Maryland.*

### *Quality Control Through Standard Reference Materials*

At the July 1979 meeting of the National Conference on Weights and Measures, Donald R. Johnson, programs director for the National Measurement Laboratory, reviewed a few of the many contributions made by the NBS program in Standard Reference Materials (OSRM) to quality control of commercial products. The new chief of the OSRM program was George A. Uriano, a physicist with 10 years' research experience in the Electricity Division, 5 years as Deputy Director of the Institute for Materials Research, and 3 years as Deputy Chief of the OSRM. Uriano succeeded J. Paul Cali as chief; Cali had served in that position for a decade.

Areas singled out by Johnson as particularly benefitting from NBS work included the following:

- Control of the composition of steel, through reference materials and standard procedures. The Bureau offered more than 100 SRMs for steel.
- Identification and measurement of toxic contaminants in food.
- Accuracy in clinical chemistry.
- Development and enforcement of environmental and occupational regulations, which required SRMs for use under the Clean Air Act and the Clean Water Act, as well as for use by the Occupational Safety and Health Administration.
- Measurements of automobile fuel economy.
- Identification and measurement of materials involved in resource recovery programs.

At that time, some 900 Standard Reference Materials in 70 different categories were available from NBS.

### *Excitable Chemical Species*

Important advances in understanding the effects of radiation on chemical species, as well as the nature of chemical reactions among excited molecules were made at NBS over a long period of time.

Although the Free Radicals program was formally discontinued in July 1959, Bureau work on the chemistry of excited molecules continued in several divisions, owing to the wealth of information to be obtained from such studies.

During 1975, Pierre J. Ausloos, a radiation chemist trained at the University of Louvain, Belgium, and Sharon G. Lias—a Bureau scientist who first visited NBS as a student, then as a Visiting Professor from Rockefeller University in New York City—wrote a textbook on the role of ion-molecule reactions in radiation chemistry.[54] The book was one of a series planned for the U.S. Energy Research and Development Administration.

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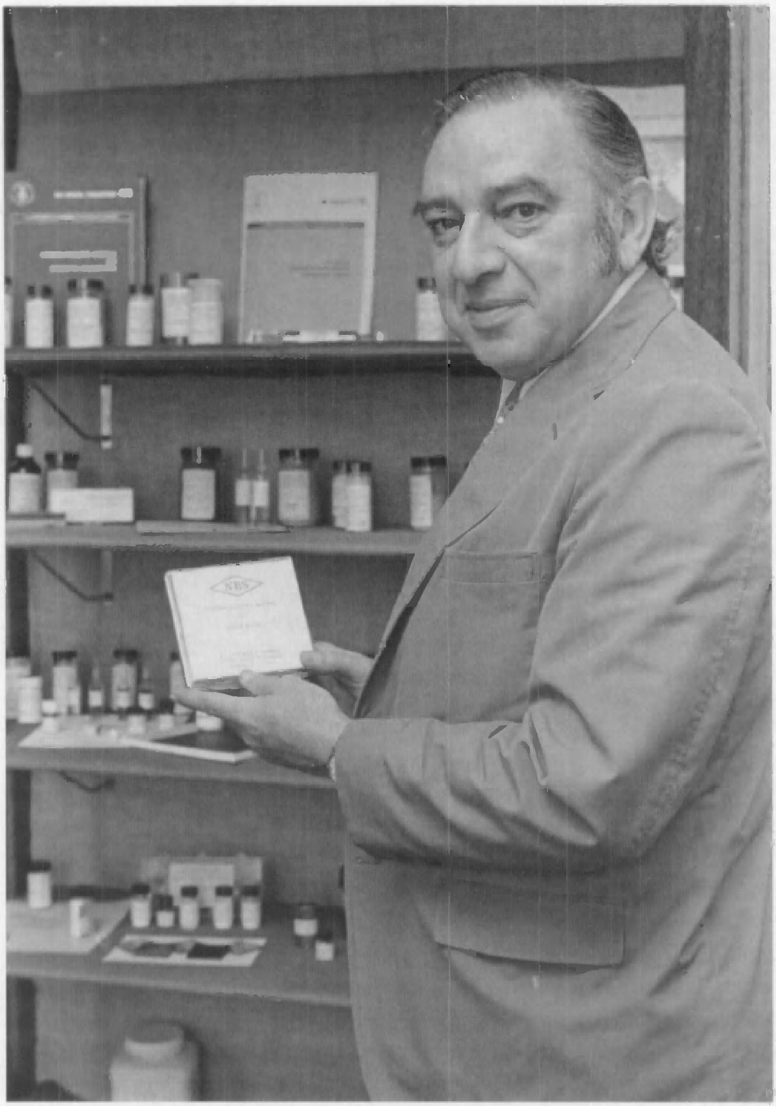
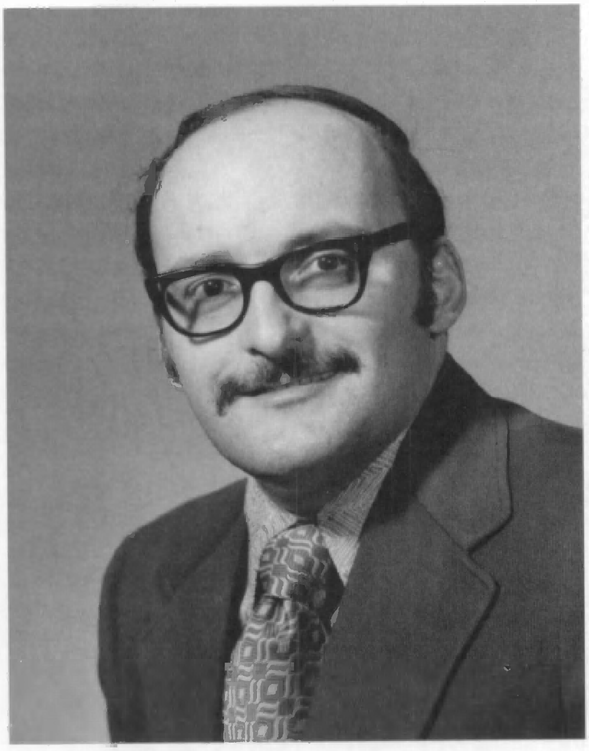
[54] Sharon G. Lias and Pierre Ausloos, *Ion-Molecule Reactions: Their Role in Radiation Chemistry* (Washington, DC: American Chemical Society, 1975) 205 pp.



J. Paul Cali joined NBS in 1966 to manage the production and certification of Standard Reference Materials. He later headed the SRM program until his retirement in 1978.

In a study of the effect of solar radiation on chlorofluorocarbons and carbon tetrachloride, Ausloos, Richard E. Rebbert, and their colleague Lois Glassgow, a guest worker, discovered evidence that even sunlight that had filtered through the earth's atmosphere could dissociate these substances under the right conditions.[55] It was noted

[55] P. Ausloos, R. E. Rebbert, and L. Glassgow, "Photodecomposition of chloromethanes absorbed on silica surfaces," *J. Res. NBS* **82**, No. 1, pp. 1-8, 1977.



George A. Uriano served NBS/NIST in a variety of ways during his 32 years at the Bureau—as a bench scientist, as deputy to the director of the Institute for Materials Research, as chief of the Standard Reference Materials program, and as director of the Advanced Technology program.

by a science writer that the breakdown of halocarbons by solar radiation played a strong role in the durability of the earth's ozone layer.[56]

In recognition of his substantial contributions to excitation chemistry, Ausloos received the Department of Commerce Gold Medal award in 1976. Among the many achievements recorded by Ausloos and his colleagues were numerous experiments; the development of inert-gas lamps, some with special aluminum windows to permit passage of high-energy radiation, to provide radiant sources in the energy range 8 eV to 21 eV; editing of a text on *Fundamental Processes in Radiation Chemistry;* and organizing, for the North Atlantic Treaty Organization Advanced Study Institute, conferences in 1973 and 1974 devoted to the discussion of chemical spectroscopy and photochemistry in the vacuum ultraviolet.

The specialty of Hideo Okabe was ultraviolet photochemistry—especially the study of photodissociation and fluorescence in various types of materials. He evaluated air-pollution aspects of sulfur dioxide ($SO_2$), developing a detector with a linear response at levels ranging from 20 ppb to 1600 ppm. This work had an immediate impact on the work of the Environmental Protection Agency and industrial firms

[56] *Industrial Research,* April 1977, p. 19.

NBS researcher Albert E. Ledford adjusted an instrument developed at the Bureau to measure very small amounts of ozone, a serious pollutant at ground level but protector against ultraviolet radiation in the upper atmosphere.

engaged in pollution monitoring and control, and it led to the Department of Commerce Gold Medal award for Okabe in 1973.[57] Okabe also investigated the photodissociation of thiophosgene.[58] He also wrote a book, *Photochemistry of Small Molecules,* that became a classic in the field of photochemistry.[59] It was translated into several languages.

Ion-molecule reactions were found to be important in the chemistry of the upper atmosphere of the earth, as well as in excited environments such as flames and plasmas; the reactions were observed in mass-spectrometric studies of the earth's upper atmosphere. Stephen R. Leone, chemist in the Quantum Physics Division and the Joint Institute for Laboratory Astrophysics, developed a new technique for the study of the elusive products of ion-molecule reactions.

Leone and his university colleagues used an infrared detection technique to observe the afterglow in flow of excited helium gas carrying negatively charged oxygen atoms, which reacted with carbon monoxide in a flow tube. Vibrational chemiluminescence was observed from the carbon dioxide molecules formed by the ion-molecule reaction; it was the first such observation reported. The group found evidence of vibrational excitation in the $CO_2$ spectrum, and they obtained to obtain information on the dynamics of the reactions and on the rates of energy loss from the excited vibrational states.[60]

### *Calorimetry, a Basic Tool for Chemists*

Calorimetry, the experimental determination of the heat content of materials, was a basic tool for chemists from the earliest days of the study of chemistry. Yielding information about the thermodynamic properties of a test substance and about the thermal changes occurring in chemical reactions, calorimetry provided essential guidance for the chemist and the chemical engineer.

Since it was an important science, the study of calorimetry was a continuing program from the beginning of NBS. By the year 1911, the Bureau already was supplying about 100 types of combustion samples for use in the calibration of calorimeters.[61] These calibration samples were extremely valuable to calorimetrists because each of their measurements was performed in a home-made instrument.

In 1946, a meeting of a group of low-temperature calorimetrists was organized by Hugh M. Huffman, a scientist at the Bureau of Mines in Bartlesville Oklahoma, in conjunction with a meeting of the American Chemical Society. The meeting was sponsored by the Committee on Thermal Data for the Chemical Industry, an arm of the National Research Council.

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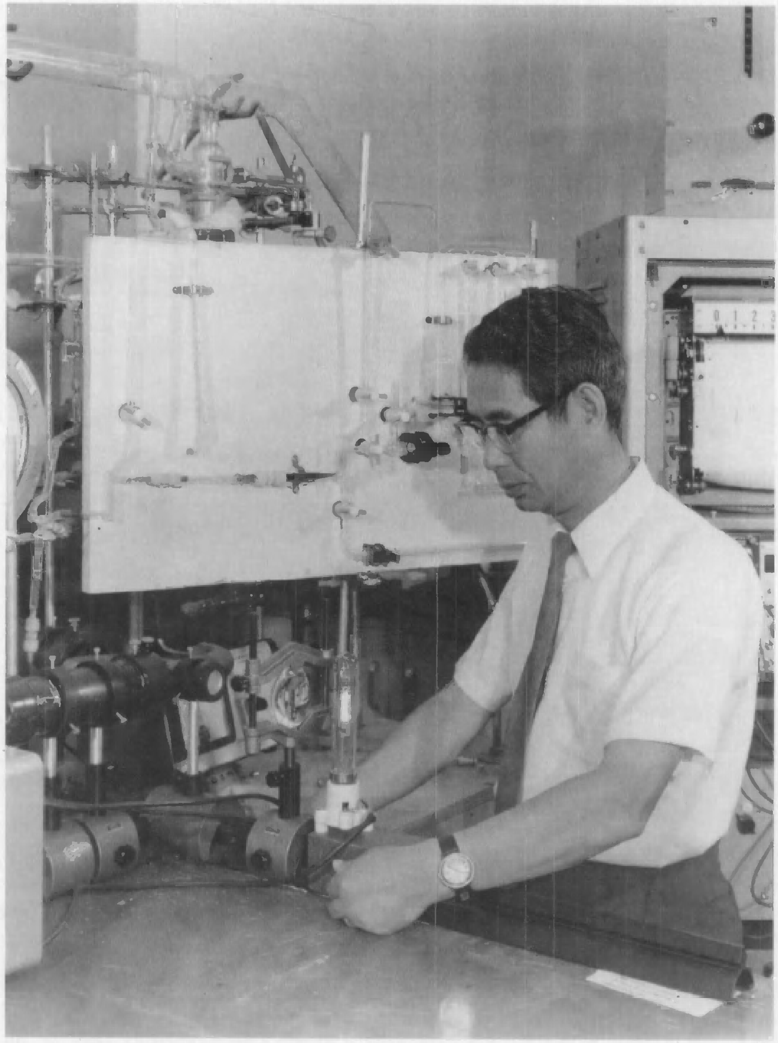
[57] H. Okabe, "Fluorescence quenching of sulfur dioxide by source emission gases," *Anal. Chem.* **48**, No. 11, 1487-1489 (1976).

[58] H. Okabe, "Photodissociation of phosgene," *J. Chem. Phys.* **66**, No. 5, 2058-2062 (1977).

[59] Hideo Okabe, *Photochemistry of Small Molecules* (New York: Wiley-Interscience, 1978).

[60] V. M. Bierbaum, G. B. Ellison, J. H. Futrell, and S. R. Leone, "Vibrational chemiluminescence from ion-molecule reactions: $O^- + CO = CO_2 + e^-$," *J. Chem. Phys. Lett.* **67**, No. 5, 2375-2376 (1977).

[61] NBS Annual Report for 1911, p. 80.



In work that was recognized by the Gold Medal Award from the Department of Commerce, chemist Hideo Okabe developed a sulfur dioxide monitor. Here, he was shown adjusting the apparatus.

The opportunity for calorimetrists to meet regularly with other scientists who shared their concerns so captivated them that they immediately made the calorimetry meeting an annual event called the Calorimetry Conference. It was decided quickly that conference topics should include high temperatures as well as low. Attendance at the conferences grew from 40 in 1947 to as many as 200 during the 1980s.

Gradually, a loose structure for the conferences was formed by members in academia, in industry, and in government. Eventually, each conference elected officers including a chair, a treasurer, a Board of Directors, and Counselors. The Bureau was involved in the Calorimetry Conferences from the start. Ferdinand G. Brickwedde and Russell B. Scott were among only 14 scientists who attended the first meeting.[62]

The expressed intention from the beginning of the conferences was to cater to scientists actively practicing thermal measurements. The primary focus of the first meeting was on accuracy of measurements. Necessarily, that topic included an emphasis on the accuracy of the temperature scale and on the quality of available thermometers.

Hugh Huffman died in 1950; 4 years later an award for excellence in calorimetry research was created in his name. Brickwedde was the second scientist to receive the Huffman Award. Other NBS winners of the award included Frederick D. Rossini, in 1956; Charles W. Beckett, in 1967; and Edward J. Prosen, in 1979.

Many Bureau staff members were involved in administering the conferences.[63] These include service as:

- Conference Chair: Prosen (1954), George T. Armstrong (1964), E. Dale West (1971), Patrick A. G. O'Hare (1985), Jane E. Callanan (1989), and Eugene S. Domalski (1995).
- Secretary-Treasurer: George T. Furukawa (1961-63).
- Members of the Board of Directors: George T. Furukawa (1956, 1966, and 1973), Armstrong (1961), West (1967), Prosen (1968), Robert N. Goldberg (1974 and 1993), Kenneth L. Churney (1976), Callanan (1983), Duane R. Kirklin (1986), Jennifer C. Colbert (1989), and Yadu B. Tewari (1992).
- Counselors: Armstrong (1979-80), Callanan (1985-86), and Domalski (1988-92).

Brief notes describing the Bureau's Huffman Award winners and members of the Bureau staff who chaired various conferences provides a precis of NBS activities in calorimetry:

- Some of Brickwedde's accomplishments—producing the first measurable quantities of deuterium for Professor Harold Urey, and helping to create equipment for the liquefaction of liquid hydrogen in record quantities—have been chronicled earlier in this volume. His 30-year career at NBS also included thermodynamic studies of hydrogen and deuterium and a variety of thermometry and calorimetry work. He received the Department of Commerce Gold Medal in 1953. Brickwedde served as Chief of the NBS Low Temperature Laboratory from 1926-46 and as Chief of the Heat and Power Division from 1945-56.

[62] R. M. Izatt, P. R. Brown, and J. L. Oscarson, "The history of the Calorimetry Conference: 1946-1995," *J. Chem. Thermodynamics* **27**, No. 5, pp. 449-464 (1995).

[63] Eugene S. Domalski, Private communication. Much of the information contained in this section was kindly provided by Domalski.

- Rossini was a Bureau staff member from 1928 to 1950. He served for more than a decade on the Commission on Thermochemistry of the International Union of Pure and Applied Chemistry—5 years as its Chair. He built calorimeters for use in the study of the enthalpy of reaction of hydrogen and oxygen and also to measure the heat of combustion of methane and many other hydrocarbons. Besides some 200 scientific papers, Rossini was the author of 11 books. In 1942, he accepted the directorship of a project of the American Petroleum Institute—*Project 44,* the collection, calculation and compilation of a great variety of data of interest to the petroleum industry. His greatest legacy was *NBS Circular 500,* "Selected Values of Chemical Thermodynamic Properties." It became a valued reference for chemists and chemical engineers.

- Charles Beckett joined NBS as a research chemist in 1950. He soon became Chief of the Thermodynamics Section of the Heat and Power Division. His scientific work, in the course of which he received the Department of Commerce Gold Medal Award, was achieved despite the effects of severe arthritis. He performed research in mass spectrometry, shock-tube studies, flame, drop, and bomb calorimetry, statistical mechanics, molecular and microwave spectroscopy, and high-speed thermodynamic measurements.

  Later, Beckett agreed to serve as Project Coordinator for an Air Force rocketry program to derive thermodynamic information on light elements. During the 1960s and 1970s, thermal-properties research of national importance was performed in the Heat Division by Joseph F. Masi, Beckett, Armstrong, and others under contract with the U.S. Army and the U.S. Air Force. Many NBS staff members contributed scientific work to this project over a period of several years. Beckett also edited the NBS Journal of Research from 1962-75.

  Upon Beckett's retirement from NBS in 1976, a symposium on the topic of chemical thermodynamics was held in his honor.

- Edward Prosen came to NBS in 1936, before completing his formal training in science. His initial position was that of an assistant in physics. During his nearly 45 years at the Bureau, he became known internationally for his work in thermodynamics, hydrocarbon bomb calorimetry and the reactions of boron compounds. He was a member of the International Union of Pure and Applied Chemistry (IUPAC) Commission on Thermodynamics. He won the Department of Commerce Gold Medal Award in 1956.

  As late as 1977, Prosen participated in a microcalorimetric study of heart pacemakers, a project intended to assess the feasibility of using that method to measure energy loss in the cardiac devices in a nondestructive manner.[64]

- A transplanted Irishman, Patrick A. G. O'Hare spent most of his scientific career in physical chemistry research at the Argonne National Laboratory. He joined NIST in 1989. His principal calorimetric interests lay in bomb calorimetry, where he studied fluorides, selenides, silicides, and tellurides.

[64] E. J. Prosen and J. C. Colbert, "Microcalorimetric study of cardiac pacemakers," *NBSIR 77-1310,* September 1977, 21 pp.

- George T. Armstrong came to NBS from Yale University in 1951 as a member of the Heat and Power Division. His early work focused on the vapor pressures of fuels and other high-energy substances.[65] By the early 1960s he directed the Combustion Calorimetry Laboratory in the division's Heat Measurements Section, with responsibility for creating techniques and standards of heats of combustion. He developed a special interest there in fluorine thermochemistry, for which he received the Department of Commerce Silver Medal Award in 1967.[66]
- E. Dale West joined NBS in 1948. His principal interests at the Bureau were in adiabatic calorimetry at high temperatures. He studied the heat capacity, transition temperatures and heats of transition in sulfur and made similar measurements in sapphire and graphite. West headed the Heat Measurements Section of the Heat Division for 2 years, then transferred to Boulder, where he headed the Laser Radiometry Section of the Quantum Electronics Division. There he developed a reference calorimeter for the measurement of laser power. He retired from NBS in 1980 to create a company for the commercial design and construction of calorimeters.
- Jane E. Callanan came to NBS in 1981 as a research chemist. Her research interests were varied: low temperature heat capacity, standards for differential scanning calorimetry, thermal characterization, and thermodynamic properties. She left the Bureau in 1991 to establish a consulting firm in Boulder, Colorado.
- Eugene S. Domalski joined NBS early in 1959 as a member of the Heat Measurements Section of the Heat Division. Soon he began collaborating with George Armstrong in studies of heats of formation and heats of combustion. Later he took an active role in preparing thermodynamic data, including two definitive compilations of heat capacity of organic compounds, for the Office of Standard Reference Data, and in the calorimetry of refuse-derived fuels for the energy-conservation program.

Discussion of the Bureau's activities in calorimetry would be incomplete without acknowledgment of the large role played by George T. Furukawa and his associates. Furukawa joined NBS in 1949 as a member of the Thermodynamics Section of the Heat and Power Division. Ferdinand G. Brickwedde was chief of both the section and the division at that time. Furukawa's considerable ability as a calorimetrist was directed immediately to providing calorimetric data of interest to the members of the Calorimetry Conference. With his colleagues Defoe C. Ginnings, Robert E. McCoskey, Raymond A. Nelson, Gerard J. King, Martin L. Reilly, Thomas B. Douglas, Anne F. Ball, Jeanette H. Piccirelli, William G. Saba, and Andrew C. Victor, Furukawa furnished calorimetric properties data on a succession of materials intended for use as standard samples dedicated to the purposes of the Calorimetry Conference.

[65] George T. Armstrong, F. G. Brickwedde, and R. B. Scott, "The vapor pressure of the deuteromethanes," *J. Chem. Phys.* **21**, 1297 (1953).

[66] E. S. Domalski and G. T. Armstrong, "The heats of combustion of polytetrafluoroethylene (Teflon) and graphite in elemental fluorine," *J. Res. NBS* **71A** No. 2, 105-118 (1967).

When the Heat Measurements Section of the Heat Division was disbanded in 1970, Furukawa transferred his attention to more specifically thermometric problems with the same characteristic thoroughness he had earlier given to calorimetry.

### *New Equations for Steam*

Steam, one of man's oldest sources of motive power and a key ingredient in many manufacturing processes, would seem an unlikely prospect for an NBS investigation. Yet Lester Haar and John S. Gallagher of the NBS Thermophysics Division and George S. Kell, a colleague from the National Research Council in Ottawa, Canada undertook the task of re-formulating the equations that provided thermodynamic properties for water and steam.

The work was requested by the International Association for the Properties of Steam and performed under the auspices of the National Research Council of Canada (NRC) and the Bureau's Office of Standard Reference Data. The three scientists prepared new equations to cover the temperature range from 0 °C to 2000 °C and the pressure range from 0 GPa to 3 GPa (about 30,000 times atmospheric pressure).

Demand for the new tables, entitled "NBS/NRC Steam Tables: Thermodynamic and Transport Properties and Computer Programs for the Vapor and Liquid States of Water in SI Units" was sufficiently large that the Hemisphere Publication Corporation of Washington, DC printed the tables in book form.[67]

The new tables quickly became a "best seller" among NBS reports. Demand remained brisk for more than a decade.

## A Hectic Decade for NBS Fire Science

Following release of "America Burning," a dramatic report issued in 1973 by the National Commission on Fire Prevention, the Nation's efforts in fire protection received more attention. In brief, the report indicted the United States as possessing the worst record for fire deaths and property loss of any of the major industrial nations. Enactment of the *Federal Fire Prevention and Control Act of 1974* soon followed.

The following account is lengthy, primarily to portray a coherent picture of a large Bureau program—fire science—over a long period of time. The account also illustrates well the level of dedication that came from a group whose very existence was questioned at the highest executive levels.

### *An NBS Center for Fire Research*

By direct instruction of the *Federal Fire Prevention and Control Act of 1974,*[68] the Bureau created a Center for Fire Research, "to conduct basic and applied fire research, research into the factors influencing human victims of fire, and operation tests, demonstration projects, and fire investigations."

[67] L. Haar, J. S. Gallagher, and G. S. Kell, "*NBS/NRC Steam Tables: Thermodynamic and Transport Properties and Computer Programs for the Vapor and Liquid States of Water in SI Units*" (Washington, DC: Hemisphere Publication Corporation, 1984) 320 pp.

[68] Public Law PL93-498, 88 Stat. 1535-1549, enacted October 29, 1974.

As we noted in chapter 3, Director of the new center was John Lyons, hired by Director Richard Roberts in October, 1973 to give new leadership to the entire program of fire research at NBS. By September, 1975, Lyons had in place his senior management team.

Heading the Fire Science Division was Robert S. Levine, newly arrived from NASA's Langley Research Center with experience in rocket technology. The division's program for physics and dynamics was led by John A. Rockett, an experienced fire hand who had joined the Bureau in 1968 to plan for the implementation of the *Fire Research and Safety Act of 1968*. The division's program for fire chemistry was headed by Clayton M. Huggett, who since 1970 had supervised research on the chemistry of ignition and combustion, fire retardants, and the toxicity of combustion products. Acting Director of the program for toxicology of combustion products was Merritt M. Birky, a 1961 NAS/NRC postdoctoral research associate in chemical thermodynamics with 7 years' subsequent experience in atomic physics and 4 years with the fire science program. Acting chief of the Office of Information and Hazard Analysis was Benjamin Buchbinder.

The Fire Safety Engineering Division was headed by Irwin A. Benjamin, a structural engineer who joined NBS in 1968 as Chief of the Fire Research Section of the Building Research Division. Studies of fire prevention were headed by James H. Winger—since his entry to NBS in 1971 heavily involved in the development and evaluation of fire test methods. A program in control of fire in furnishings was led by Sanford Davis, newly arrived from the BASF Wyandotte Corp. A project in fire design concepts was headed by Harold E. Nelson. Acting chief for control of fire in construction was Daniel Gross, since 1950 involved at NBS in various aspects of fire research. Acting chief of a program in fire detection and control systems was Richard G. Bright.

By the end of 1974, the NBS fire program had stopped using test facilities at the former Bureau site in Washington, DC. The Fire Research building at Gaithersburg, begun in October 1973, was occupied in April 1974, dedicated on June 25, 1974, but completed only during October 1975. The building was located somewhat away from the general-purpose laboratories for improved safety. With forward-looking management at all levels, the program was well into its most productive era, but one that would not be free of controversy.

### *Topsy-Turvy Funding*

The Center for Fire Research was staffed by 90 full-time permanent employees during 1974. This staff was augmented by perhaps 20 Industrial Research Associates, postdoctoral research associates, and guest scientists. They worked with great effectiveness on a variety of projects, as we shall soon see. However, funding for the new center was very much out of the ordinary, mainly because of repeated changes in the administration of the Nation's fire programs.

A chronological treatment of the House Appropriations Commerce Subcommittee may best illustrate the uneven support that the funding process produced for the NBS fire program:

- **Date: April 9, 1974**

Hearings on National Bureau of Fire Prevention.[69]
Testimony given by: Betsy Ancker-Johnson, Assistant Secretary of Commerce for Science and Technology and John W. Lyons, Director, NBS Fire Programs.

At the time of these hearings by the 93rd Congress in its second session, authorizing legislation for a *National Bureau of Fire Prevention* had passed the Senate and was awaiting floor action in the House. Assuming that the NBFP would come to exist, the Subcommittee intended to fund its planned $4 million budget from two sources: the *National Science Foundation* which, through its program on "Research Applied to National Needs," would contribute $1.7 million; and NBS, which would contribute $3 million from its fire program. The Subcommittee's uncertainty regarding the future of the Bureau's fire research program can be detected in the following exchange:

> Mr. Slack: Do you or do you not propose to have the National Bureau of Standards continue its program with your reimbursing them for their work?
> Dr. Ancker-Johnson: Yes, Sir, NBS will continue work with the $3 million in programs transferred to the new Bureau. At this time, we intend to do no research in-house. We will use the National Bureau of Standards facilities.

As she had done the previous year, Ancker-Johnson presented the NBS budget as a part of a larger "Science and Technology" activity. During that presentation, the NBS fire program was discussed only briefly:

> Mr. Slack: What fire research work would remain as part of your regular appropriation in NBS?
> Dr. Ancker-Johnson: In Fiscal Year 1975, Mr. Chairman, there will be a base program funded at a level of $1,181,000.[70]

- **Date: October 29, 1974**

*Federal Fire Prevention and Control Act of 1974*

The FFPCA-74 created new agencies for fire prevention and research, but the *Bureau of Fire Prevention* was not among them. Instead, the act established a *National Fire Prevention and Control Administration* as part of the Department of Commerce and a *Fire Research Center* as part of NBS. Joseph E. Clark, former chief of the Bureau's Fire Technology Division, was named Acting Administrator of the NFPCA. The NFPCA was authorized $10 million for the Fiscal Year ending June 30, 1975, and $15 million for the fiscal year ending June 30, 1976. The NBS Fire Research Center (as the Act called it) was authorized $3.5 million and $4 million for the same periods.

[69] House Appropriations Subcommittee hearings, Part 3, Commerce, pp. 824-845.

[70] Ibid., p. 1008.

- **Date: April 15, 1975**

Hearings on Fiscal 1976, House Appropriations Subcommittee on Commerce:

A. National Fire Prevention and Control Administration.[71] Testimony of Joseph E. Clark, Acting Administrator, NFPCA:

The $3 million from the NBS Fiscal 1975 funding that was to have gone to the Bureau of Fire Prevention instead went to the NFPCA and thence back to NBS in reimbursement for services rendered. In his general statement, Clark observed:

> The 1975 (NFPCA) budget included a transfer of $1.7 million from the NSF. . . RANN program. . . and a transfer of $3 million from the NBS fire research and safety program. In 1976, the remaining $1.1 million of the NBS fire research and safety program is being transferred to the NFPCA to consolidate all Commerce fire programs within one appropriation. The Fire Research Center located at the NBS Gaithersburg, MD, facilities will be funded on a reimbursable basis by the NFPCA.[72]

Carrying out the plan outlined by Clark would place the entire NBS program in fire research under the direction of another agency. The Bureau had fought this type of problem earlier—Allen Astin had struggled during the post-WWII period to bring the fraction of direct congressional funding for NBS from 40 % to a more livable 80 %. To have an entire Bureau center under outside control—no matter the level of communication with the outside agency—would rob the Bureau of its ability to direct its own work.

Mr. Slack displayed his puzzlement about the Commerce Department intentions in the following exchange:

> Mr. Slack: Is the Fire Research Center a separate organization?
> Mr. Clark: The legislation established a Fire Research Center in a formal sense as a separate entity.
> Mr. Slack: Would you tell us about the proposed transfer of this $1.1 million from NBS?
> Mr. Clark: The transfer of $1.1 million in 1976 from NBS to the Fire Administration is for the purpose of consolidating in one appropriation all of the Commerce Department fire programs.[73]

B. The NBS Fire Research Center

Director Richard Roberts, testifying on behalf of NBS, submitted a detailed budget for the Bureau that showed[74] the loss of $3 million in fire-research base funding for Fiscal 1975, and the plan to transfer the remaining $1 million base support for fire

[71] Ibid., pp. 301-367.

[72] Ibid., p. 335.

[73] Ibid., p. 364.

[74] Ibid., p. 470.

research in Fiscal 1976. This plan was repeated in his discussion with Congressman Joseph D. Early of Massachusetts.

> Mr. Early: So in two transactions we are transferring $3.2 million [originally in the NBS budget] from the National Fire Prevention and Control Administration, and in another section of this request we are transferring $1.1 million from NBS?
> Mr. Roberts: That is correct, sir. We decided in the Department of Commerce that it would make more sense to budget all of the dollars in one place.[75]

Congressman Early, perhaps not sure he was hearing the story correctly, asked Roberts to repeat it. Roberts did.

In the House hearings through Fiscal 1979, there is no evidence of base-funding support for the NBS Center for Fire Research. All of the support came from outside, mostly (about $4 million to $5 million) from the National Fire Prevention and Control Administration.[76]

- **Date: February 28, 1979**

Hearings of Fiscal 1980, 96th Congress, House Appropriations Subcommittee on Commerce.

During the hearings for Fiscal Year 1980, Jordan J. Baruch, Assistant Secretary of Commerce for Science and Technology under President Jimmy Carter, presented the NBS budget as had his immediate predecessor. Baruch sought to reverse the funds transfer that had taken place years before.[77]

> Mr. Slack: I note that you propose a transfer of $1.1 million from the U.S. Fire Administration [new name for the National Fire Prevention and Control Administration]. What is the alleged purpose of that transfer?
> Dr. Baruch: The research and development activity at the bureau in fundamental effects of fire would be moved out of the Federal Energy Emergency Management Association directly to the bureau [NBS]. The $1.1 million is dictated primarily by some needs for basic fire research.
> Mr. Slack: If you can, tell me again why would we not transfer all of the funds for fire research to NBS?
> Dr. Baruch: Good question.

As the Fiscal 1980 NBS appropriations bill was enacted, it included the restoration of $1.1 million for its basic work in fire research. Direct Congressional funding for the NBS fire science program was back. The funding level stayed near $1.2 million for

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[75] Ibid., p. 689.

[76] House hearings, March 10, 1978, p. 631.

[77] House hearings, February 28, 1979, pp. 630-633.

several years; then in 1982, Director Ambler suggested[78] that certain funds appropriated for the Federal Emergency Management Agency[79] but customarily earmarked for NBS fire research be transferred to the Bureau's Fiscal 1983 budget. Remarkably, this change was made—the fire program received more than $5 million.

Any joy in the Center for Fire Research as a result of receiving direct appropriations for most of its program was short-lived. In the next cycle of hearings by the Commerce Subcommittee on Appropriations, it was Ernest Ambler's duty to request that the NBS fire program not be funded at all.[80] Ambler's narrative accompanying the request stated:

> This program is proposed for elimination in support of the [Reagan] Administration's policy of concentrating Federal research activities on fundamental and basic research efforts and on a determination that the research conducted in this program should be undertaken by the private sector.

The Center for Building Technology was to join the Center for Fire Research in the "Ancient History" file, thus slimming the NBS budget submission by a bit more than $9 million.

At that moment Ambler was in the same tight box that occasionally encloses many a manager. He was constrained by the need to show "team spirit" with the Presidential decision to eliminate programs that industry or state-and-local governments could accomplish; his other option was to resign in protest, a questionable tactic. Despite efforts by Congressman Bernard J. Dwyer, acting chair of the subcommittee, to elicit a murmur of protest from the Bureau director, Ambler hewed to the Administration line. The Congress did not entirely share the President's view; when the Fiscal 1984 appropriation bills were enacted, the fire research program was funded at the level of $5.1 million.[81] The building research funding also survived, at the $3 million level.[82]

The same process of elimination was repeated for the beleaguered building and fire programs as the Administration's Fiscal 1985 budget was presented.[83] Congressman Dwyer left no doubt about his views on eliminating the NBS fire program:[84]

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[78] House Appropriations Subcommittee hearings on Commerce, March 8, 1982, p. 1337.

[79] FEMA was established under President Carter by Reorganization Plan No.3 of 1978 and Executive Orders 12127, April 1, 1979, and 12148, July 15, 1979. The National Fire Prevention and Control Administration was made part of FEMA along with its funding, which included monies previously transferred to NFPCA from the NBS Center for Fire Research.

[80] House Appropriations Subcommittee hearings on Commerce, March 10, 1983, p. 1218, pp. 1287-1290.

[81] House Appropriations Subcommittee hearings on Commerce, March 15, 1984, p. 903.

[82] Ibid., p. 933.

[83] Ibid., p. 943 (building), p. 962 (fire).

[84] Ibid., p. 1029.

Mr. Dwyer: I don't agree with the Administration or whoever recommended the cut of $4 million, to discontinue the research and experiments that go on to try to save lives of people who live in high-rise apartments and in places of public assembly.

It seems to me that this work is most important, because of the new materials that are being developed and installed in these buildings. I think it is really the obligation of the Federal Government to be helpful and useful in that area in protecting these lives.

Once again, the Congress overrode the wishes of the Reagan Administration, funding the fire program for Fiscal 1985 at the level of $5 million.[85]

Prior to the Department of Commerce budget submission for Fiscal 1988 (March 24, 1987), a new strategy for dealing with the NBS fire science program was devised. In this plan, the centers for fire research and building research were combined and their direct appropriation requests pared to reach a total of $5 million. Ultimately, this strategy prevailed, although it appeared to fly in the face of the *Federal Fire Prevention and Control Act of 1974*, which required an administratively separate center for fire research.

Although the staff of the Center for Fire Research might have suffered some nervousness as they watched their appropriations numbers bounce up and down, their productivity during this period was impressive. A rapid search of the excellent facilities of the Fire Research Information Service produced nearly 3000 references to publications by the CFR staff and their colleagues in fire-science programs around the world during the period 1968-1993.

Over the years, the NBS fire program was marked by its wide range of studies—in the theories of fire, in the development of testing devices, and in the examination of actual fire disasters. In the sheer numbers of collaborations with workers in other laboratories and in other disciplines, too, the program set an example for effectiveness.[86]

In the following accounts, we illustrate the breadth of the fire program.

### *Flammable Fabrics*

Public Law 90-189, the Flammable Fabrics Act, amendment of 21967, substantially broadened the responsibilities of NBS.[87] Although these responsibilities declined drastically when the Consumer Product Safety Commission was formed late in 1972, work on fabric flammability continued.

[85] House Appropriations Subcommittee hearings on Commerce, March 6, 1985, p. 1729.

[86] D. Gross, "Fire Research at NBS: The First 75 Years," *Proc. 3rd Intnl Symp. on Fire Safety Sci, July 8-12, 1991, Edinburgh Scotland,* G. Cox and B. Langford, editors (New York: Elsevier Applied Science, 1991), pp. 119-133.

[87] 81 Stat. 568, December 1967.

When the Flammable Fabrics Act amendment was passed, the Bureau got a taste of the life of a regulatory agency; the Congress specified that interstate trade would become illegal for fabrics that could not pass a test devised by NBS. Joseph E. Clark, Chief of the NBS Office of Flammable Fabrics, reviewed the new legal responsibilities of NBS for a textiles periodical.[88] The Bureau, he wrote, was directed to provide the technical underpinning to permit the Secretary of Commerce to define reasonable and useful standards for fabrics, such as rugs, carpets, and clothing. The tools for this work would be flame ignition testing and evaluating the propagation of fire in the fabrics. One of the first fabric standards related to the flammability of children's nightwear. As reported by Emil Braun, James H. Winger, and James A. Slater, garments for children of ages 0 to 12 were chosen because of the relatively high probability of fire-induced injury in that age group. Study of actual fire data showed that fire spread rapidly in such garments, consuming most of the fabric within 30 seconds after ignition. The standard involved the use of a test stand in which the effectiveness of fire retardant could be evaluated.[89]

Refinement of a test cell designed to characterize the chemical and physical properties important to the generation of flash fires in polymeric materials was described by James E. Brown and John J. Comeford in December 1975. The new cell permitted measurement of temperature, geometry, sample orientation and sample size. [90]

After the formation of the Consumer Product Safety Commission (CPSC), NBS was asked to prepare a test that would help minimize the probability of ignition in fabrics and the likelihood of burns. Braun, John F. Krasny, Richard D. Peacock, and Anne K. Stratton reported the development of such a test at the 9th Annual Meeting of the Information Council on Fabric Flammability, held in New York City on December 11, 1975. Called the Mushroom Apparel Flammability Test, it embodied a test stand that approximated real fire accidents, measured real-life hazards, was simple and repeatable, and discriminated between dangerous and safe fabrics.[91]

Braun and his group later investigated the effectiveness of protective clothing worn by fire-fighters, industrial workers, and others whose duties involved exposure to high heat loads. They developed a test stand with which they could apply either radiative or convective heating to a fabric and measure the transmitted heat.[92] Results obtained

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[88] J. E. Clark, "Federal Role in Fabric Flammability Research and Standards," *Textile Information Source and Resources* **4**, No. 4, 7-9, April 1971.

[89] E. Braun, J. H. Winger, and J. A. Slater, "Development of the standards for the flammability of children's sleepwear," in *NBS Special Publication 411; Fire Safety Research, Proceedings of a Symposium at NBS Gaithersburg, August 22, 1973, Mary Jo Butler and James A. Slater, editors,* November 1974, pp. 5-15.

[90] J. E. Brown and J. J. Comeford, "Technique for the measurement of flash fire potential of polymeric materials," *NBSIR 75-757,* December 1975, 32 pp.

[91] E. Braun, J. F. Krasny, R. D. Peacock, and A. Stratton, *NBS Activities in Apparel Flammability,* (Galveston Texas; Information Council of Fabric Flammability, 1975, 317 pp.) pp. 263-277.

[92] E. Braun, D. Cobb, V. B. Cobble, J. F. Krasny, and R. D. Peacock, "Measurement of the protective value of apparel fabrics in a fire environment," *Journal of Consumer Product Flammability* **7**, No. 1, pp. 15-25, March 1980.

with the new test stand as reported by John Krasny became part of a Special Technical Publication published by the American Society for Testing and Materials. Krasny noted the requirements of protective clothing—the fabric should not ignite, shrink, melt, or become brittle, yet it should insulate the wearer against external heat without inhibiting bodily motion. Seven types of fabric were tested in the study, including aramid, fire-retardant cotton, modacrylic, polyester, and wool. In general, 15-45 seconds of protection against injury were provided by a single layer of any of the fabrics.[93]

The CPSC continued to fund fire-research projects at NBS for some time.

An excellent tool used to evaluate specimen flammability was called the cone calorimeter. Vytenis Babrauskas, a versatile fire-protection engineer, who came to NBS in 1977, developed the cone calorimeter in collaboration with William H. Twilley. Babrauskas also undertook the combustion calorimetry of furnishings, fire modeling, and test procedures. The cone calorimeter employed a load cell for automatically recording the changing mass of the specimen during the test, ignition by either spark or radiation, and monitors for released gases and smoke. Liquid, solid, or composite samples could be accommodated in either a vertical or a horizontal position. The cone calorimeter was chosen by Research and Development magazine for its R&D 100 award in 1988.[94]

James Brown, Emil Braun, and William H. Twilley used the cone calorimeter to evaluate U.S. Navy ship components made of synthetic resins or composites of fiber-reinforced resins, often chosen for light weight or non-magnetic properties. They were able to derive indicators for five material parameters: the amount of radiant flux necessary to produce ignition within a preset time; burn intensity as a function of heat load; propensity to continue burning; yields of gaseous pyrolytic products; and the average area of extinction.[95]

## *Laboratory Work in Fire Fundamentals*

### *Atomic and Molecular Studies*

One of the earlier projects in the fundamentals of fire science was initiated by a scientist from another laboratory—John W. Hastie, a flame spectroscopist who worked in the Inorganic Materials Division. Hastie prepared a detailed discussion of fire retardants from the point of view of molecular reactivity. He considered well-known retardants that contained antimony, phosphorus, and halogens. It appeared that these compounds acted as *radical traps* in the preflame or reaction zones. He pointed out the need for thermochemical and reaction kinetics data, as well as rates of vaporization.[96]

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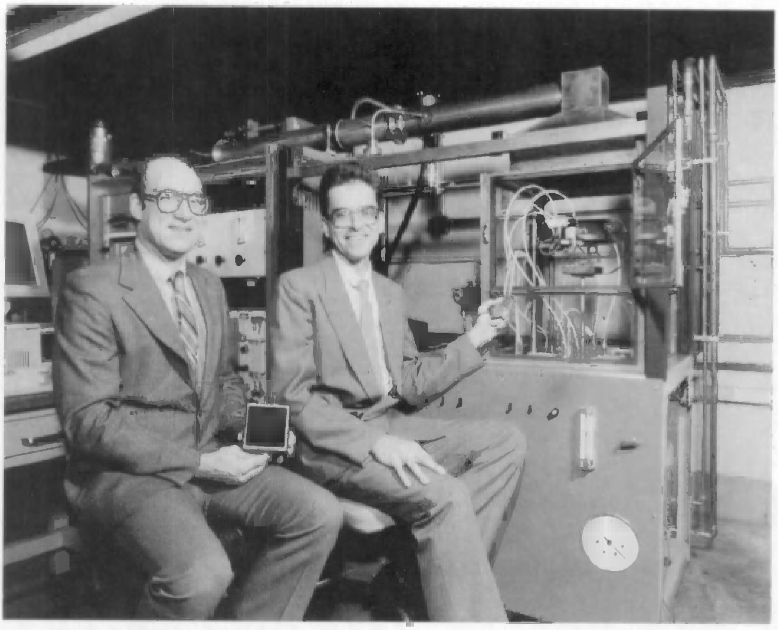
[93] J. F. Krasny, "Some characteristics of fabrics for heat protective garments," *ASTM STP 900,* R. L. Barker and G. C. Coletta, editors, (Philadelphia: ASTM, 1986) pp. 463-474.

[94] V. Brabrauskas, "The cone calorimeter, a new tool for fire safety engineering," *ASTM Standardization News* **18**, No. 1, pp. 32-35, January 1990.

[95] J. E. Brown, E. Braun, and W. H. Twilley, "Cone calorimeter evaluation of the flammability of composite materials," *NBSIR 88- 3733,* March 1988, 61 pp.

[96] J. W. Hastie, "Molecular basis of flame inhibition," *J Res NBS* **77A**, No. 6, 733-754 (1973).



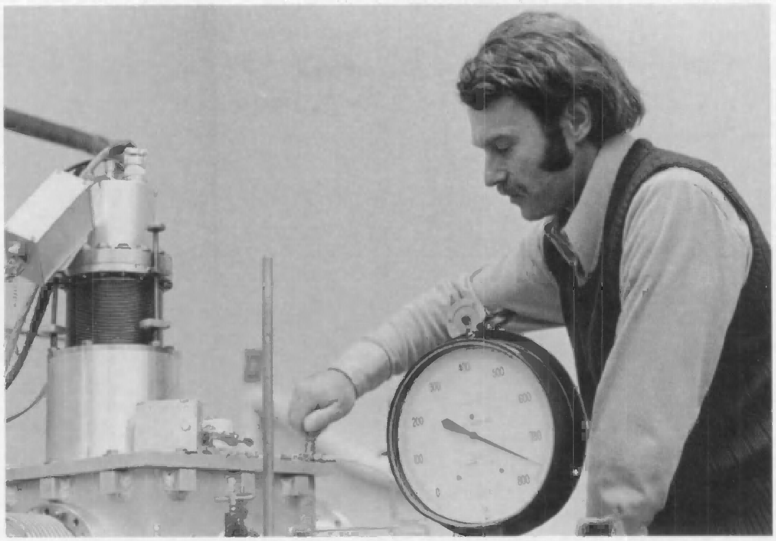
William H. Twilley (left) and Vytenis Babrauskas with the cone calorimeter that they developed. The cone calorimeter, which won an IR-100 Award from *Industrial and Research and Development* magazine, provided data critical to predicting the fire hazard of a product from a small sample of its material.

Later, collaborating with David W. Bonnell of the Inorganic Materials Division, Hastie developed "a new thermochemical tool"—transpiration mass spectrometry—to sample high-temperature gases and vapors.[97] The two scientists had overcome traditional limitations associated with classical vaporization methods. The new method did not require the use of low pressures, and it permitted positive identification of transport molecules. They found that use of the new instrument permitted them to sample reactive gases at temperatures as high as 1500 °C and pressures as high as 1 MPa (10 atmospheres), with little or no loss of accuracy in resulting thermochemical data.

The transpiration mass spectrometer was selected for an IR-100 award as one of the best technical developments of 1980.

An interdivisional team of scientists—Ilan Chabay of the Analytical Chemistry Division, Gregory J. Rosasco of the Inorganic Materials Division, and Takashi Kashiwagi of the Fire Science Division—developed a method of using fast-Fourier transforms of Raman signals from pollutant gases in turbulent air streams. For

[97] J. W. Hastie and D. W. Bonnell, "Transpiration mass spectrometry—a new thermochemical tool," pp. 183-233 in *Thermochemistry and Its Applications to Chemical and Biochemical Systems*, M. A. V. Ribeiro da Silva, Editor (D. Reidel Publishing Company, 1984).



John W. Hastie of the Bureau's Inorganic Materials Division adjusted the pressure in a flame-sampling mass spectrometer prior to observation of species involved in flame inhibition.

illustrative purposes, they tracked methane as an impurity in air, measuring the average concentration, its change with time, and its change with frequency. The measurements could be recorded for different positions with respect to the apparatus. The method was expected to prove useful in studies of smoke and fire.[98]

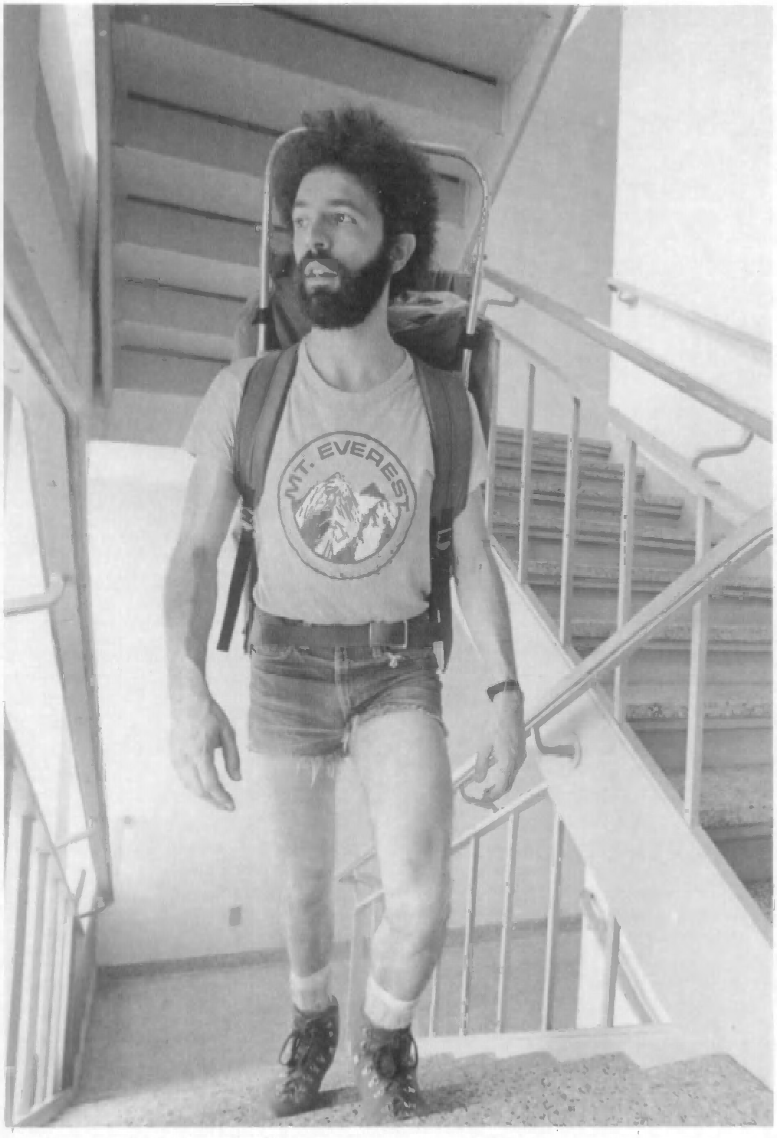
A method for tracking ions and neutral species by the opto-galvanic effect was presented by Peter Schenck. He found that when an atomic species in an electrical discharge was irradiated at a wavelength sufficiently low to cause an electronic transition, an easily detectable voltage signal arose because of the absorption.[99]

In an effort to create a reference method for estimating $^{13}C$ chemical shifts in solids that would still relate to earlier work with liquid tetramethylsilane, William L. Earl and David L. VanderHart performed nuclear magnetic resonance experiments on polydimethylsilane and several other materials. It was their hope to more easily characterize solid materials, including synthetic polymers.[100]

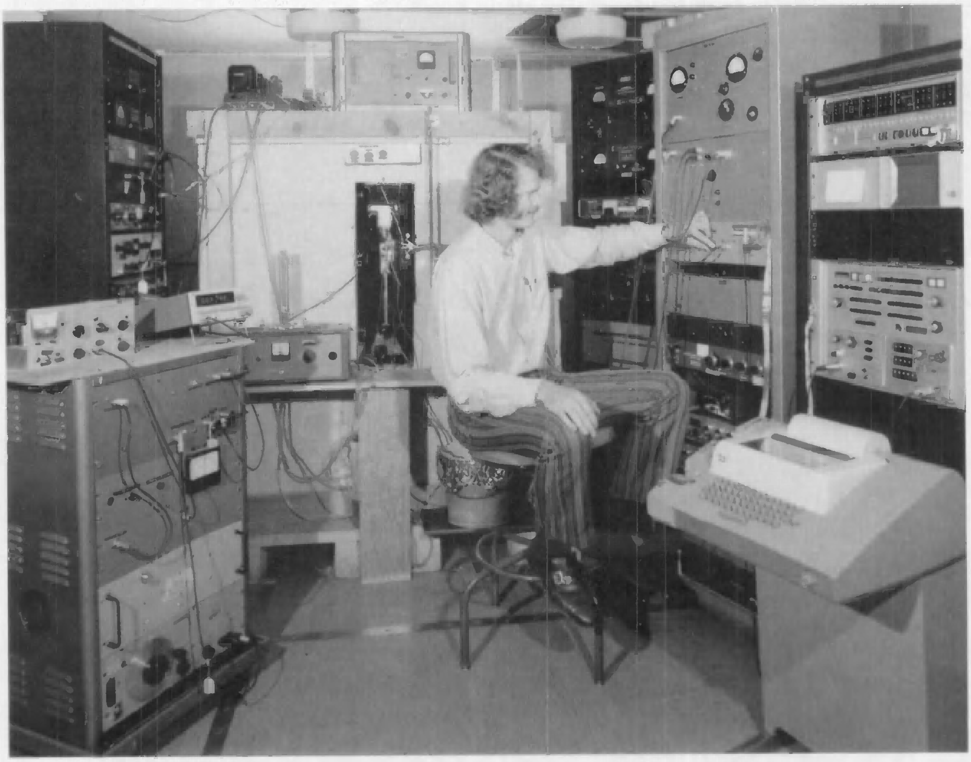
[98] I. Chabay, G. J. Rosasco, and T. Kashiwagi, "Non-intrusive technique measures concentration fluctuations in turbulent gas flow," *NBS Dimensions* **62**, pp. 22-23, April 1978. See also same authors, "Species-specific Raman spectroscopic measurements of concentration fluctuations in unsteady flow," *Journal of Chemical Physics* **70**, No. 9, 4149-4154, May 1979.

[99] P. K. Schenck and K. C. Smyth, "Opto-galvanic spectroscopy of atomic neutrals and ions in discharges," *J. Opt. Soc. Amer*. **68**, 626-627 (1978).

[100] W. L. Earl and D. L. VanderHart, "Measurement of $^{13}C$ chemical shifts in solids," *J. Mag. Res.* **48**, 35-54 (1982).




NBS chemist Ilan Chabay prepared for the rigors of his backpacking trips by running up and down the stairs in the 11-story Gaithersburg Administration Building with a 38 kilogram pack on his back.



David L. Vanderhart, scientist in the Bureau's Polymers Division, tuned a homemade nuclear magnetic resonance spectrometer in studies of chemical shifts in solids.

Kermit Smyth teamed with free-radical experts Sharon Lias and Pierre Ausloos from the Center for Chemical Physics to study the ion-molecule $C_3H_3^+$, which they felt played a leading role in soot formation, particularly in fuel-rich acetylene and benzene flames. They sought chemical reactivity data at thermal energies for $C_3H_3^+$ with alkenes, alkynes, and aromatic molecules. During their work, they found two isomers of $C_3H_3^+$, one linear and a second, more stable, cyclic isomer. They expected the work to be of use in the modeling of fires.[101]

The role of polycyclic aromatic hydrocarbons (PAH) in soot formation was elucidated in optical studies by J. Houston Miller, W. Gary Mallard, and Kermit Smyth. Looking for reactive intermediates, they observed PAH by optical measurements in premixed and diffusion flames, obtaining data on fluorescence in various portions of the flames.[102]

[101] K. C. Smyth, S. G. Lias, and P. Ausloos, "Ion-molecule chemistry of $C_3H_3^+$ and the implications for soot formation," *Combustion Science and Technology* **28**, 147-154 (1982).

[102] J. H. Miller, W. G. Mallard, and K. C. Smyth, "Optical studies of polycyclic aromatic hydrocarbons in pyrolysis and diffusion flame environments," pp. 905-919 in *Polynuclear aromatic hydrocarbons, 7th International Symposium on Formation, Metabolism, and Measurement,* M. W. Cooke and A. J. Dennis, editors (Battelle Press, Columbus Ohio, 1982).

Later, a test stand was built for the study of concentration behavior within turbulent flows. Nelson P. Bryner, Cecilia D. Richards, and William M. Pitts designed the stand large enough (2.4 m by 2.4 m) to examine large flows and plumes, and they utilized Rayleigh light-scattering so that concentration values could be monitored in real time in regimes of flow which heretofore were inaccessible. The stand was constructed so as to minimize optical glare and scattering by dust particles.[103]

*Combustibility and Combustion Products*

The question of the relative safety of hydrogen—under consideration for use as a vehicular fuel—in comparison with methane (natural gas) and gasoline was treated by Jesse Hord. Hord called attention to the relatively rapid mixing between air and hydrogen, leading quickly to an explosive atmosphere. Gasoline, by contrast, mixed relatively slowly. Each of the three substances offered fire and explosion danger, with the level of risk depending upon the circumstances of use.[104]

By the end of the 1970s, it was realized that heat-transfer fluids involving the use of polychlorinated biphenyls (PCBs) created a severe biological hazard. One of the major uses of PCBs was in electrical transformers, where the liquid was used to conduct to the outer casing any heat that was generated by electrical losses in the transformer core and in the windings. In a fire, the PCBs were likely to be spilled or ejected from the casing. Richard G. Gann published a discussion in which he noted the requirements for a replacement fluid in transformers, taking account of the high probability that either slow leakage or explosion would release the fluid. Likely candidates identified were hydrocarbons, silicone oil, and chlorinated aromatics.[105]

In 1981, Frederic B. Clarke, Irwin Benjamin, and Merritt Birky pointed out the need for laboratory toxicology measurements. These could establish the sources of toxic smoke and gases in order to provide a strong basis for regulatory decisions on construction, furnishings, and finishing materials.[106]

Toxicology was also the topic of a study by Barbara C. Levin and Emil Braun. They prepared a test stand with a combustion system that would accommodate samples of various sizes, an analytical chemistry system, and an animal exposure system. They could analyze for CO, $CO_2$, and $O_2$ in the test chamber on a real-time basis, as well as record temperature continuously. The goal of the work was to develop a new test method for toxicity.[107]

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[103] N. P. Bryner, C. D. Richards, and W. M. Pitts, "Rayleigh light scattering facility for the investigation of free jets and plumes," *Rev. Sci. Inst.* 63, No. 7, 3629-3635 (1992).

[104] J. Hord, "Is hydrogen safe?," *NBS Tech Note 690*, October 1976, 34 pp.

[105] R. G. Gann, "Development of flammability criteria for transformer dielectric fluids," *NBSIR 80-1992*, March 1980, 53 pp.

[106] F. B. Clarke, I. A. Benjamin, and M. M. Birky, "Laboratory toxicology measurements," Letter to the Editor, *Fire and Materials* 5, No. 2, 86 (1981).

[107] B. C. Levin and E. Braun, "NBS toxicity measurement method development," paper No. 11 in *3rd Expert Meeting of the Canada- Japan- USA Trilateral Cooperative Study on Fire Gas Toxicity, October 23-25, 1984*, unpublished.

The inhibition of combustion in cellulose by powders containing boron, phosphorus, sulfur or halogens as anions was tested by Robert J. McCarter. Of 185 substances tested against samples of cellulosic "terrycloth," McCarter found about half to inhibit flame formation and about one-third to inhibit both flame and smolder.[108]

In 1978, John W. Rowen reported the results of a comparative study of fire retardants in cellulose and cellular plastic. Plywood and hardboard treated by the manufacturer with fire retardant comprised the cellulose samples, and polyurethane and polystyrene, also treated by the manufacturer, made up the cellular plastic samples. The fire-retardant effectiveness was evaluated during ignition and in the rate of the heat release during the tests. Rowen found that the treated cellulose products performed better according to both criteria than did the cellular plastic.[109]

During the late 1970s, Clayton Huggett and William Parker identified a new principle, oxygen consumption, for measuring the rate of heat release, now accepted as the central property affecting fire growth. Prior measurements were based on temperature rise of the ambient air, leading to large errors because of the uneven distribution of radiant energy.[110] The ideas contained in Huggett's analysis were incorporated in the development of cone calorimeter by Babrauskas and Twilley, and later provided the basis for several international standards.

The plenary lecture at the 7th Conference on the Nonflammability of Polymers, held in Czechoslovakia during April 1983, was given by Clayton Huggett. He described some of the work of the Center for Fire Research, focusing on the flammability of both natural and synthetic polymers, and the influence of fire retardants on their performance in fires.[111]

In 1982, Alex Robertson published a description of an improved radiant heat source for use in combustion testing. A gas-fired unit, it was capable of creating temperatures as high as 935 °C over a surface 0.3 m $\times$ 0.5 m. The unit proved to be adaptable to existing test stands.[112]

Combustion products of wood under the heat fluxes found in fires interested CFR scientists Thomas J. Ohlemiller, Takashi Kashiwagi, and K. Werner. They wanted to determine the kind and level of pollutants to be expected from wood-burning stoves, which were responsible for many residential deaths. Subjecting a variety of types of wood to radiant heat in atmospheres of 0-20 % $O_2$ in nitrogen, they directly monitored the temperature and concentrations of $H_2O$, $CO$ and $CO_2$, and total hydrocarbons.

[108] R. J. McCarter, "Combustion inhibition of cellulose by powders: preliminary data and hypotheses," *Fire and Materials* 5, No. 2, pp. 66-72, June 1981.

[109] J. W. Rowen, "Role of fire retardants in time for ignition and heat release measurements," in *Proceedings of the 3rd International Conference on fire safety, January 16-20, 1978, San Francisco, CA,* unpublished.

[110] C. Huggett, "Estimation of rate of heat release by means of oxygen consumption measurements," *Fire and Materials* **4**, pp. 61-65 (1980).

[111] C. Huggett, "Fire retardant testing and fire performance," Plenary Lecture, unpublished.

[112] A. Robertson, "Development of an improved radiant heat source for fire testing," *Fire and Materials* **6**, No. 2, 68-71, 1982.

The hydrocarbons were further examined by gas chromatography and mass spectrometry, as appropriate. While they found the products to be fully as complex as they had expected, they were confident that the majority of the species could be identified and quantified.[113]

*Combustibility Studies in the Space Shuttle*

In a program that eventually would propel astronaut Gregory T. Linteris into space, Clayton Huggett joined a team of fire scientists to evaluate the usefulness of a space environment for the study of combustion. A. L. Berlad and C. H. Yang of the State University of New York, Frederick Kaufman of the University of Pittsburgh, George H. Markstein of the Factory Mutual Research Corporation, and Howard B. Palmer of Pennsylvania State University made up the balance of the team. After considerable thought, they came to the conclusion that the lack of gravity and the possibility of scaled-gravity experiments, the elimination of convective effects, and the possibility of homogeneous mixing of materials that could not be accomplished on earth constituted a unique experimental situation that should be pursued further, as indeed it was. Tentative assignment of experiments involved single-drop gas jets, porous solid arrays, unmixed solid-gas samples, and particle clouds.[114]

In a first for the agency, one of its own scientists performed the experiments designed for the Space Shuttle. Gregory T. Linteris, Princeton-trained mechanical/aerospace engineer, became a NIST staff scientist in 1992. He helped bring the low-gravity experiment package to completion, then applied for a spot on the shuttle microgravity mission as a payload specialist so that he could actually conduct the experiments in space. The idea suited NASA well—they wanted members of their scientific missions to be working scientists, and it was even better if the scientists had firsthand knowledge of the experiments.

Linteris and the combustion experimental package were sent into space in April 1997. After only 4 days, however, suspicious readings from one of the fuel cells of the Columbia prompted NASA to recall the flight. On July 1, 1997, a second liftoff was entirely successful. Mission STS-94, with the same crew as its predecessor, turned into a "routine"—the word seems entirely out of place for any flight into space—shuttle mission. For nearly 3 weeks, Linteris and his colleagues conducted a variety of microgravity experiments, including the combustion package prepared at NIST.[115]

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[113] T. J. Ohlemiller, T. Kashiwagi, and K. Werner, "Wood gasification at fire level heat fluxes," *Combustion and Flame* **69**, No. 2, 155-170, 1987.

[114] A. L. Berlad, C. Huggett, F. Kaufman, G. H. Markstein, H. B. Palmer, and C. H. Yang, "Study of combustion experiments in space," *NASA Report CR-134744*, November 1974, unpublished.

[115] See, for example, "Second Time's the Charm," *NIST Connections*, October 1997, p. 2.

*Smoke Detectors and Alarms*

Interest in the topic of smoke detection in residences was spurred by fire statistics obtained for the year 1972. In that year, fire deaths per million of population in the United States reached the level of 57, nearly double the per-capita fire-death rate in Canada, the only other major industrial country experiencing a rate as high 20 deaths per million population.[116]

In 1974, Richard G. Bright urged the wider use of smoke detectors in residences, an improvement which he estimated could reduce the loss of life by 40 % to 50 %. However, he noted that the reliability of smoke detectors available at that time was uneven, and that there were no published standards for detectors. He analyzed historical data on residential fires, as well as work done at NBS and elsewhere to improve smoke detectors.[117]

Bright's paper was reprinted in 1982 in *Fire Protection Structure and Systems Design Reader,* published by Ginn Custom Publishing Company of Lexington, Massachusetts, as part of its *Open Learning Fire Service Program.*

Irwin Benjamin, then chief of the Fire Safety Engineering Division, prepared during 1980 a detailed study of the designs of fire detectors then in use in large buildings. Fire detectors, he noted, typically activated an alarm, an extinguishing system, or a specialized device. Available detectors were designed to respond to one of three conditions: when a set-point temperature was exceeded, when an aerosol exceeding a certain concentration was encountered, or when a pre-set level of radiant energy was exceeded. Temperature-activated detectors, usually employing a fusible link, a bimetallic switch, or a pneumatic switch, generally activated a sprinkler head. Aerosol detectors usually employed a photocell or an ion chamber to set off an alarm. Radiant-energy detectors made use of infrared filters, a lens, and a photocell, with the photocell signal connected to an alarm; although in some cases ultraviolet detection, at wavelengths in the range 200 nm to 300 nm, was used.[118]

A few years later, Richard W. Bukowski, at that time leader of the fire analysis group in the Center for Fire Research, described the elements of fire detection and alarm during a workshop on the technology of fire protection held in Egypt.[119] His was one of nearly a dozen CFR contributions to the workshop.

[116] "International Fire Statistics, 1972," Fire Record Department, Natl. Fire Prot. Assn., *Fire Journal* **67**, No. 6, pp. 50-51, November 1973.

[117] R. G. Bright, "Advances in residential smoke detection," *Fire Journal* **68**, No. 6, 69-77, November 1974.

[118] I. A. Benjamin, "Detector response in large buildings," pp. 1-24 in *Proc. Engineering Applications of Fire Technology Workshop, April 16-18, 1980, NBS Gaithersburg,* H. E. Nelson, editor (Boston: Society of Fire Protection Engineers, 1983).

[119] R. W. Bukowski, "Fire detection and alarm systems," *NBSIR 86-3360,* April 1986, Kurt F. J. Heinrich, Andrew Fowell, and Doris Bluebond, editors, pp. 25-38.

A handy tool in the study of smoke or other aerosols is a reference material that will permit the ready evaluation of the size of particulates. This tool was provided in 1985 by a team consisting of George W. Mullholland of the Center for Fire Research and Arie W. Hartman, G. G. Hembree, Egon Marx, and Thomas R. Lettieri, all from the Center for Manufacturing Engineering. They created Standard Reference Material 1690, an aqueous suspension of selected polystyrene spheres of approximately 1 μm diameter. The spheres were remarkable in that quantities were produced both in the NBS laboratories and in a space-shuttle experiment.[120] Although the spheres were produced during a 1982 space shuttle flight, SRM 1690 was offered for sale to the public after SRM 1960, described in "Measuring Tiny Space Beads" later in this chapter.

The group determined the average size of the particles in three ways; by observing the scattering of polarized laser light as it passed through the suspension; by observing the scattering of light from individual particles; and by measuring the row length generated by hexagonal close packing of the spheres in a two-dimensional array, using an optical microscope. The three methods agreed within ±0.5 %. Judging the overall uncertainty to be somewhat larger, they specified the average diameter of the spheres as $(0.895 \pm 0.007)$ μm.[121]

Even smaller aerosol particles, useful for simulating smoke conditions below the range of visible detection, could be produced with the use of low fuel flows in a laminar diffusion burner, according to more recent studies by Thomas G. Cleary, George Mulholland, Lewis K. Ives, and Robert A. Fletcher of the CFR, who collaborated on the project with J. W. Gentry of the University of Maryland. The group used acetylene, $C_2H_2$, to produce ultrafine aerosols, invisible to the eye but measured by transmission electron microscopy to be particles of 10 nm diameter. Particle densities of $10^6\ cm^{-3}$ were estimated.[122]

The growth of soot in laminar flames was observed by Robert J. Santoro, Tsyh T. Yeh, John J. Horvath, and Hratch G. Semerjian, all of the Center for Chemical Engineering. The group noted that flames occurring in actual fires are not laminar, but they were convinced that soot growth in the two types of flame would be similar. In their experiment, the group prepared an ethene-air, co-annular diffusion flame and monitored the temperature and velocity of the flame as well as the size, velocity, and concentration of soot that formed at low fuel rates.[123]

[120] G. Mulholland, G. Hembree, and A. Hartman, "Sizing of polystyrene spheres produced in microgravity," *NBSIR 84-2914,* July 1985, 26 pp.

[121] G. W. Mulholland, A. W. Hartman, G. G. Hembree, Egon Marx, and Thomas R. Lettieri, "Development of a one-micrometer-diameter particle size Standard Reference Material," *J.Res. NBS* **90**, No. 1, 3-26 (1985).

[122] T. G. Cleary, G. W. Mulholland, L. K. Ives, R. A. Fletcher and J. W. Gentry, "Ultrafine combustion aerosol generator," *Aerosol Science and Technology* **16**, 166-170 (1992).

[123] R. J. Santoro, T. T. Yeh, J. J. Horvath, and H. G. Semerjian, "Transport and growth of soot particles in laminar diffusion flames," *Combustion Science and Technology* **53**, 89-115, 1987.

Growing interest in the disposal of oil from leaking ocean-transport vessels led to experiments on the consequences of burning the spilled oil at sea. A CFR group, David D. Evans, George W. Mulholland, Daniel Gross, Howard R. Baum, and William D. Walton, collaborating with K. Saito of the University of Kentucky, created an apparatus in which they could float a pool of oil of a specified thickness on water and monitor its burning. They recorded the flame temperature, energy release rate, rate of radiation feedback, the nature of the oil residue, the pattern of the burn, and the heat balance at the burning surface. It was expected that these would become base data to be used later in modeling such oil fires.[124]

The Handbook of Fire Protection issued its first edition in 1988. It was composed of four sections: fundamentals, hazard analysis, design calculations, and risk calculations. One of the "fundamentals" contributions came from George Mulholland, who described the production and properties of smoke.[125]

The burning of oil from spills was the topic pursued by a multinational group including Bruce A. Benner, Jr., Nelson P. Bryner, Stephen A. Wise, and George Mulholland, all of CFR, and Robert C. Lao and Mervin F. Fingas of Environment Canada. Referring to the difficulties involved in disposing of oil spills in remote locations, they pressed further the question of the consequences of burning the oil *in situ.* Laboratory study and modeling convinced them that polycyclic aromatic hydrocarbons involved in such a combustion situation would be substantially reduced and that the combustion products would disperse with relatively short-lived damage to the environment.[126]

An effective, long-term investigation of the role of smoke in creating danger to humans involved in fire came from John H. Klote. Klote spent several years studying the movement and control of smoke in buildings. With J. W. Fothergill, he wrote a handbook[127] that proved very popular, serving as a text in courses on the topic and later being re-issued by the American Society for Heating, Refrigeration, and Air-Conditioning Engineering as its *Smoke Control Handbook.*

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[124] D. D. Evans, G. W. Mulholland, D. Gross, H. R. Baum, and W. D. Walton, "Burning, smoke production, and smoke dispersal from oil spill combustion," *NISTIR 89-4091*, October 1989, 57 pp.

[125] G. W. Mulholland, "Smoke production and properties," pp. 1/368-377 in *Handbook of Fire Protection Engineering,* 1st Edition, 1988, Philip. J. DiNenno, editor-in-chief, (Quincy Massachusetts: National Fire Protection Association, 1988) 700 pp.

[126] B. A. Benner, Jr., N. P. Bryner, S. A. Wise, G. W. Mulholland, R. C. Lao, and M. F. Fingas, "Polycyclic aromatic hydrocarbon emissions from the combustion of crude oil on water," *Environmental Science and Technology* **24**, No. 9, 1418-1427 (1990).

[127] J. H. Klote and J. W. Fothergill, "Design of smoke control systems for buildings," *NBS Nandbook 141,* 1983.

In a discussion prepared in 1992 for the Council on Tall Buildings and Urban Habitat, Klote wrote, "Smoke is recognized as the major killer in all fire situations." He went on to discuss details of the efforts to conquer the fatal effects of smoke in tall-building fires; we review these comments later in this section.[128]

*Education*

Considerable effort of the Center for Fire Research was given to activities that could be recorded under the heading of education. Lack of awareness of the dangers of fire on the part of industrial designers and workers, as well as designers, builders, and occupants of dwelling units has been cited over and over again as the single biggest contributor to fire deaths and economic loss from fire in the United States.

In this section, we cite just three examples of educational material made available by the CFR staff. John Lyons, then Director of the CFR, outlined the U.S. efforts in fire loss reduction—both contemporary and planned—as a result of the 1974 *Fire Prevention and Control Act* during an international symposium on fire safety. He noted the many organizations that participate in the fire-reduction effort in the United States: Federal, state, and local governments writing fire codes; the American Society for Testing and Materials and the National Fire Protection Association developing test methods, often with the technical assistance of the National Bureau of Standards; and the Consumer Product Safety Commission working to reduce fire danger inherent in consumer goods. Lyons called attention to the change in focus of fire science from studies devoted exclusively to fire endurance and the compartmentalization of fire to "concern for the occupants in the room of origin"—leading to more effort to understand the processes and consequences of the burning of furnishings and interior finish materials of rooms in offices, hotels, and dwelling units. He expressed the view that the new Fire Academy, given better understanding and tools, would make rapid progress in improving fire-fighting in America and in educating its citizens on fire safety.[129]

John Rockett provided a more technical form of education in a contribution to the first edition of the Society for Fire Protection Engineering Handbook. His efforts were directed to fire protection engineers; the topic was a "short course" in heat conduction in solids. Taking as his text the famous book written by Carslaw and Jaeger,[130] Rockett reviewed the mechanisms of heat transfer by radiation, conduction, and convection, applying the concepts to the special conditions and geometries of fire.[131]

[128] J. H. Klote, "Control of smoke and combustion products," pp. 17-52 in *Fire Safety in Tall Buildings,* D. Sfintesco, C. Scawthorn, and J. Zicherman, editors (New York: McGraw-Hill, 1992).

[129] J. W. Lyons, "Requirements for fire safety of combustible materials in the United States," pp. 12-19 in *International Symposium on Fire Safety of Combustible Materials, October, 1975, University of Edinburgh* (Edinburgh: University of Edinburgh, Centre for Industrial Consultancy and Liaison, 1975).

[130] H. S. Carslaw and J. C. Jaeger, "Conduction of Heat in Solids," 2nd Edition (Oxford, England: Clarendon Press, 1959).

[131] J. A. Rockett, "Conduction of heat in solids," pp. 1/49-64 in *SFPE Handbook of Fire Protection Engineering* (Quincy, Massachusetts: National Fire Protection Association, 1988).

A suggestion for a new test facility involving the generation of large-scale air motion represented a kind of educational effort, too. William M. Pitts presented such a suggestion in 1991, recalling the mass fires—fire storms and conflagrations—that accompanied the destruction of entire cities by fire, as well as countless acres of forest. Fire storms called to his mind the destructive effects of war-time bombing, resulting in tall heat columns and inwardly rushing winds that completely destroyed the targets. Wind-driven conflagrations such as those that destroyed Chelsea, Massachusetts in 1973 and routinely burned timberlands moved as the wind directed them, halting only when their fuel was gone.

Pitts assessed the need for a test facility that would help elucidate the nature and control methodology of mass fires, and he offered criteria for its design. His idea was to build a chamber similar to a wind-tunnel.[132]

### *Combustion of Furnishings and Room Interiors*

An early discussion of combustion in rooms was given by Jin Bao Fang and Daniel Gross. They described a test facility that would allow the evaluation of the contents of a room—from wastebaskets and furniture to the ceiling, floor, and walls—from the point of view of fire science. These aspects would include the study of the items as fuel for fire, as well as the products of their combustion—smoke and toxic gases—and likely scenarios for the progress of fire in a room environment. The test chamber fire was to be ignited by a stack, or crib, of wood. With such a heat source, the scientists could examine time-to-ignition, extent of surface flame and flame penetration, and smoke and heat generation. In the work reported, Fang and Gross presented results obtained with various types of room-finish materials such as particle board, plywood, gypsum board, melamine, and vinyl and acoustic tile.[133]

The close connection they found between death from fire in space heaters and residences caused Alan Gomberg of the CFR to team with John R. Hall of the Federal Emergency Management Agency to compile statistics on the topic. Studying some 1600 fatalities occurring in 12 states over the years 1978-1979, they found that, at 53 deaths per million population, rural Americans (those in communities smaller than 2500 people) were twice as likely as their urban neighbors to die in fire. The causes that predominated for the fatal fires involved space heaters—wood stoves, kerosene heaters, and electric baseboard heaters. Improper handling of the equipment, spills during filling or cleaning, or the ignition of paper or furnishings by the devices all led to disaster.[134]

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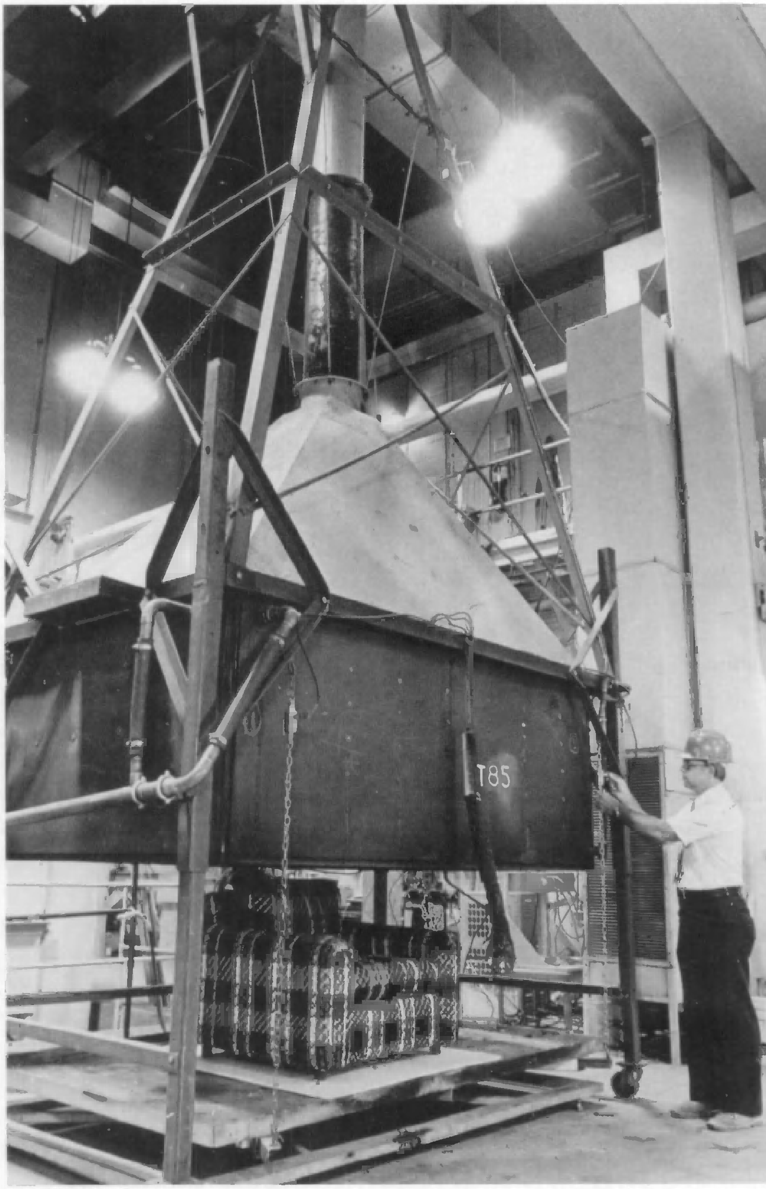
[132] W. M. Pitts, "Wind effects on fires," *Progress in Energy and Combustion Science* **17**, 83-134 (1991).

[133] J. B. Fang and D. Gross, "Contribution of interior finish materials to fire growth in a room," pp. 125-138 in *NBS Special Publication 411*, "Fire Safety Research: Proceedings of a Symposium, August 22, 1973, Gaithersburg, Maryland," Mary Jo Butler and James A. Slater, editors.

[134] A. Gomberg and J. R. Hall, "Space heater—rural death link," *Fire Service Today* **49**, No. 9, pp. 18-21, September 1982.




Bureau scientist Randall Lawson adjusted instrumentation on the furniture calorimeter, part of an NBS-developed method to measure the rate at which heat was released from burning furnishings in offices and residences.

By 1983, there existed a proposed American Society for Testing and Materials standard method for the testing of wall and ceiling materials in rooms. William J. Parker described for an international workshop NBS efforts to obtain accurate and reliable data on which the proposed standard and other advances could rest.[135]

Andrew J. Fowell addressed the methods recommended to control industrial fires, during a workshop in Cairo, Egypt in 1986. Fowell pointed out the value of using non-combustible materials in construction, of providing for the isolation of a burning area, of installing automatic sprinkler or other fire-suppression systems, and of providing for smoke control. He dwelt especially on the design aspects of sprinkler systems—water supply, valving, distribution, and release mechanisms.[136]

The results of studies of flammability of upholstered furniture and mattresses were summarized by Vytenis Babrauskas and John F. Krasny in a chapter of the *Fire Protection Handbook.* The two veterans recounted frightening fire statistics from 1982. Nearly 80,000 fires were triggered by upholstered furniture and mattresses; these translated into 1900 deaths, more than 10,000 injuries, and $500 million in economic loss. Cigarettes played the key role in 65 % of the deaths, although half of the dead were not themselves the smoker; often a forgotten cigarette would fall into a crevice in the furniture, smoldering for hours before toxic gases would snuff out the lives of sleeping residents. Babrauskas and Krasny noted that some 15 tests were available for the evaluation of fire danger from particular items of furniture, including monitoring of CO, $CO_2$, HCl, HCN, and $NO_x$. [137]

Kathy A. Notarianni of CFR described a test bay set up at the request of the National Institutes of Health to simulate a two-bed hospital room with automatic sprinklers. The setup included, besides the room itself, a simulated bathroom, corridor, HVAC system, and ports for ventilation. Both pendant and sidewall sprinkler heads could be installed. The tests involved timing the operation of various positions and types of sprinklers and smoke alarms and monitoring temperatures, smoke meters, heat flux meters, a radiometer, and concentration of gases (CO, $CO_2$, and $O_2$) throughout the bay in response to flames generated within it.[138]

[135] W. J. Parker, "NBS activities in room fire tests and heat release rates of materials," pp. 44-47 in *CIB Report Publication 81: Modeling of Pre-Flashover Fires; CIB W14 Workshop, Borös, Sweden, May 1983,* P. H. Thomas and U. Wickström, editors (Bors, Sweden: Conseil International du Batiment, Statens Provningsanstalt, 1983).

[136] A. J. Fowell, "Industrial fire suppression," pp. 63-66 in *NBSIR 86-3360,* Kurt Heinrich, Andrew Fowell, and Doris Bluebond, editors, April 1986.

[137] V. Brabauskas and J. F. Krasny, "Upholstered furniture and mattresses," pp. 12/120-128 in *Fire Protection Handbook,* 16th Edition, A. E. Cote and J. L. Linville, editors (Quincy, Massachusetts: National Fire Protection Association, 1986).

[138] K. A. Notarianni, "Five small flaming fire tests in a simulated hospital room protected by automatic fire sprinklers," *Report of Test FR 3982,* 23 pp., October 31, 1990, unpublished.

*Combustion of Buildings, Aircraft, and Spacecraft*

In April 1971, a disastrous fire in a nursing home killed 31 residents. The extraordinarily high loss of life was traced to unusual flammability of the floor covering used in the home's corridors. In response to this well-defined problem, L. G. Hartzell was asked by his employer, the Armstrong Cork Company, to devise a test method for flooring materials. He worked on two aspects of flammability: ease of ignition of the flooring material, to establish its danger as a source of fire; and flammability rate, to establish its contribution to prolonging and extending a fire. As his work progressed, he came to NBS as a Research Associate to help adapt the method for possible use by the ASTM.[139] Sanford Davis of the CFR and his colleague C. Howard Adams, a Bureau Research Associate from the Society of the Plastics Industry, later summarized the results of the test-method development, which eventually incorporated a device that would subject a 20 cm × 100 cm specimen to radiant or burner heating while allowing measurements of air supply and temperatures, both by radiometric means and by thermocouple thermometers.[140]

In 1972, the National Transportation Safety Board requested that NBS help in the investigation of an explosion on March 24, 1972, that killed several residents of Canterbury Woods, Virginia, and destroyed or damaged three homes when a backhoe ruptured a natural gas pipeline in the vicinity. Robert W. Beausoliel, Clinton W. Phillips, and Jack E. Snell responded to the request and, using tracer gas, were able to determine the pathways by which the natural gas penetrated the homes in order to build up explosive gas concentrations.[141]

Dozens of tall buildings suffered disastrous fires throughout the world in this century, leading to considerable effort on the process by which the smoke and flame could be restricted to a small area of the building. Francis C. Fung described experiments conducted in the 36-story Seattle Federal Building and in the 42-story Chicago Federal Building, using $SF_6$ tracer gas to mark the path of simulated smoke through the rooms and corridors as emergency smoke-control air-handling systems attempted to isolate the "burn room." The burn room was equipped with a heavy-duty blower to propel the heated air-plus-tracer-gas mixture into the corridor. The experiment showed that the emergency systems succeeded by exhausting the air from the fire zone, replacing it with pressurized air from both above and below.[142]

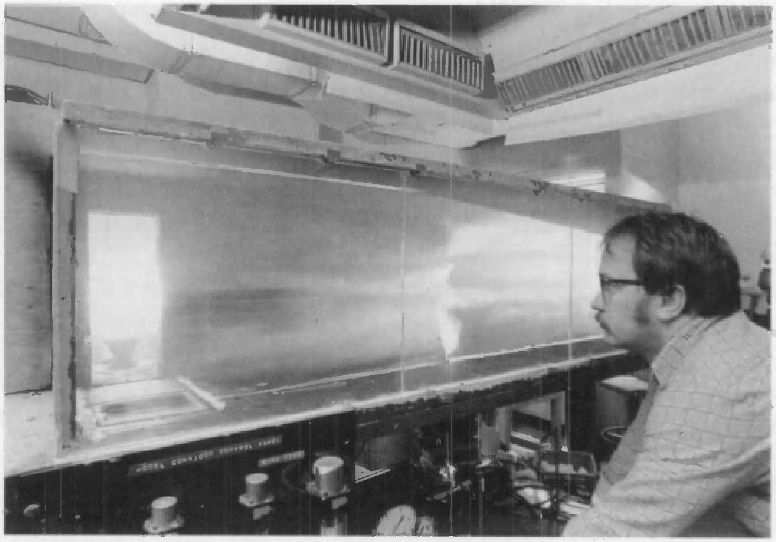
A deadly fire broke out in the 26-story MGM Grand Hotel, crowded with visitors to Las Vegas, Nevada, on November 21, 1980. The blaze left 85 persons dead. In an

[139] L. G. Hartzell, "Development of a radiant panel test for flooring materials," *NBS Interagency Report NBSIR 74-495*, May 1974, 49 pp.

[140] C. Howard Adams and Sanford Davis, "Development of the flooring radiant panel test as a standards test method," *NBSIR 79-1954*, March 1980.

[141] R. W. Beausoliel, C. W. Phillips, and J. E. Snell, "Field investigation of natural gas pipeline accident: Canterbury Woods, Annandale, Virginia," *Fire Journal* **68**, No. 3, 77-84, May 1974.

[142] F. C. W. Fung, "Smoke control by systematic pressurization," *Fire Technology* **11**, No. 4, 261-269 (1975).



As part of a general NBS study to develop effective means of predicting fire behavior in buildings, William J. Rinkinen observed streak lines from titanium dioxide smoke injected into a room-corridor fire-simulation model. The apparatus contained instruments to record pressure, temperature, and gas flow.

effort to establish the cause of death, Merritt Birky, Maya Paabo, and NBS Guest worker Dolores Malek teamed with D. Mayne, Coroner of Clark County, Nevada, to study tissue samples from the victims. Tests indicated that the great majority of the victims—75—died from inhalation of smoke and carbon monoxide. Another eight died from smoke inhalation, burns, or a combination of these causes. One died of a blow to the head during the fire, and one suffered a fatal heart attack. The results showed again the potent danger of smoke and toxic gases in fires.[143]

Another casino fire, this time in the Dupont Plaza Hotel and Casino in San Juan, Puerto Rico, on New Year's Eve, 1986, took 97 lives. All but a few were so badly burned as to be unidentifiable. The Bureau staff once again was involved in the analysis of the fire.[144] Harold E. Nelson prepared an engineering analysis of the fire. The fire apparently ignited in a cardboard box containing upholstered furniture that was stored on the first floor of the 20-story hotel. Also on the first floor were a ballroom complex, a foyer, a lobby, and connecting corridors. Nelson, part of a team that included representatives of the Bureau of Alcohol, Tobacco, and Firearms; the U.S. Fire Administration; the U.S. Fire Academy; and the National Fire Protection Association, used eyewitness accounts where available to verify the actual progress of the fire in

143 M. M. Birky, D. Malek, D. Mayne, and M. Paabo, "Study of biological samples obtained from victims of MGM Grand Hotel fire," *J. Analytical Toxicity* 7, 265-271 (1983).

144 H. E. Nelson, "Engineering analysis of the early stages of fire development: the fire at the Dupont Plaza Hotel and Casino, December 31, 1986," *NBSIR 87-3560,* 113 pp., April 1987.

comparison with a model prepared using available data on the structure and its furnishings. He found that 10 minutes after ignition, the fire had spread through the ballroom and had created sufficient momentum that flashover occurred, bursting windows and sending fatal concentrations of smoke and toxic gases throughout the ballroom and foyer areas. Within another 3 minutes, the casino area was in flames. Nelson was able to provide other fire scientists with detailed predictions—estimated to be accurate within about 25 %—of many features of the fire, including mass burn rates, rates of heat release, smoke temperatures, velocities of the fire and smoke fronts, and response of fire-suppression sprinklers.

Barbara Levin, an expert in toxicology, participated with Pio R. Rechani, Fransisco Landron, Jose R. Rodriguez, Lucy Droz, Flor M. deCabrera, and Sidney Kaye of the Puerto Rico Institute of Forensic Science (IFS), with Joshua L. Gurman of the American Iron and Steel Institute, and with Helene M. Clark and Margaret F. Yoklavich of the University of Pittsburgh, in a study of tissue and blood samples from the fire victims.[145] Levin and her group screened the samples for carboxyhemoglobin and cyanide at the IFS in Puerto Rico, moving the positive samples to NBS for quantitative testing. They found that those persons who were badly burned in the fire—some 78 of the victims—were not killed by toxic gas, but rather by heat alone, so intense was the fire.

Jack Snell was asked by the Subcommittee on Science, Research, and Technology of the House Committee on Science, Space, and Technology to testify on NBS work on the Dupont Plaza fire. Later, with the assistance of Harold Nelson, Snell published the substance of the testimony as part of the *4th International Fire Conference.* Snell recounted that Nelson and James Quintiere of the CFR had been able to provide on-the-spot-analysis of the fire to assist local investigators, using portable computers programmed with CFR fire-modeling information. He noted that arson was suspected in the origin of the fire, but that the proximate cause of death for most of the dozens of victims lay with the design and construction of the hotel, with its fire-protection systems, and with the level of emergency training given the hotel staff.

Snell stated that several minor changes in the situation would have saved both life and property:

- Had an operating sprinkler head been located within 10 feet of the point of origin, the fire would have been extinguished within 3 minutes, well short of causing fatalities.

- Had an operating smoke detector been located in the room of origination, an alarm would have sounded within 15 seconds of ignition.

[145] B. C. Levin, P. R. Rechani, F. Landron, J. R. Rodriguez, L. Droz, F. M. deCabrera, S. Kaye, J. L. Gurman, H. M. Clark, and M. F. Yoklavich, "Analysis of carboxyhemoglobin and cyanide in blood from victims of the Dupont Plaza Hotel fire in Puerto Rico," *J. Forensic Sciences* **35**, No. 1, 151-168 (1990).

- Had an existing standard code for fire resistance of interior walls (providing a 1 hour delay in fire penetration) been applied to the hotel construction, the foyer and casino fatalities would likely not have occurred.[146]

The frightening predicaments encountered by residents of high-rise retirement homes were illustrated by a deadly fire in Johnson City, Tennessee, that occurred the day before Christmas, 1989, in the John Sevier Retirement Center. The 11-story structure was flanked by a single-story wing on one side and by a three-story wing on the other. Fire broke out in the one-story wing, igniting combustible ceiling materials. Although the local fire department responded promptly (estimated at 4 minutes after the alarm), hot, toxic gases killed 16 residents, almost all on upper floors of the central building. Kenneth D. Steckler, James G. Quintiere, and John H. Klote analyzed the fire debris and noted two key features that doomed the victims: firstly, the hidden combustible ceiling materials—mostly wood-fiber tiles—provided so much fuel that when flashover occurred, oxygen levels were severely depleted, leading to fatal concentrations of carbon monoxide; secondly, the elevator shafts provided a natural chimney for the hot, toxic gases to reach the upper floors, trapping the occupants, many of whom could not use the stairs because of their physical disabilities.[147]

In the Introduction to a publication mentioned earlier,[148] Joseph Zicherman catalogued some 37 major fires occurring in tall buildings. The fires in the Las Vegas MGM Grand Hotel, the San Juan Dupont Plaza, and the Johnson City Sevier Retirement Center, disastrous as they were in terms of loss of life and property, served to illustrate the central fact of tall-building fires: smoke and toxic gas was the killing agent most of the time. John Klote, in a 35-page discussion, described progress in the treatment of smoke in high-rise buildings. He noted that pressurization of stairwells was introduced in the 1960s, requiring zoned HVAC systems. The next step was the "pressure sandwich"; pressurization from above a burning floor and below was coupled with exhaust from the burn area to restrict smoke and gases to the burning floor. Specialized air-handling equipment was needed for emergency use, along with smoke barriers, vents and shafts.

Relatively little was written about the psychology of arson. According to Bernard M. Levin, this paucity resulted from the fact that only the "least successful" arsonists—those who were caught and those who confessed—were available for study. Writing in the journal *Fire and Arson Investigator*, Levin identified three major

[146] J. E. Snell and H. E. Nelson, "Summary of the National Bureau of Standards' analysis of the Dupont Plaza Hotel Fire," pp. 98-105 in *4th International Fire conference, March 22-24, 1988, Cambridge, England,* Interflam '88, Vol. 13, "Fire and Materials," S. P. Rogers and R. M. Quarterman, editors (New York: John Wiley and Sons, 1988).

[147] K. D. Steckler, J. G. Quintiere, and J. H. Klote, "Johnson City fire: Key factors," NIST Letter Report, 1990, unpublished.

[148] J. H. Klote, "Control of smoke and combustion products," pp. 17-52 in *Fire Safety in Tall Buildings,* D. Sfintesco, C. Scawthorn, and J. Zicherman, editors (New York: McGraw-Hill, 1992).

motivations for arson: for-profit, typified by insurance fraud and arson to cover criminal evidence; revenge or pyromania, generally involving only one person; and vandalism, riot, or political motives, generally involving a group of people.[149]

Early in a study of residential fire (although residential fires constituted only 28 % of reported fires, they accounted for 78 % of the deaths and 58 % of the economic dollar losses at that time), room-scale floor-fire testing was described by Jin Bao Fang. Tests of seven weighted structures, four of unprotected wood and three of light steel, resulted in average time-to-failure of 10-12 minutes and less than 4 minutes, respectively. The steel floor, though not itself combustible, buckled long before the wood lost its strength. Protecting the steel members by a covering of gypsum board lengthened its service life to about 16 minutes.[150]

A survey of the types and amounts of "fuel" available in residential fires was conducted by Lionel A. Issen. He reported data for 359 residences in the Washington, DC area, mostly single-family detached houses but including single-family attached and mobile homes. The logic used in cataloging the value of household furnishings as "fuel" involved the use of an average figure for their energy of combustion—8000 Btu/lb. This simplification permitted the survey to estimate the total energy available in terms of the total weight of the furnishings in any given room.[151]

A major source of fire in residences, particularly those in which wood-burning stoves contributed to the heating, was chimneys. Accordingly, the CFR carried out experiments on behalf of the Consumer Product Safety Commission and the U.S. Department of Energy in which several chimneys were purchased or constructed, then loaded with condensibles from fires of various kinds of wood. Richard D. Peacock, who reported the results, noted that the vernacular name for the condensibles was "creosote," which often was taken to include "everything but the birds' nests." The test burns were performed on the chimneys with no external restrictions on airflow; the results were given in terms of maximum chimney temperature and fire duration. The maximum temperatures generally reached 800 °C (1500 °F). Peacock gave minimum specifications for safe use of masonry chimneys; a fire-clay liner of at least 1.6 cm thickness, masonry of at least 10 cm thickness, and an air gap separating the two.[152]

A user-interactive computer program for evaluating heat-detection systems installed in buildings was presented in a massive (557-page) tome both in the *BASIC* and the *FORTRAN* languages. The compilation was prepared by David W. Stroup, David D. Evans, and Phyllis M. Martin.[153] The report included a number of examples treated with the use of the program.

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[149] B. M. Levin, "Psychological characteristics of firesetters," *Fire and Arson Investigator* 27, No. 4, 12-22 (1977).

[150] J. B. Fang, "Fire performance of selected residential floor materials," *NBSIR 80-2134*, December 1980, 79 pp.

[151] L. A. Issen, "Single-family residential fire and live loads survey," *NBSIR 80-2155*, December 1980, 176 pp.

[152] R. D. Peacock, "Chimney fires: Intensity and duration," *Fire Technology* 22, No. 3, 234-252 (1986).

[153] D. W. Stroup, D. D. Evans, and P. M. Martin, "Evaluating thermal fire detection systems (SI Units). Final Report," *NBS Special Publication 713*, April 1986, 557 pp.

In response to a request from the National Institutes of Health for data on which to base the design of new chemical laboratories, William D. Walton of CFR prepared a test facility to simulate the response of various types of sprinkler systems to bench-top fires. Acetone, an extremely flammable solvent, was selected as the test fuel; measurements were made of the flame temperature and the concentrations of $O_2$, CO, and $CO_2$ as standard sprinklers, quick-acting sprinklers, or no sprinklers at all were used to suppress the fire. Both types of sprinkler were effective in dousing the flames, but without sprinkler protection, the fires were judged to be lethal to bystanders.[154]

On October 17, 1989, a strong earthquake shook northern California; it was estimated to have been the most severe disturbance along the San Andreas fault since 1906. The epicenter of what came to be called the *Loma Prieta Earthquake* was placed at a spot 16 km northeast of the city of Santa Cruz and some 18 km deep in the earth. Damage in the Bay Area was extensive—62 dead, more than 3500 injured, 12,000 people displaced from their homes, some $6 billion in property loss. A 50-foot span of the San Francisco-Oakland Bay bridge collapsed, as did elevated sections of Interstate 880 in Oakland. A six-member team from NIST, led by Hai S. Lew, joined representatives of the Federal Highway Administration, the Department of Housing and Urban Development, and the U.S. Geological Survey to assess the damage.

Harold E. Nelson of CFR examined the state of the Bay Area fire protection systems after the shock. He found that most private fire-protection facilities survived the quake in serviceable condition, but that the public fire-protection systems suffered extensive interruption. Had the quake been accompanied by widespread fire in San Francisco, he said, the public fire response would have been hamstrung by inoperative equipment. In Nelson's opinion, substantial fire losses were avoided only because electric utilities were shut down according to emergency procedures and because safeguards had become so common on the pilot lights of gas appliances. Good fortune also played a role—the weather was warm, so that most home-heating furnaces were turned off, and there was little or no wind on that day.[155]

At a U.S. Navy facility, equipment used to train fire-fighters was found to malfunction in high winds. Designed to simulate actual pool fires involving jet fuel, the trainer propane-burner assembly located beneath the apparatus would become engulfed in flame under certain conditions on very windy days. Glenn P. Forney and William D. Davis modeled the trainer geometry in an effort to quickly determine how best to counter this malfunction. Their model indicated that the blow-down could be corrected by the installation of a wind-deflecting fence plus pressurization of the burner area. The solution proved satisfactory, quickly restoring full use of the trainer.[156]

[154] W. D. Walton, "Quick response sprinklers in chemical laboratories: fire test results," *NISTIR 89-4200*, November 1989, 49 pp.

[155] H. E. Nelson, "Performance of fire protection systems," pp. 6/1-3 in *NIST Special Publication 778*, "Performance of Structures During the Loma Prieta Earthquake of October 17, 1989," H. S. Lew, editor, 201 pp., January 1990. The Loma Prieta earthquake is discussed from a structures perspective in Ch. 6.

[156] G. P. Forney and W. D. Davis, "Analyzing strategies for eliminating flame blow-down occurring in the Navy's 19F4 fire fighting trainer," *NISTIR 4825*, 56 pp., May 1992.

Fire aboard spacecraft remained a terrifying prospect throughout the decades of the 1970s and 1980s. The Center for Fire Research was involved in both experimentation and modeling in order to minimize the danger from fire. Takashi Kashiwagi participated in a workshop on combustion in microgravity which was sponsored by the National Aeronautics and Space Administration during January of 1989.

Kashiwagi noted the differences between ordinary building fires on earth and fires in spacecraft:

- Most obvious, the crew of the spacecraft could not evacuate a burning compartment at a moment's notice.
- Detection of space combustion was made more difficult by the lack of upward, buoyancy-induced convection.
- Quick detection and nearly no false alarms were vitally important.
- Equally crucial was rapid suppression of any actual blaze, perhaps with a nitrogen-pressurized foam.
- Emergency extinguishment was a necessary option, perhaps by venting ambient oxygen in the cabin to space.

Kashiwagi also suggested a number of areas in which research could usefully be undertaken: flow calculations in the capsule; development of a fire-decision algorithm; development of specialized detectors for space use; data on the burning of materials in microgravity; and development of specialized fire extinguishers for use in space.[157]

Later, Kashiwagi teamed with Richard L. Smith to further explore the idea of an "expert system" for space use which would combine problem-solving programs with a knowledge base and a reasoning mechanism. Such a system, according to Kashiwagi and Smith, could provide solutions to the problems of quick fire detection and suppression and drastic measures for coping with out-of-control fires.[158]

The deliberate setting of oil-well fires in Kuwait during the invasion of Kuwait by Iraq consumed an enormous amount of crude oil in the Al Mawqa-Al Ahmadi fields. The Kuwait Oil Company estimated a peak loss of 6 million barrels of oil per day during the height of the action. Daniel Madrzykowski and David D. Evans performed thermal radiation measurements in an effort to test the feasibility of determining the heat-release rates of individual well fires by a combination of radiation and flame-height data. Data were obtained on a dozen fires burning at estimated rates of 1500-30,000 barrels per day. Extrapolating these measurements to the total of 651 wells yielded a figure of 7.4 million barrels per day, in good agreement with the Kuwait Oil Company estimate.[159]

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[157] T. Kashiwagi, "Suggested approach for fire safety of the space station," pp. 1-5 in *NASA International Workshop. on Microgravity Combustion,* January 25-26, 1989, Cleveland Ohio, unpublished.

[158] R. L. Smith and T. Kashiwagi, "Expert systems applied to spacecraft fire safety," *Journal of Applied Fire Science* **1**, No. 2, pp. 102-113, 1990.

[159] D. Madrzykowski D. D. Evans, and Gerald A. Hayes, "Large fires: Kuwait," *Proceedings of the 12th panel meeting of the United States-Japan Government Cooperative Program on Natural Resources, October 27- November 2, 1992,* unpublished.

### *Fire Data Compilations and Calculations*

Throughout its existence, the Center for Fire Research actively engaged in compiling fire data and recording the results of fire calculations, often obtained by modeling techniques. These contributions sometimes involved basic heat, heat-transfer and thermodynamic data, the modeling of particular types and properties of fire, or the effects of fire on people.

A key ingredient to the usefulness of CFR work was the ready availability of reports, books, and compilations. The Fire Research Information Service, headed by Nora H. Jason, offered annual compilations of references to research in fire.[160]

#### *Data on Fire-related Properties of Materials*

As examples of the compilation of information on the properties of materials as they relate to fire, we cite the calculation of emissivity and absorptivity of combustion products in building corridors, by K. Bromberg and James G. Quintiere, and a comparison of the relative influence on flame extinction of induced temperature decrease and heats of combustion of fuels, by Andrej Macek.[161]

#### *Fire Modeling*

Daniel Gross and Alexander Robertson produced theoretical models of fire as early as the mid-1960s, while John Rockett was beginning his own work in modeling. During the 1970s, the focus of modeling changed from predictions relating to the burn duration for entire buildings to more detailed efforts to model the early stages of residential fires. So-called "zone" models treated individual rooms or floors of buildings. Jeffrey P. Cohn described the Work of Gross, Robinson, and Rockett, and also more recent work by Walter Jones on the modeling of smoke movement.[162]

One of Director Ambler's efforts to stimulate new scientific work at NBS was to set aside a small amount of money to fund what were called *Competence Proposals.* One of the first of these went to Howard Baum of the Center for Fire Research and Ronald Rehm of the Center for Applied Mathematics, who collaborated on a study that eventually formed the basis for all of the computational fluid dynamics modeling of

[160] See, for example, N. H. Jason, "Fire Research Publications, 1980," *NBSIR 81-2272,* 16 pp., April 1982. These bibliographies typically provided access to journal articles, conference proceedings, NBS publications—interagency reports, technical notes, special publications, and handbooks—contract and grant reports, and an author index.

[161] K. Bromberg and J. G. Quintiere, "Radiative heat transfer from products of combustion in building corridor fires," *NBSIR 74-596,* 26 pp., February 1975. See also Andrej Macek, "Flammability limits: Thermodynamics and kinetics," *NBSIR 76-1076,* 22 pp., May 1976.

[162] J. P. Cohn, "Firefighting in the computer age using math and computer models to study fire," *NBS Dimensions* **65**, No. 6, pp. 2-5, August 1981.

fire and combustion over a 20-year span.[163] Their work—cited by many researchers both within and outside NBS—made possible the development of simulations that could quickly be prepared for calculation on desktop computers.

There were many other contributions to the science of modeling fire. For example, Howard Baum also calculated how a point source of heat could generate laminar airflow in the surrounding volume.[164] In another example, David Evans generated a model for the temperature rise from resistive heating in electrical cables.[165] And in 1980 Robert Levine developed a model to predict the growth of fire in compartments.[166]

Other contributors to fire modeling included Fred I. Stahl, Leonard Y. Cooper, Robert E. Chapman, James G. Quintiere, Rosalie T. Ruegg, Ronald G. Rehm, Daniel W. Lozier, Daniel M. Corley, Vytenis Babrauskas, Richard W. Bukowski, Henri E. Mitler, Marc R. Nyden, Glenn Forney, and James E. Brown.

*Fire Statistics*

Edward K. Budnick collected statistics on U.S. fire deaths in relation to the installation of smoke detectors and sprinklers. He found that, per capita, more people died in residential fires than in other types of buildings. However, the use of smoke detectors and sprinklers reduced the probability of death by as much as 75 %.[167]

Statistics on electrical fires were collected by John R. Hall, Richard W. Bukowski, and Alan Gomberg. They surveyed some 105 fire reports in ten U.S. cities—Akron, Grand Rapids, Long Beach, Oakland, Portland, Sacramento, San Diego, San Francisco, San Jose, and Toledo. They catalogued the locations of the fires and the extent of code violations (as many as 60 %) associated with them.[168]

***Books and Conference Proceedings***

In fire science, it was important to communicate information on advances in fighting fire—lives depended upon it. For many responsible parties, conference attendance provided a vital boost to fire-fighting progress; information could be obtained directly from the primary investigators and they could be quizzed about the best means to apply new results.

[163] R. Rehm and H. Baum, "The equations of motion for thermally driven, buoyant flows," *J. Res. NBS* **83**, pp. 297-308 (1978).

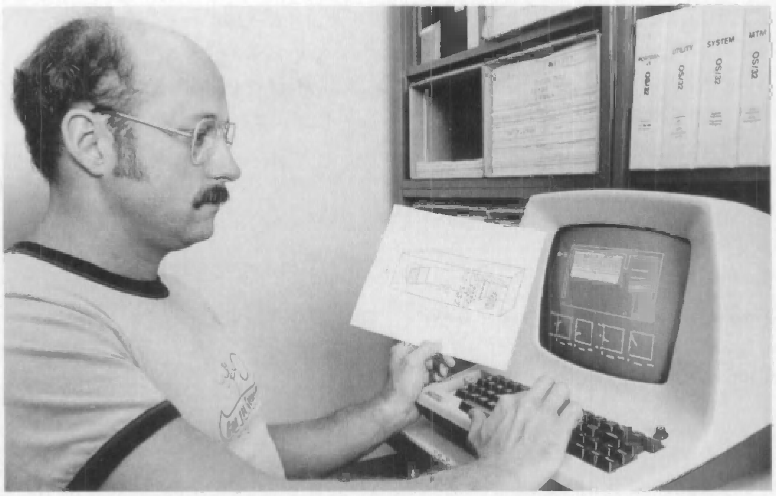
[164] H. R. Baum, "Laminar flow induced by a point source of heat," *J. Res. NBS* **81B**, No. 1, pp. 45-60, 1977.

[165] D. D. Evans, "Modeling for determination of temperatures of electrical cables within thermally insulated walls," *NBSIR 80-2129,* 28 pp., October 1980.

[166] R. S. Levine, "Mathematical modeling of fires," *NBSIR 80-2107,* 44 pp., September 1980.

[167] E. K. Budnick, "Estimating effectiveness of state-of-the-art detectors and automatics sprinklers on life safety in residential occupancies," *Fire Technology* **20**, No. 3, pp. 5-22, August 1984.

[168] J. R. Hall, R. W. Bukowski, and A. Gomberg, "Analysis of electrical fire investigations in ten cities," *NBSIR 83-2803,* 35 pp., December 1983.



Walter W. Jones of the NBS Center for Fire Research compared the results of a computer model's calculations with a schematic of the actual experiment that the model simulated.

Bureau fire staffers participated frequently in conferences and contributed to books and handbooks on the subject of fire research. A partial listing of conferences routinely attended by CFR personnel and handbooks and texts written by them follows. The organizations sponsoring the production of the handbooks and textbooks are included in parentheses:

*Conferences Attended*

- International Symposium on Combustion.
- National Heat Transfer Conference.
- Heat Release and Fire Hazards.
- International Symposium on Fire Safety Science.
- International Conference on Fire and Materials.
- Information Council on Fabric Flammability.
- International Conference on Flammability.

*Handbooks*

- Handbook of Fire Protection Engineering (Society for Fire Protection Engineering).
- Fire Protection Handbook (National Fire Protection Association).
- Fire Investigation Handbook (NBS Handbook 134).

*Textbooks*

- Heat Release in Fires (Elsevier Applied Science).
- Fire and Flammability of Furnishings and Contents of Buildings (ASTM STP 1233).
- Fire Safety: Science and Engineering (ASTM STP 882).
- Mathematical Modeling of Fires (ASTM STP 983).
- Fire Standards and Safety (ASTM STP 614).
- Performance of Protective Clothing (ASTM STP 900).

## Standards and Calibration

Work in the areas of standards and calibration occupied many researchers and other staff members of NBS during this period, as the following selections demonstrate.

### *Proton Gyromagnetic Ratio*

After several years of painstaking research, Edwin R. Williams and P. Thomas Olsen completed a redetermination of the gyromagnetic ratio of the proton in 1979. In turn, their measurement allowed them to set a new value for the fine-structure constant, a central component of one of the most fundamental and accurate theories of physics—quantum electrodynamics (QED).[169]

Quantum electrodynamics was used in discussions of all the physical phenomena that did not directly involve nuclear forces, gravitation, or weak interactions. Electrical and magnetic interactions of subatomic particles, for example, could be accounted for by the use of QED. The fine-structure constant, designated by the Greek letter $\alpha$, entered QED as one of the physical quantities that appeared in many of its equations; therefore better accuracy for the fine-structure constant could lead immediately to more penetrating tests of the reliability of QED as a physical theory.

The two Bureau physicists set up their experiment around a small spherical sample of water—a substance dense in protons—positioned within a solenoid wound, with great precision, of copper wire. The solenoid was powered by a direct current that was carefully measured in terms of the U.S. standard ampere. Detection of the precession frequency of the protons by nuclear magnetic resonance, a determination involving highly accurate frequency measurements, was possible with an uncertainty considerably less than 1 ppm. Part-per-million calculation of the magnetic flux density generated by the solenoid, however, presented a serious stumbling block to the success of the experiment. this was so because of the uncertainty of the solenoid dimensions and the

[169] E. R. Williams and P. T. Olsen, "New measurement of the proton gyromagnetic ratio and a derived value of the fine- structure constant accurate to a part in $10^7$," *Phys. Rev. Lett.* **42**, No. 24, 1575-1579 (1979).

uncertainty of the location of the current elements within the copper wire. Williams and Olsen finally hit upon use of sensitive probe coils and a laser interferometer to minimize uncertainty in the magnetic flux density determination.[170]

As a result of their experiment, Williams and Olsen evaluated $\alpha$ to one part in $10^7$, reducing its uncertainty by a factor of ten.[171] The Williams-Olsen experiment also had the virtue that its determination of the fine-structure constant was independent of QED theory; thus their value could be used to test the theory itself.

Study of the gyromagnetic ratio of the proton had a long history at NBS even before the work of Williams and Olsen. Raymond L. Driscoll and Peter L. Bender used laboratory space borrowed in 1958 from the U.S. Coast and Geodetic Survey to provide the first high-accuracy measurement (about ten parts per million) of the quantity. Their work led to improved electrical standards, allowing a continuing check on the stability of the NBS chemical cells used to define the volt until about 1970.

By 1988, the Williams-Olsen experiment had been refined, its uncertainty being reduced by about a factor of two. The new research was performed in collaboration with Marvin E. Cage, Ronald F. Dziuba, Randolph E. Elmquist, Bruce F. Field, George R. Jones, Willliam D. Phillips, John Q. Shields, Richard L. Steiner, and Barry N. Taylor. The group's experiments provided information about the time-dependence of the NBS ohm and the NBS volt representation, as well as the low-field proton gyromagnetic ratio.[172]

In 1989, Cage, Dziuba, Olsen, Shields, Taylor, and Williams received the Department of Commerce Gold Medal Award for their group effort on behalf of electrical standards. The justification for the award read, in part:

> This group has made contributions without which the 1990 international adjustment of electrical units could not take place. They performed four key experiments linking the (International System of Units) definitions of the electrical units to NIST national standards at unprecedented levels of accuracy.

[170] A discussion of the experiment in down-to-earth language was given by Michael Baum, "The precisely precessing proton," *Dimensions/NBS* **63**, No. 11, November 1979, pp. 10-17.

[171] The reported values were: for the gyromagnetic ratio of the proton, measured at low magnetic field in water, $2.675\,132\,29 \times 10^8\ s^{-1}\ T_{NBS}^{-1}$, within 0.21 ppm; for the inverse of the fine- structure constant, 137.035 963, within 0.11 ppm.

[172] M. E. Cage, R. F. Dziuba, R. E. Elmquist, B. F. Field, G. R. Jones, P. T. Olsen, Willliam D. Phillips, J. Q. Shields, R. L. Steiner, Barry N. Taylor, and E. R. Williams, "NBS determination of the fine-structure constant, and of the quantized Hall resistance and Josephson frequency-to-voltage quotient in SI units," *IEEE Transactions on Instrumentation and Measurements* **IM- 38**, No. 2, pp. 284-289 (1989). See also E. R. Williams, G. R. Jones, S. Ye, R. Liu, H. Sasaki, P. T. Olsen, W. D. Phillips, and H. P. Layer, "Low field determination of the proton gyromagnetic ratio in water," *IEEE Transactions on Instrumentation and Measurement* **IM-38**, No. 2, pp. 233-237 (1989).

### *High-Precision Measurement and Test Equipment Program*

On June 13, 1977, the U.S. General Accounting Office (GAO), "charged with examining all matters relating to the receipt and disbursement of public funds,"[173] recommended that the Office of Management and Budget (OMB) create a centralized scheme for program direction and coordination of instrument calibration systems used by civilian agencies. In turn, the OMB quickly asked Commerce Secretary Juanita Kreps to have NBS take the lead for coordinating improvements in the management and use of "high-precision" measurement and test equipment (PMTE) among civilian agencies.

The Federal expenditure in the category represented by PMTE exceeded $2.7 billion per year, including more than $250 million in direct calibration expenses. The GAO had recently commended the Department of Defense for its sophisticated system that coordinated PMTE use within the military, although the GAO was less happy with the duplication of effort that it found there.[174] Coordination among civilian agencies was poor, according to the GAO; considerable savings appeared possible if the civilian system were to be improved.[175]

Responding to the Secretary's request, Director Ambler assigned the Office of Measurement Services (OMS) to prepare a plan to take the lead role as requested, to help civilian agencies improve their PMTE programs, and to report to the Office of Management and Budget any needed actions. Brian C. Belanger, then head of the OMS, directed the planning effort, which was approved by OMB in mid-1978.

The new PMTE Project was managed by Jack Vogt. His staff included Kathryn Leedy, Kenneth Edinger, Brenda Schriver, and Joanne Mobley. The array of Federal agencies using highly precise measurement and test equipment was impressive. Besides the Department of Defense, the list included most of the technical agencies—the departments of transportation, energy, health and human services, agriculture, and labor, as well as subsidiary or independent organizations such as National Oceanic and Atmospheric Administration, National Aeronautics and Space Administration, the U.S. Postal Service, the Federal Communications Commission, the General Services Administration, the Tennessee Valley Administration, the Consumer Product Safety Commission, and the Nuclear Regulatory Commission. Coordinating PMTE activities among such a large group would be no easy task.

One of the first activities undertaken by the PMTE project staff was the preparation of a *Catalog of Federal Metrology and Calibration Capabilities,* intended to promote cooperation among federal agencies. It contained a listing of laboratories using highly

[173] *The United States Government Manual 1997-98,* (Washington, DC: Office of the Federal Register, National Archives and Records Administration, 1997) p. 46.

[174] GAO Report #LCD-427 *A Centralized Manager is Needed to Coordinate the Military Diagnostic and Calibration Program.*

[175] GAO Report #LCD-426 *Centralized Direction Needed for Calibration Program.*

precise measurements and their equipment, along with the name of a contact person in each laboratory. The entries were coded to indicate 17 different types of measurements used in some 270 laboratories.[176]

A newsletter, *PMTE Update,* was issued twice a year to improve communications among the user laboratories on topics such as new developments in precise equipment, publications and meetings, management strategies, and current issues in testing and calibration. Two thousand copies of the newsletter were circulated in 1981.

The NBS project funded cost-effectiveness studies performed by the Raytheon Service Company. These covered calibrations, measurement assurance programs, and government-wide calibration-interval practices.

Issues such as the use of Automatic Test Equipment, traceability of measurements to national standards, focal points for improved training and recruitment, standardization of procedures for calibration, and a handbook of standard terms and definitions were treated during the comparatively short (3 years) lifetime of the project.

Pressed by a personnel shortage during 1981, the Bureau abandoned the PMTE project, ending its short but useful life.[177]

### *Voltage and Resistance Standards Based on Quantum Phenomena*

A 60-page *NBS Technical Note* entitled *Guidelines for Implementing the New Representations of the Volt and Ohm, Effective January 1, 1990* was published by Norman B. Belecki, Ronald F. Dziuba, Bruce F. Field, and Barry N. Taylor in 1989.[178] Issuance of the guidelines was the culmination of brilliant technical work that extended over 20 years. Laboratories contributing to final values for the new standards encompassed the earth, bringing a revolutionary change to two of the oldest standards of physical measurement.

For a century and a half, electrochemical cells were used as standards of voltage; such cells had provided NBS with its voltage references from the time of its founding. The history of standard cells was described by Hamer in 1965.[179] The most stable type of cell, the Weston cadmium cell, dated from 1891.[180] Enclosed in an H-shaped glass

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[176] Kathryn O. Leedy, "Catalog of Federal Metrology and Calibration Capabilities," *NBS Special Publication 546,* first issued, June 1979, 48 pp.; re-issued, September, 1980, 65 pp.

[177] Brian C. Belanger kindly provided historical materials on the PMTE project.

[178] Norman B. Belecki, Ronald F. Dziuba, Bruce F. Field, and Barry N. Taylor, "Guidelines for Implementing the New Representations of the Volt and Ohm," Effective January 1, 1990, *NIST Technical Note 1263,* June 1989, 60 pp.

[179] Walter J. Hamer, "Standard cells, their construction, maintenance, and characteristics," *NBS Monograph 84,* January 1965, 38 pp.

[180] Forest K. Harris, *Electrical Measurements* (New York: John Wiley & Sons, 1952), p. 185. The Weston cell is also described in *NBS Monograph 84,* by Hamer.

container, each column contained an electrode and the cross-tube contained a saturated cadmium sulfate electrolyte. When carefully prepared and aged and maintained at a constant temperature, a group of such cells could provide the same reference voltage (about 1.018 V) within a few microvolts.

The actual value of the volt was derived from the basic SI units of length, mass, time, and electric current. The great care needed to maintain Weston cells at constant temperature and to avoid mechanical disturbance made their calibration a complex and time-consuming process. In its *Calibration Services Users Guide,* the Bureau recommended the use of thermoregulated containers maintained in an upright position for transporting the cells, with a minimum of one week given to stabilizing the cell at NBS, followed by a month of measurements to achieve voltage uncertainties of 1 ppm.[181]

With a similarly venerable history, the NBS standard of dc resistance was embodied in a group of wires. James L. Thomas devised a stable resistance standard for NBS during the 1930s, using bare manganin[182] wire coiled in a stress-free manner in a carefully prepared, sealed atmosphere. A group of 1 Ω Thomas-type resistors was found invariant in resistance within 1 ppm over several years.[183] Although manganin wire had a low temperature coefficient of resistivity, standard resistors were maintained at a constant temperature to minimize resistance changes.

Both Weston cells and Thomas resistors provided standards known as *artifacts*—each copy yielding a slightly different value of the standard depending upon the workmanship of the maker.

The discovery in 1962 of a superconductive tunneling effect by Brian Josephson at the Cavendish Laboratory in Cambridge, England markedly changed the situation for the voltage standard. Josephson received the 1973 Nobel Prize in physics for his theoretical prediction that the flow of electrons between two superconductors connected by a thin insulating layer would be quantized according to the applied voltage. It was found that when a properly prepared Josephson tunnel junction was irradiated with microwave radiation, its current-voltage curve would exhibit steps at precise, quantized voltages characterized by the microwave frequency, by an integer denoting the step number, and by a constant relating the Josephson voltages to the frequency. None of these three numbers involved the identity of the particular Josephson junction, nor even the materials from which it was made.

Realizing the implications of the Josephson effect for voltage standards, scientists from national laboratories in Holland, England, the United States (Barry N. Taylor from NBS), and the International Bureau of Weights and Measures (BIPM) in Paris

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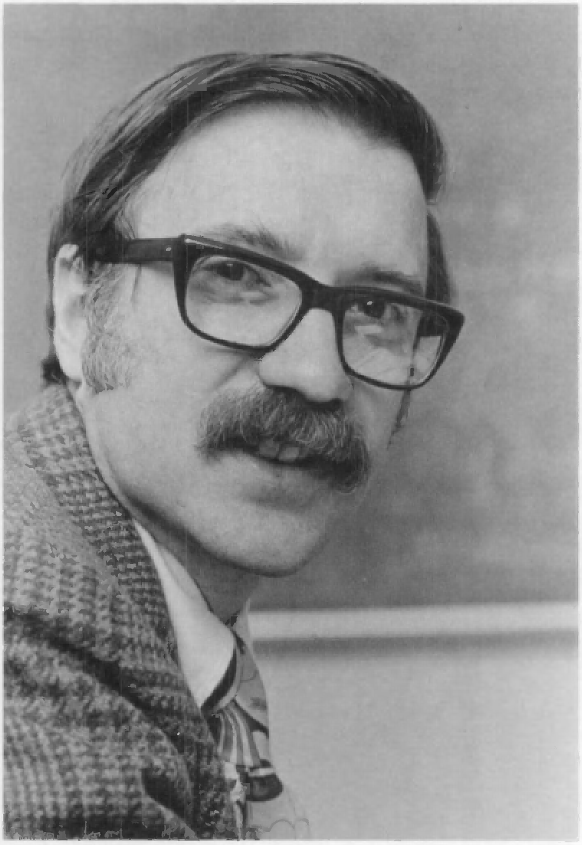
[181] Bruce F. Field, "NBS Measurement Services: Standard Cell Calibrations," *NBS Special Publication 250-24*, October 1987, 52 pp. Also see "NIST Calibration Services Users Guide, 1989," Joe D. Simmons, editor, *NIST Special Publication 250*, January 1989, pp. 114-118.

[182] "Manganin" is an alloy containing approximately 84 % copper, 12 % manganese, and 4 % nickel, chosen for its low temperature coefficient of resistivity and its chemical stability.

[183] Harris, op. cit, p. 213.

formed a working group under the aegis of the BIPM to evaluate the Josephson voltage-to-frequency quotient in units consistent with the International System (SI).[184] In 1988, the International Committee of Weights and Measures suggested that the national laboratories adopt the value of the quotient to be 483 597.9 GHz/V, with the transition to the new voltage standard to take place on January 1, 1990.[185]

While evaluation of the Josephson voltage effect was in progress, Klaus von Klitzing discovered a quantum effect related to measurements of the Hall coefficient in semiconductors.[186] If a high-electron-mobility semiconductor was cooled to a few kelvins above absolute zero and a magnetic flux density of 10 T was applied to it, the two-dimensional electron gas which the system approximated became quantized. As a



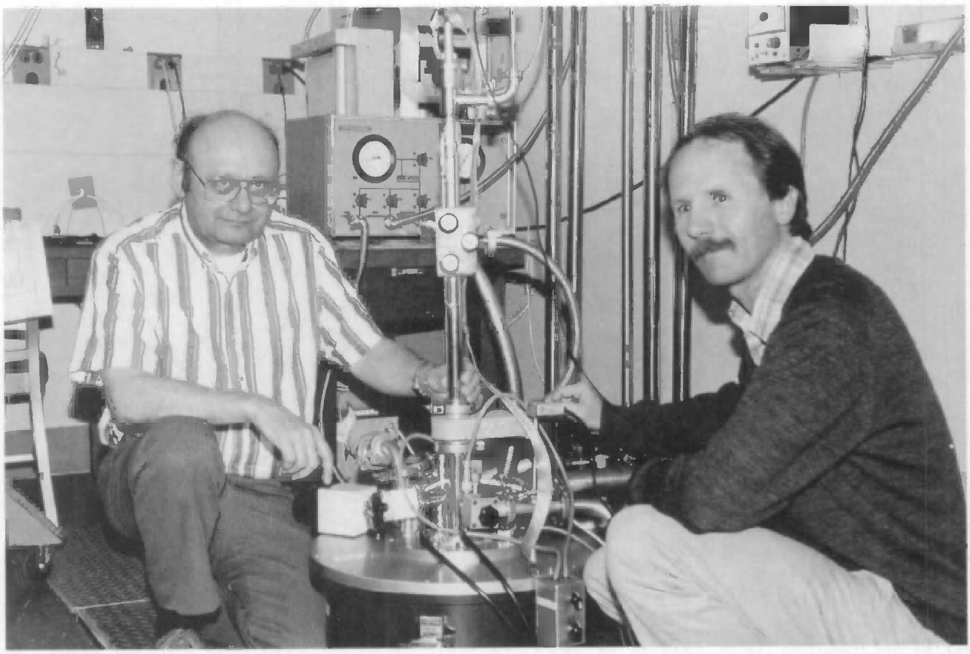
Barry N. Taylor joined NBS in 1970 as chief of the Electrical Measurements Section. An expert in the field of superconductivity, Taylor became a major contributor to the analysis of international physical standards and fundamental constants.

[184] B. N. Taylor and T. J. Witt, "New international electrical reference standards based on the Josephson and quantum Hall effects," *Metrologia* **26**, 47-62 (1989).

[185] B. N. Taylor, "New internationally adopted reference standards of voltage and resistance," *J. Res. NIST* **94**, No. 2, 95 (1989).

[186] K. v. Klitzing, G. Dorda, and M. Pepper, *Phys. Rev. Lett.* **45**, 494-497 (1980).

result, the plot of Hall voltage (at fixed current) vs flux density exhibited plateaus of resistance characterized by a constant which, like the Josephson frequency-to-voltage quotient, was independent of material parameters. The BIPM working group happily accepted the task of determining the best possible value of the "von Klitzing constant" in SI units; following their recommendation during its 1988 meeting, the CIPM selected 25 812.807 Ω as the adopted value. As might have been expected, convincing NBS customers (and their counterparts in other countries) of the wisdom of accepting a change in the volt and the ohm for any reason—let alone on the basis of quantum physics—was a challenging task as well.[187]



Ronald F. Dzuiba and R. E. Elmquist were photographed kneeling on a removable panel above a helium-3 refrigerator and high-field superconducting magnet system, part of a measurement system for the realization of the U.S. ohm using the quantum Hall effect.

[187] K. B. Jaeger and B. N. Taylor, "U.S. perspective on possible changes in the electrical units," *IEEE Transactions on Instrumentation and Measurement,* Vol. IM-36, No. 2, pp. 672-675, June 1987.

## *Building a New Temperature Scale*

Promulgation of the International Practical Temperature Scale of 1968 (IPTS-68) relieved but little of the pressure to improve standard thermometry. The measurement of temperature pervaded all areas of science and engineering, and there was a growing demand for improved range, accuracy, and measurement methods.

Creating an adequate replacement for the IPTS-68 was necessarily a team activity. This was so because of the many features that made up such a scale—many temperature reference points, specialized thermometers for the various temperature ranges, and recipes to define calibration procedures. The devices used to create reference temperatures for thermometer calibration needed to be available commercially or relatively easy to prepare, and they had to be reasonably easy to use at the desired level of precision. Thermometers selected to realize scale temperatures had to be reliable. Choosing appropriate values for the reference temperatures, selecting suitable standard thermometers, and designing workable calibration methods all required considerable work. No one person—no one laboratory—possessed the resources needed to replace the International Practical Temperature Scale of 1968.

Spurred by the discoveries of Evans and Wood, and of Guildner, Anderson, and Edsinger (noted in Ch. 2) that demonstrated flaws in the IPTS-68, scientists at NBS and in many other laboratories set to work to improve it. Realizing that goal would take two decades of hard work.

### *Provisional 0.5 K to 30 K Scale of 1976 (EPT-76)*

Better understanding of the relations between thermodynamic temperatures below 30 K and various laboratory scales, aided by development of new thermometry methods, led to the promulgation of a new Provisional 0. 5 K to 30 K Scale of 1976 (EPT-76). Bureau contributions to the new scale included temperature reference values obtained by Harmon H. Plumb and George Cataland[188] and by George T. Furukawa, William R. Bigge, and John L. Riddle;[189] helium vapor pressure measurements by Roland Gonano;[190] and reference temperatures based on superconductivity, by Robert J. Soulen, Jr, and James F. Schooley.[191]

The new provisional scale proved to be very useful, and it led eventually to the formulation of the International Temperature Scale of 1990 (ITS-90), which defined scale temperatures down to 0.65 K.

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[188] H. H. Plumb and G. Cataland, "Acoustical thermometer and the National Bureau of Standards Provisional Scale 2-20 (1965), *Metrologia* **2**, 127 (1966).

[189] G. T. Furukawa, W. R. Bigge, and J. L. Riddle, "Triple point of argon," pp. 231-243 in *Temperature, Its Measurement and Control in Science and Industry* **4**, 1972, H. H. Plumb, Editor.

[190] R. Gonano, "Isothermal comparisons of $He^3$ and $He^4$ vapor pressures," pp. 121-126 in *Temperature, Its Measurement and Control in Science and Industry* **4**, 1972, H.H. Plumb, Editor.

[191] J. F. Schooley and R. J. Soulen, Jr., "Superconductive thermometric fixed points," pp. 251-260 in *Temperature, Its Measurement and Control in Science and Industry* **5**, 1982, J. F. Schooley, Editor.

*Temperatures High and Low*

The NBS gas thermometry program is discussed in some detail in Ch. 6. Pursued over a period of several decades, it was a principal contributor to the ability to more accurately realize the thermodynamic temperature scale in the range 0 °C to 660 °C. Temperatures chosen for the ITS-90 in that range were derived mainly from Bureau gas thermometry measurements.

Leslie A. Guildner and Robert E. Edsinger, utilizing a mercury manometer of unique accuracy to measure the pressure of a gas thermometer, found that IPTS-68 temperatures were higher than the gas thermometer temperatures by 0. 025 °C at 100 °C, by 0.044 °C at 231 °C, and by 0.079 °C at 457 °C.[192] These were startling numbers, showing that the IPTS-68 was not nearly so representative of thermodynamic temperatures as had been supposed when it was prepared.

Guildner retired from the Bureau before he and Edsinger completed their plan to operate the NBS gas thermometer to its highest design temperature, 660 °C. James Schooley was given the opportunity to collaborate with Edsinger in finishing the measurements. This he did.[193] The newer results generally corroborated the earlier Guildner-Edsinger findings in the range of overlap between the two experiments, although Edsinger and Schooley found the discrepancies between the IPTS-68 and thermodynamic temperatures to be smaller than had been evaluated earlier. Their values for the differences were 0.03 °C ± 0.002 °C at 230 °C, 0.045 °C ± 0.005 °C at 457 °C, and 0.11 °C ± 0.01 °C at 660 °C.

In constructing the 1990 International Temperature Scale, the international thermometry body—the Consultative Committee for Thermometry (CCT)—took an average of all of the NBS gas thermometry results as the basis for the new scale in the range 0 °C to 660 °C.

*Nuclear Orientation Thermometry*

The technique of nuclear orientation thermometry was applied by Harvey Marshak to the evaluation of thermodynamic temperatures in the range 0.01 K to 1.2 K. In this elegant method, single crystals of cobalt and holmium were made slightly radioactive by neutron irradiation. The materials were chosen carefully; both elements were naturally monoisotopic and both produced thermometrically useful radioactive samples on irradiation. In his experiments, Marshak carefully aligned the samples in a $^3$He-$^4$He dilution refrigerator, then measured the anisotropy of the gamma radiation given off by the decay of the radioactive $^{60}$Co or $^{166m}$Ho atoms with respect to the appropriate crystal axes. Because the nuclear orientation parameters for each system were known,

[192] L. A. Guildner and R. E. Edsinger, "Deviation of international practical temperatures from thermodynamic temperatures in the range from 273.16 K to 730 K," *J. Res. NBS* **80A**, pp. 703-738 (1976).

[193] R. E. Edsinger and J. F. Schooley, "Difference between thermodynamic temperature and t(IPTS-68) in the range 230 °C to 660 °C," *Metrologia* 26, pp. 95-106 (1989).

Marshak was able to calculate, within about 0.5 %, thermodynamic temperatures indicated by the measured radiation anisotropies.[194] Marshak's work helped the CCT to prepare the ITS-90, as well as laying the foundation for possible extension of international scale temperatures below 0.1 K.

*Sealed Triple-Point Cells*

During this period, a far-reaching idea occurred to thermometrists. In simplest terms, they decided to rid themselves of the aggravation of dealing with "open" cells for the realization of liquid-state reference points used below room temperature. In this context, "open" cells were those which incorporated a capillary tube for adding and removing gas, or for measuring pressure. For many years, use of such open cells had led to experimental difficulties and irreproducibilities arising from changing purity levels in supposedly "pure" substances.

The model for the sealed cell was the water triple-point device. Made of glass in the form of a long, closed tube with a re-entrant central thermometer well, it contained only water. When the device was cooled sufficiently, a portion of the water would freeze. While the three phases—ice, water, and water vapor—co-existed in thermal equilibrium, the temperature in the re-entrant well remained at 273.16 K, usually within 0.001 K. With no tubes or wires attached, it provided one of the two fundamental defining temperatures for all of thermometry.[195]

George T. Furukawa and William R. Bigge examined several water triple-point cells in preparation for a new scale. They found that all cells of a group of 20 provided the same temperature within 0.0002 °C.

It should be clear that in abandoning open cells one effectively abandoned the use of vapor pressures for thermometry as well as the use of boiling points, since these thermometry schemes required the measurement of pressure as part of the thermometric process. In return for the loss of these measurement opportunities, the thermometrist obtained triple-point temperatures of higher quality.

John Ancsin of the National Research Council laboratory in Canada showed the way to the expanded use of triple points for scale thermometry by measuring the triple-point temperature of oxygen adiabatically.[196] At the Istituto di Metrologia "G. Colonnetti" in Torino, Italy, Franco Pavese used Ancsin's method for the measurement of triple points of gases purified and sealed into high-pressure cells at room temperature. Once prepared, these cells were sealed permanently so that their characteristics—in the absence of leaks—never changed.

George Furukawa brought NBS into the low-temperature-sealed-cell arena with a study of the triple point of purified argon. Constructing three miniature cells with volumes of only 50 ml, Furukawa determined the reproducibility of the triple-point

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[194] H. Marshak, "Nuclear orientation thermometry from ~0.001 to ~1.2 K," pp. 95-101 in *Temperature, Its Measurement and Control in Science and Industry* **5**, 1982, J. F. Schooley, Editor.

[195] The reader may recall that the other fundamental temperature reference point was the zero point of the thermodynamic scale. It was inaccessible and thus was not realized in any device.

[196] J. Ancsin, "The triple point of oxygen and its change by noble gas impurities," *Metrologia* **6**, 53 (1970).

temperature, using the methods of adiabatic calorimetry with which he was familiar.[197] He found agreement among the three cells within $10^{-4}$ K, demonstrating the viability of the technique for low-temperature reference points.

Billy W. Mangum and Donald D. Thornton, a Postdoctoral Research Associate, carefully compared the triple-point temperatures of purified gallium metal obtained from several sources. They found the material to provide an excellent reference temperature near 30 °C. Relatively inexpensive and easy to use in reference cells, the highest-purity gallium (impurities estimated at no more than 1 ppm) offered reproducibility at its triple point within $10^{-4}$ K.[198] Mangum and Thornton tried both plastic and steel containers for the gallium, and they found no systematic differences.

Mangum and Thornton suggested that the excellent thermal conductivity of gallium, coupled with its ease of use, might make it superior to water as a defining reference temperature for the international scale.[199]


NBS Postdoctoral Research Associate Donald D. Thornton (left) and NBS physicist Billy W. Mangum inspected an assembled gallium triple-point cell. Able to fix an important temperature reference point to within a few ten-thousandths of a degree Celsius, the device was selected by *Industrial Research and Development* magazine as one of the 100 most significant new technical products of 1978.

[197] G. T. Furukawa, "Reproducibility of the triple point of argon in sealed transportable cells," pp. 239-248 in *Temperature, Its Measurement and Control in Science and Industry* **5**, 1982, J. F. Schooley, Editor.

[198] B. W. Mangum and D. D. Thornton, "Determination of the triple-point temperature of gallium," *Metrologia* **15**, No. 4, 201- 215 (1979).

[199] B. W. Mangum and D. D. Thornton, submission to the 12th Session of the Consultative Committee for Thermometry, Paris, May 9-10, 1978.

*Radiation Thermometry*

Malcolm S. Morse and Ared Cezairliyan teamed with G. M. Foley, a colleague from the Canal Winchester Company, to propose the use of a specially designed, two-wavelength radiation thermometer to measure temperatures in the range 2000 K to 6000 K.[200] They used the device to measure the changing temperatures of rapidly heated specimens on a microsecond time scale. In the analysis quoted, they gave special attention to its accuracy, estimating that the experimental uncertainties of the two channels might range from ±3.7 K to ±30 K. They expected these levels to diminish if the instrument would be used in conjunction with a high-quality laboratory blackbody.

*Flame Temperatures*

A high-temperature measurement problem rarely faced in the laboratory but common in industrial thermometry was the measurement of flame temperatures. Hratch G. Semerjian and Robert J. Santoro addressed this problem in conjunction with their colleagues P. J. Emmerman and R. Goulard of George Washington University.[201] The technique suggested by this group involved laser tomography, a multi-angular absorption method in which the spatial temperature variation within the flame could be evaluated by computer analysis of the absorption data.

*A Resistance Bridge for Thermometry*

A notable advance in thermometry using standard platinum resistance thermometers resulted from the development of a new microprocessor-based resistance bridge by Robert D. Cutkosky.[202] Prior to Cutkosky's invention, taking data with resistance thermometers typically was accomplished by manual balancing of a resistance bridge, accompanied by manual recording of resistance values using pen and paper. As soon as his design for an automatic bridge was available, several copies were constructed for use at NBS, providing enormous savings of time and effort through computerized data acquisition and calculation.

The bridges employed five-stage transformers, five standard resistors, and microprocessors that controlled the generation of 15 Hz or 30 Hz measuring signals at a current level variable in steps between 1 mA and 8 mA, the iterative bridge balance, and the display of the unknown resistance to 1 μΩ. The output also could be obtained from a standard computer bus. Two versions of the bridge quickly became "standard"—one with a resistance limit of 32 Ω and a second that could measure resistances up to 100 Ω.

[200] G. M. Foley, M. S. Morse, and A. Cezairliyan, "Two-color microsecond pyrometer for 2000 to 6000 K," pp. 447-452 in *Temperature, Its Measurement and Control in Science and Industry* **5**, 1982, J. F. Schooley, Editor.

[201] H. G. Semerjian, R. J. Santoro, P. J. Emmerman, and R. Goulard, "Laser tomography for temperature measurements in flames," pp. 649-660 in *Temperature, Its Measurement and Control in Science and Industry* **5**, 1982, J. F. Schooley, Editor.

[202] R. D. Cutkosky, *IEEE Trans. Instr. and Meas.* **IM-29**, 330 (1980).

The advent of the automatic resistance bridge was accompanied by efforts to improve the standard resistance thermometer. Along with separate experiments by colleagues in China and Germany, the Heat Division's John Evans sought to create a thermometer design that would allow the resistance thermometer to be used to temperatures as high as 1100 °C—the melting temperature of gold, and, traditionally, the temperature above which radiation thermometry defined the international scale.[203] This proved to be a difficult goal to reach for a variety of reasons, but Evans' thermometer designs helped make the platinum resistance thermometer the standard instrument up to the melting temperature of silver.[204]

### *Frequency of Visible Light*

Continuing the absolute frequency-measurement chain described in chapter 3, Donald A. Jennings, F. Russell Petersen, and Kenneth M. Evenson extended the technique into the range of visible light. The trio determined the frequency of the strong 1.15 μm laser line in $^{20}Ne$ at 260 THz and lines in iodine at twice that frequency. The frequencies were synthesized in solid-state crystals, $CdGeAs_2$, $AgAsS_3$, and $LiNbO_3$.[205]

An automatic fringe-counting interferometer was developed by John L. Hall and his student Siu Au Lee for the calibration of continuous-wave laser sources during the same period. The two scientists were able to demonstrate uncertainty levels well below 1 ppm with the new instrument.[206]

### *Calibrating Radio Antennas With the Moon and the Stars*

Scientists in the Boulder Electromagnetic Fields Division worked long and hard to develop a system for the calibration of radio antennas and for the minimization of unwanted radio noise. David F. Wait described in 1978 an Earth Terminal Measurement System (EMTS). It could be used to measure earth terminal and satellite parameters such as figure of merit, antenna gain relative to a reproducible reference level, satellite effective isotropic radiated power, ratio of carrier power to operating noise temperature, and noise ulterior flux. Wait's report included troubleshooting hints and software description.[207]

[203] J. P. Evans, "Experiences with high-temperature platinum resistance thermometers," pp. 771-781 in *Temperature, Its Measurement and Control in Science and Industry* **5**, 1982, J. F. Schooley, Editor.

[204] H. Preston-Thomas, "The International Temperature Scale of 1990 (ITS-90)," *Metrologia* **27**, 3-10 (1990).

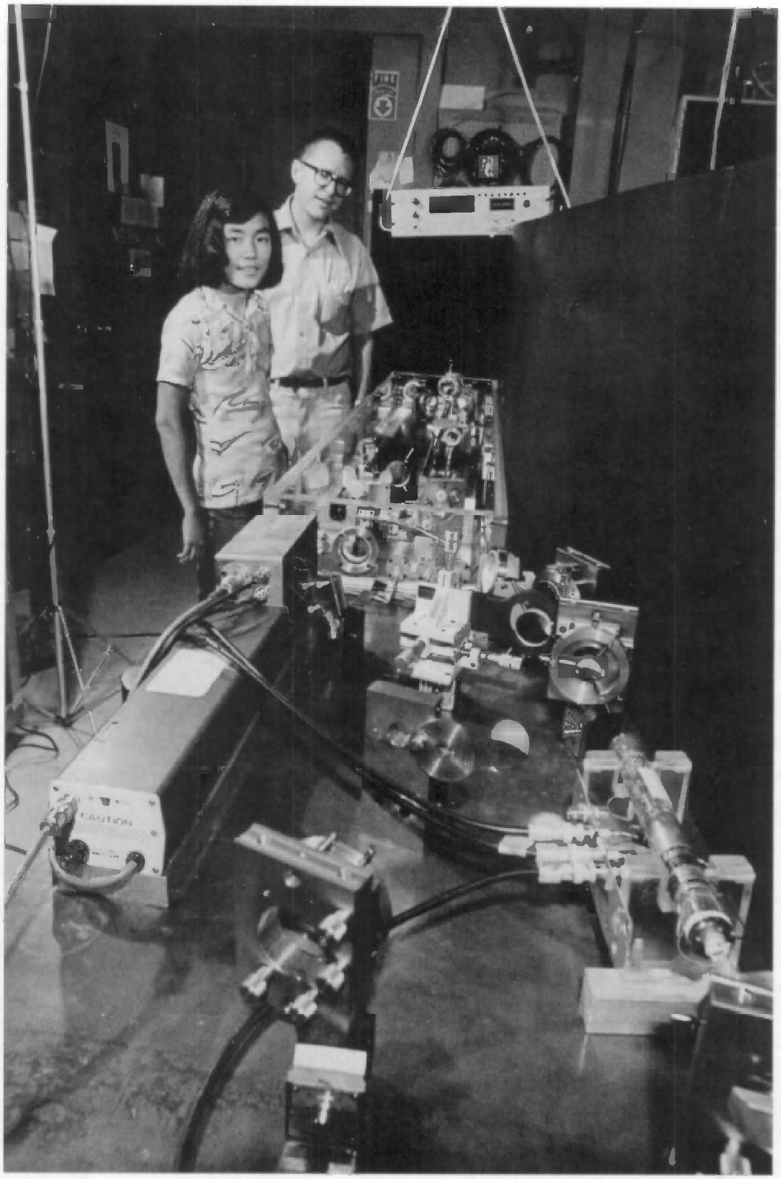
[205] D. A. Jennings, F. R. Petersen, and K. M. Evenson, "Direct frequency measurement of the 260 Thz (1.15 μm) $^{20}Ne$ laser, and beyond," *Laser Spectroscopy*, Vol IV, H. Walther and K. W. Rothe, editors, (New York: Springer-Verlag, 1979) pp. 41-48.

[206] J. L. Hall and S. A. Lee, "Interferometric real-time display of cw dye laser wavelength with sub-Doppler accuracy," *Appl Phys. Lett.* **29**, No. 6, 367-369 (1976).

[207] D. F. Wait, "Earth Terminal Measurement System operations manual," *NBSIR 78-879*, 268 pp., April 1978.

A computer-driven, automatic resistance bridge was only one of many achievements by NBS scientist Robert D. Cutkosky. His research on electrical standards won him the Gold Medal Award of the Department of Commerce.

By 1984, Wait and William C. Daywitt had worked out methods by which certain stars and the moon could be used as electromagnetic reference sources, relying on the reproducible nature of the radiation emitted by Cassiopiea A and the lunar surface. The sun, a more powerful source, was less reproducible because of its intense and variable solar flares and other activity.



John L. Hall and his student, Siu Au Lee, stood beside their wavelength-calibration interferometer. Dubbed the "Laser Wavelength Meter," the instrument received an IR-100 award from *Research and Development* magazine as one of the most significant new products of 1977.

With the use of the celestial sources, the ETMS noise measurements typically provided 5 % to 15 % uncertainty levels for frequencies in the range 1 GHz to 10 GHz.[208]

### *A Load-Cell Mass Comparator*

Conventional mass comparison balances were mechanical devices capable of weighing up to 30 kg with an uncertainty of about one part per million in the early 1980s. Their cost was about $20,000 and the reading was generally recorded manually by the operator. Electronic load cells were comparatively inexpensive commercial devices that produced electrical signals in response to weight. While the devices were capable of excellent resolution, their response curves tended to drift when the applied load was removed between weighings.

Randall M. Schoonover devised a comparator which made use of the load cell for its low cost, its inherent resolution, and its computer-compatible signal but avoided the drift problem. His solution, in principle, was to maintain the force on the load cell while the test mass was replaced by a reference mass—a principle that was introduced a century ago and is employed in virtually all present-day high-precision balances. Using electronics developed by Robert J. Cutkosky and Richard M. Davis, Schoonover built a prototype of the new device. It exhibited 1 ppm repeatability.[209]

The Texas state metrology laboratory was happy to undertake field tests of the new comparator. Its cost was expected to range from $6000 to $7000; its time for measurement, about 2 minutes, compared with about 15 minutes by the mechanical balance it replaced.

### *Low-Velocity Airflow Facility*

Philip Klebanoff and Patrick Purtell developed a new low-velocity airflow facility that could produce uniform flows at velocities in the range 3 m/min to 1000 m/min, with nearly no turbulence. The two scientists devised a laser-based system to establish a primary standard for the measurement of low air velocities.[210]

One of the first customers for the new facility was the U.S. Bureau of Mines, when a USBM staff member brought to NBS a vane anemometer for calibration to improve its use in monitoring mine ventilation.

Ultimately the earlier air-speed calibration standard, the pitot tube, was replaced by a fiber optic laser Doppler anemometer (LDA) developed by Vern E. Bean and J. Michael Hall. The LDA measured the speed of a flowing stream of air by observing very small particles entrained in the air. Once the measurement technique was worked

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[208] D. F. Wait, "Precision measurement of antenna system noise using radio stars," *IEEE Trans. Instrum. Meas.* **IM-32**, No. 1, 110-116 (1983). See also W. C. Daywitt, "Error analysis for the use of presently available lunar radio flux data in broadbeam antenna-system measurements," *NBS Technical Note 1073*, 39 pp., February 1984.

[209] R. M. Schoonover, "A 30 kg capacity high precision load cell mass comparator," *J. Res. NBS* **87**, No. 1, 47-48 (1982).

[210] L. P. Purtell and P. S. Klebanoff, "A low-velocity airflow calibration and research facility," *NBS Technical Note 989*, March 1979, 21 pp.

out, it became a simple matter to calibrate the LDA system; Bean and Hall fixed a vertical tungsten wire of diameter 5 μm at a carefully measured radius on the perimeter of a horizontal disk rotating at a known rate, thus producing an LDA target with a calculable velocity. The uncertainty of the air-speed calibration was reduced by the new method to 0.006 m/s.[211]

### *Measuring Electromagnetic Interference*

A new portable broadband rf radiation field meter developed by Francis X. Ries and E. B. Larsen of the Electromagnetic Fields Division found immediate application in plant safety, in monitoring of power equipment, and in particularly sensitive geographical areas. Electromagnetic interference, arising from sources as ubiquitous as radio and television broadcasts, power transmission, and semiconductor-activated switchgear, produced ac radiation at levels that could injure plant workers, ruin radio reception, and interfere with the operation of sensitive equipment in hospitals or laboratories.

The new NBS field meter was able to detect radiation from 0.2 MHz to 1 GHz, thus covering the spectrum from radio waves to microwaves. The new device was isotropic in its response, thanks to the incorporation of three small, mutually orthogonal dipole antennas. Dubbed the EFM-5 Electric Field Monitor, the probe could sense field intensities in the range 1 V/m to 1000 V/m.[212] The usefulness of the new meter was so plain that one manufacturer began immediately to design a commercial version.

### *A New High-Voltage Calibration Service*

In 1985, Martin Misakian published an *NBS Technical Note* describing a new calibration service for high-voltage dividers and high-voltage resistors. The new service was important to researchers in such fundamental studies as elementary-particle physics, to operators of x-ray and other high-voltage equipment, and to the power industry.

In principle, the measurement system was simple—a guarded Wheatstone-bridge apparatus. In practice, the laboratory gave the appearance of a science-fiction movie set, with its large high-voltage insulators. Misakian was able to offer calibrations with uncertainty levels below 0.01 % for equipment useful at voltages from 10 kV to 150 kV.[213]

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[211] Vern E. Bean kindly provided information on the new laser Doppler anemometer calibration system.

[212] E. B. Larsen and F. X. Ries, "Design and calibration of the NBS isotropic electric-field monitor (EFM-5), 0.2 to 1000 MHz," *NBS Tech. Note 1033,* March 1981, 104 pp.

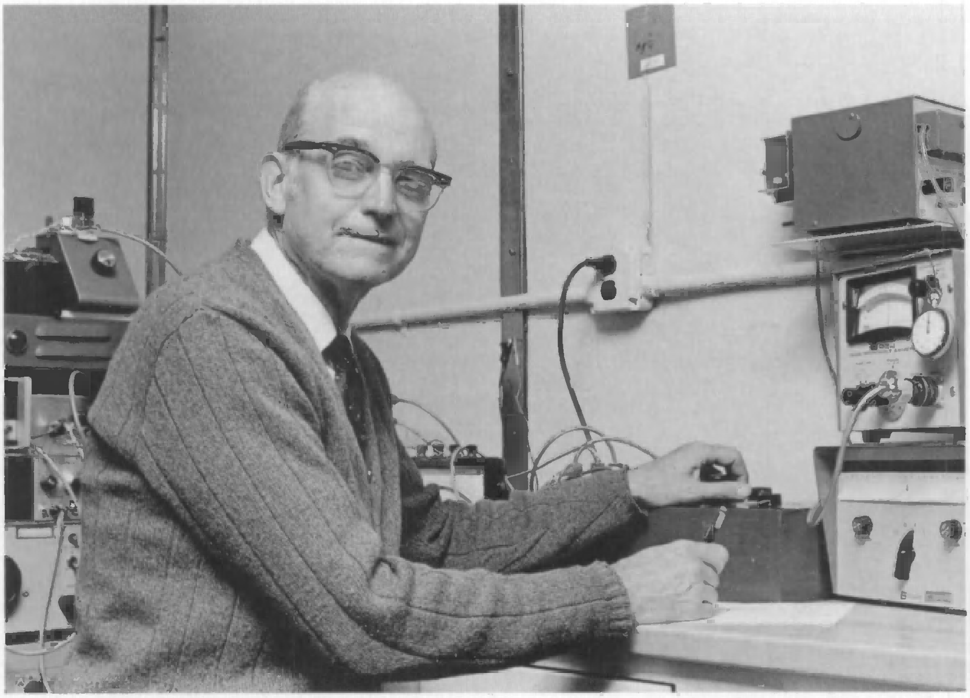
[213] M. Misakian, "High voltage divider and resistor calibrations," *NBS Technical Note 1215,* July 1985, 25 pp.

Martin Misakian prepared to evaluate the performance of a dc high-voltage power supply used for calibrating high-voltage dividers at NBS.

*A Prize for Hermach*

The Institute of Electrical and Electronics Engineering (IEEE) recognized a lifetime of contributions to electrical standards by Francis L. Hermach by presenting him with the Morris E. Leeds prize during a 1976 meeting. In one of Hermach's many projects, he developed the concept of using thermal converters as transfer standards in the measurement of ac-dc voltage differences. He made careful studies of the physical bases for the frequency-dependence found the devices.

The Leeds prize was not Hermach's first honor. Joining the NBS Electricity Division in 1939, he became chief of the Electrical Instruments Section in 1963. In recognition of his achievements in electrical standards and instrumentation, he was elected to fellowship in the IEEE and in the Instrument Society of America (ISA). In 1970, Hermach received the Silver Jubilee Award from the ISA for "his contributions to the accuracy of current and voltage measurements."



Francis L. Hermach of the Electricity Division in the National Bureau of Standards Institute for Basic Standards was awarded the prestigious 1976 Morris E. Leeds prize of the Institute of Electrical and Electronics Engineers for outstanding contributions to the field of electrical measurements.

## Technology of Buildings and Other Structures

The Bureau's building research and fire research groups often were asked to form teams to investigate natural disasters, structural failures, and fires in addition to the many in-house projects in both groups. In some cases, the investigations were sensitive in nature, having been requested by highly placed officials. National Engineering Laboratory Director John Lyons referred to such cases as "hot potatoes." The conduct of the investigations themselves, their conclusions, and any resulting reports were carefully monitored by senior managers, designated specialists, and legal counsel.

Some of the "hot potatoes" are discussed in this section; others may be found elsewhere in the volume. Such cases added spice to the lives of the investigators and gray hairs to the heads of the senior managers.

### *Designing Structures for Wind Loads*

The safe and economical design of structures for wind loads required meaningful estimates of maximum wind speeds. Historically, this design problem was a difficult one for designers. They could build using any of several estimates of extreme wind speeds, balancing maximum safety and minimum cost.

NBS scientists Emil Simiu of the Center for Building Technology and James Filliben of the Center for Applied Mathematics considered the problem in collaboration with Jaques Bietry, a French colleague, using a new approach. They employed the methods of Monte Carlo calculation to analyze existing wind data in non-hurricane areas for comparison with the historical models. Their results clearly supported the "Gumbel" model—one that limited the prediction of high-velocity winds to lower values than other models.[214]

The results obtained by the three scientists led to a change in standardization practices and building design throughout the world. Particularly affected was the area of statistical analysis. Their ideas became part of an engineering text, co-authored by Simiu, describing the fundamental effects of wind on structures.

### *Structural Disasters*

During an evening dance contest on Friday, July 17, 1981, at the Hyatt Regency Hotel in Kansas City, Missouri, two suspended walkways—carrying patrons who were watching the scene or traversing an atrium high above the festivities—gave way and fell into the mass of people below. It was the deadliest structural disaster in American history—113 dead, 186 injured. Three days later, Senator Thomas F. Eagleton and Mayor Richard L. Berkley asked NBS to help discern the cause of the catastrophe. The Bureau was ready, willing, and able to help.

A team of scientists and engineers from the Center for Building Technology in Gaithersburg and the Center for Materials Science in Boulder was assembled immediately. The team included Richard D. Marshall, Edward O. Pfrang, Edgar V. Leyendecker, Richard P. Reed, Maurice B. Kasen, and T. Robert Shives; they reached the scene the next day. The group examined the atrium area and visited a warehouse where authorities had temporarily stored debris from the collapse.

Until certain legal questions could be answered, NBS access to some of the materials needed for analysis of the disaster was delayed. But eventually Bureau scientists and engineers were able to examine the fallen walkways and remove critical portions of the debris for testing in their own laboratories. On the basis of the study, they were able to describe the course of events on the fateful evening in terms of material strengths, design criteria, and construction techniques, comparing the actual strength of the walkways with that required by the Kansas City building code.[215] Theirs is an arresting analysis of a disaster that was inevitable once construction of the walkways was complete.

The hotel was built with a tall atrium between a residential tower and an area that encompassed registration, dining, and other facilities. Three walkways traversed the atrium at different levels. The fourth-floor walkway was directly above the second-floor walkway, while a third-floor walkway crossed at some distance from the other

[214] E. Simiu, J. Filliben, and J. Bietry, "Sampling errors in the estimation of extreme winds," *J. Structural Division, Amer. Soc. of Civil Eng.* **104**, No. ST3, March 1978.

[215] Richard D. Marshall, Edward O. Pfrang, Edgar V. Leyendecker, R. P. Reed, M. B. Kasen, and T. Robert Shives, "Investigation of the Kansas City Hyatt Regency walkways collapse," *NBS Building Science Series 143*, May 1982, 350 pp.

two. Three pairs of threaded steel rods anchored in the ceiling of the atrium (hanger rods) supported the third-floor walkway, and another three pairs supported the fourth-floor walkway. Each pair of hanger rods actually supported a cross-beam, with the walkway itself lying atop the beam; the rods passed through holes in the beams which then rested on large steel washers and nuts. The way the walkway supports were installed turned out to provide an inadequate margin of safety, according to the testing done by the NBS team and the requirements of the Kansas City Building Code.

Although the original design of the hotel called for the fourth-floor walkway hanger rods to be long enough to also support the second-floor walkway, the actual construction resulted in the use of a second set of hanger rods anchored to the fourth-floor walkway beams. This deviation from the original design was a fatal error, for it effectively doubled the load on each of the fourth-floor cross-beams, causing the washer-nut connection on one of the fourth-floor beams to pull through its hole when some 40-60 people gathered on the walkways to watch the dancing.

The NBS analysis was painstaking. Micrographic analysis of the support hardware and strength testing of the beam assemblies allowed the team to estimate the load-bearing capability at each of the hanger-rod positions. The flawed design of the cross-beam, washer-and-nut connections, coupled with the unwise suspension of the second-floor walkway from the one above it, resulted in a load-carrying capacity barely strong enough to bear the weight of the walkways themselves—no more than half the capacity demanded by the local building code. The recipe for disaster required only the ingredient of a certain amount of extra weight, provided on a summer evening by the attraction of a dance contest.

### *Earthquake!*

The year 1977 saw the heaviest damage from earthquakes in four centuries, according to seismic experts. It was thought that the problem might not ease anytime soon.

Congress reacted to the perceived increase in the danger to U.S. cities with passage of the *Earthquake Hazards Reduction Act of 1977* (PL 95-124). The Act directed the President to establish and maintain a coordinated earthquake hazards reduction program, based upon improved structural design and construction methods, improved prediction techniques, and improved land-use policies. The Bureau was asked to participate in data-gathering, testing, and analysis of earthquake damage and improved construction methods.

Following are only two examples of several earthquake investigations by NBS during Ambler's tenure.

An earthquake demolished many buildings in downtown Bucharest, Romania, on March 4, 1977. Two NBS engineers led a U.S. study team to the site, where they gathered information on the types of buildings that were damaged, evident sources of the damage, and the effectiveness of earthquake-resistant construction in Bucharest. The Bureau team was directed by the Office of Foreign Disaster Assistance of the Agency for International Development.

The NBS report, written by George S. Fattal, Emil Simiu, and Charles G. Culver, ran to some 160 pages and included more than 100 photographs illustrating the damage caused by the earthquake.[216] The report also recommended methods for restoration of some of the structures, as well as suggestions for building practices for improved seismic resistance. The eventual U.S. offer of assistance to Romania was based, in part, on the NBS recommendations.

Graphic images resulting from a severe earthquake (8.1 on the Richter scale) that rocked Mexico City on September 19, 1985, stayed in the minds of many who saw—in news reports or first-hand—the extent of the damage. More than 6,000 people were killed or could not be found; some 14,000 were injured; places of employment were lost by 150,000. Contributing to the human suffering, more than 5,000 buildings were damaged more or less severely, nearly 700 of those partially or completely collapsing. Streets and water mains were shredded, along with many telephone lines. Total economic damage was expected to approach $4 billion.

Large as it was, the disaster could have been worse. The earthquake occurred at 7:19 am, before many people had left their homes to work in the medium-tall buildings that suffered some of the worst damage. And the damage, mimicking the destructive pattern of a Richter 7.5 quake that struck Mexico city in 1957, was selective. Although buildings in the 5-20 story range suffered major damage, many nearby buildings and all buildings taller than 30 stories escaped.

A team of five scientists—William C. Stone and Felix Y. Yokel of NBS and Mehmet Çelebi, Thomas Hanks, and Edgar V. Leyendecker of the U.S. Geological Survey—was dispatched under the aegis of the Interagency Committee on Seismic Safety in Construction to provide technical advice to rescuers and to assess the nature and extent of the structural damage with respect to minimizing earthquake damage in the future.[217] Professors from the Institute of Engineering of the University of Mexico assisted the U.S. team with information on subsoil conditions, building codes, and other information on Mexico City.

The team observed that most of the destruction was confined to an area of the city that once lay beneath a lake, where the soft surface land subsided continuously and noticeably with time. The substantial ground motion was amplified by the nature of the subsoil. The group analyzed the failures of buildings and their foundations in terms of existing seismographic records and obvious differential displacement of sidewalks and pavement around buildings. Many details of tilted and overturned structures showed the influence of the subsurface on the extent of earthquake damage.

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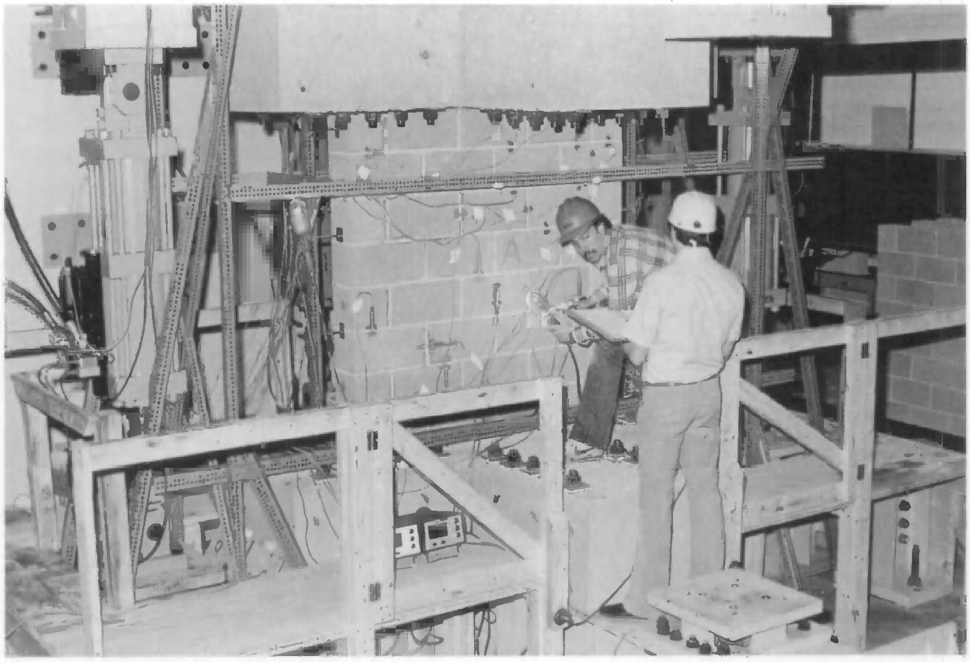
[216] G. S. Fattal, E. Simiu, and C. G. Culver, "Observations on the behavior of buildings in the Romania earthquake," *NBS Special Publication 490,* 168 pp., September 1977.

[217] William C. Stone and Felix Y. Yokel of NBS and Mehmet Çelebi, Thomas Hanks, and Edgar V. Leyendecker, "Engineering aspects of the September 19, 1985 Mexico earthquake," *NBS Building Science Series 165,* May 1987, 207 pp.



Engineers from the NBS and the Bureau of Mines collaborated in earthquake hazards prevention research, using a special tri- directional test facility at the NBS Center for Building Technology. In this photograph, engineers studied the behavior of masonry walls under shear stress.

On the basis of previous experience with earthquake damage from the relatively close Middle American Trench area that ran along the Southwest coast of Central America, the Mexico City authorities long ago issued special building codes intended to minimize earthquake damage. Structures were to be built so as to move as a unit, with minimum foundation motion. Nevertheless, not even the newest buildings escaped damage.

The disaster team from the U.S. obtained an enormous amount of detailed information about the response of a variety of structures, mainly buildings, to the well-documented forces resulting from the Mexico City earthquake. For example, a 43-story steel frame building apparently survived because its natural vibration period was well outside the resonance period of the earthquake, so that it was "detuned" from major structural damage. In other cases, buildings built close to each other suffered damage from "pounding" as they swayed and made contact with each other in response to the earthquake.

### *Stress-Wave Analysis of Concrete*

In 1983, Nicholas Carino and Mary Sansalone of the Center for Building Technology initiated a research project to develop a stress-wave-propagation technique for locating defects within concrete structures. While the use of stress waves was a familiar practice in the non-destructive evaluation of metals, little success had resulted from previous efforts in concrete analysis.

With colleagues in CBT and acoustics experts from the Center for Manufacturing Engineering, Carino and Sansalone took advantage of advances in numerical simulation methods, transducer technology, and signal processing to propose a new analytical technique which they called the "impact-echo" method.[218]

The new method was a big hit. It was adopted as an approved test method for thickness measurement by the American Society for Testing and Materials (C 1383, 1998), and it formed the basis for new commercial products for use in the Nation's highway industry.

### *Projects in Preservation*

During 1980, the White House received a much-needed face-lift with help from NBS.

Paul Campbell, Gerald Sleater, and Mildred Post of the Structures and Materials Division, Center for Building Technology, were called in during 1978 by the National Park Service for advice on cleaning and painting the exterior of the venerable residence. For nearly 2 years, the NBS team evaluated the exterior surface of the building's walls, tested certain points and cleaning methods, and made their recommendations.

Restoration began in 1980, with stripping of the paint on the building's east side, where the paint had suffered the most damage. Following the Bureau recommendations, the paint on the east side was stripped chemically and the entire building hosed with a high-pressure water spray. Defects in the exterior masonry were patched and allowed to cure, and a primer coat of paint was applied to the east side. Finally, an alkyd-based paint was applied to the entire structure. Interestingly, the paint color chosen by the White House staff was not white, but a softer cream color to make the building "more appealing" by day and night.[219] Bureau scientists undertook other investigations for the National Park Service as well, most of them of a geophysical nature.

### *Helping OSHA*

During construction of a five-story condominium building in Cocoa Beach, Florida in March 1981, the building suddenly collapsed, killing 11 workers and injuring two dozen others. Occupational Safety and Health Administration officials asked representatives of the Bureau's Center for Building Technology to investigate the disaster in order to determine its cause.

An experienced team—Hai S. Lew, Nicholas J. Carino, S. George Fattal, and Martin E. Batts—responded with on-site inspections, laboratory tests, and analytical studies. The team concluded that the construction had proceeded without full attention to certain factors, among them:

[218] M. Sansalone and N. J. Carino, "Detecting delaminations in concrete slabs with and without overlay using the impact-echo method," *ACI Materials Journal* **86**, No. 2, March-April 1989, pp. 175-184.

[219] "How do you keep the White House white?," *NBS Standard,* Vol 25, No. 18, p. 5.

Chemist James R. Clifton of the Bureau's Center for Building Technology headed an NBS project on preservation technology which was initiated at the request of the National Park Service. In the accompanying photograph, Clifton (left) and Paul Brown prepared an adobe specimen for microscopic examination by impregnating it with methyl methacrylate. The inset shows a cross section of an adobe specimen.

- Non-uniform concrete was used in the construction, and its strength was not up to code.
- Positioning of the reinforcing rods in the floor sections did not allow specified shear resistance criteria to be met. No test of this parameter had been performed, because the test had not been specified in the building design.

The result of the faulty design and construction led to failure of the building after the fifth floor was installed. The fifth floor collapsed, carrying with it all the lower floors.[220]

OSHA also requested NBS assistance in ascertaining the cause of the collapse of a highway bridge ramp in East Chicago, Indiana, which killed 13 workers and injured 17 others.

In both cases, NBS tests showed an increasing need for improved test methods for evaluating the strength of structures during construction.

### *Measuring Insulating Values*

The heat-retardant value of various types of thermal insulation received increased attention as the costs of all building materials spiraled upwards during the 1980s. At the request of the Federal Trade Commission and the Department of Energy, NBS scientists Chock In Siu and Charles Bulik designed and built a new device for improved measurement of batts of thermal insulation.

The new apparatus, a specially designed guarded hot plate, provided greatly improved precision in the measurement of the thermal conductivity of the batts, the basis of "R" values in the construction industry. Heat was applied to the samples from a line heat source, with the temperature of the surrounding guard ring set to minimize transverse energy loss. The apparatus could be used at any temperature within the range 250 K to 400 K.[221]

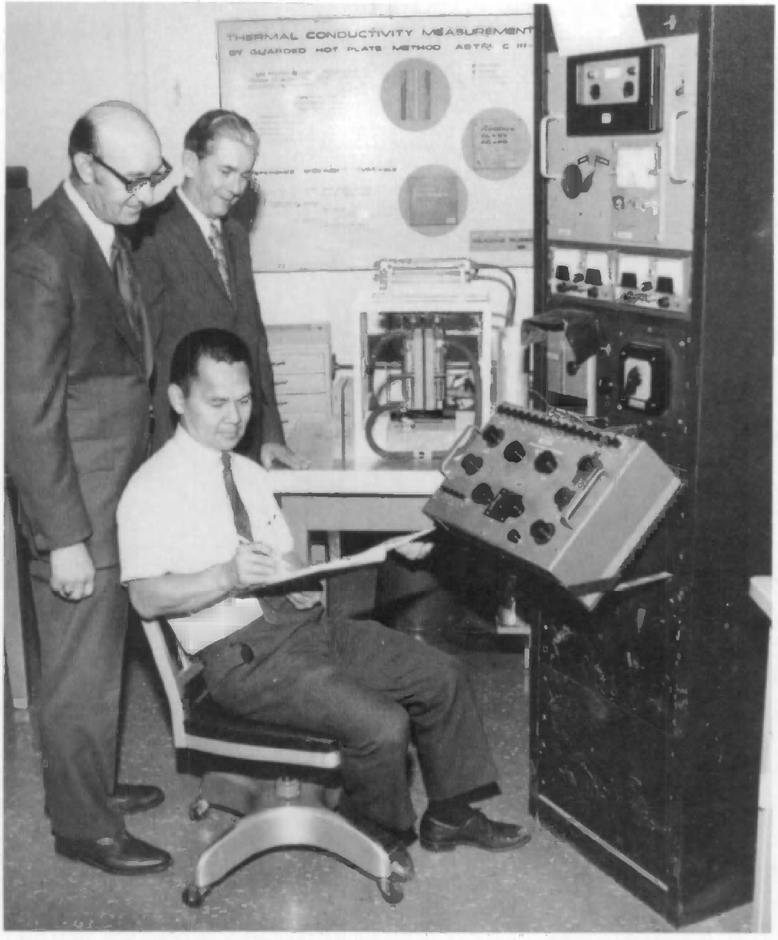
Using the new device, the National Engineering Laboratory initiated production of standard samples of insulation with thicknesses ranging from 25 mm to 150 mm for use as references for the FTC. For the first time, R-values for all thicknesses of thermal insulation materials could be based upon actual measurements.

## Health & Safety Projects

We illustrate Bureau projects relating to health and safety with an octet of programs diversely based—upon superconductivity, dentistry, high-frequency sound, ionizing radiation, mercury detection, metallurgy, thermometry, and prosthetics.

[220] H. S. Lew, N. J. Carino, S. G. Fattal, and M. E. Batts, "Investigation of construction failure of Harbour Cay condominium in Cocoa Beach, Florida," *NBSIR 81-2374*, September 1981, 138 pp.

[221] M. C. I. Siu and C. Bulik, "National Bureau of Standards line-heat-source guarded-hot-plate apparatus," *Rev. Sci. Inst.* **52**, No. 11, 1709-1716 (1981).



Frank J. Powell (standing on the left), Chief of the NBS Thermal Engineering Systems Section, and section colleague Thomas W. Watson watched as the Bureau's Chock I. Siu operated a guarded hot-plate apparatus (on table) to determine the thermal conductivity of insulation.

### *Magnetoencephalography*

In Ch. 2, we noted that James E. Zimmerman of the Boulder Cryogenics Division was a pioneer in the use of superconducting quantum interference devices (SQUID) for medical diagnostics. During the late 1970s, Zimmerman carried his studies further into medical research with the collaboration of M. Reite of the University of Colorado Medical Center, J. Edrich of the University of Denver, and J. T. Zimmerman of the University of Colorado department of Psychology.

The experiments undertaken by the group went by the generic title of magnetoencephalography, the recording of magnetic activity in the brain. The SQUID served as a magnetic gradiometer, able to detect local variations in the intensity of magnetic fields produced by brain activity. For improved sensitivity, observations were performed in a shielded room in the Boulder laboratory. The magnetic measurements of brain activity appeared to be capable of better spatial precision on the skull of human subjects than electroencephalography.

To test brain response to auditory signals, the team presented clicking sounds to four subjects through earphones. Within less than a half-second after receiving a sound pulse, each subject exhibited a magnetic response that was detectable by the apparatus near the area on the scalp thought to correspond most closely to the primary auditory cortex of the brain. It was the first demonstration of auditory evoked response by magnetoencephalography.[222]

### *Dental Work at NBS*

Collaboration between the American Dental Association (ADA) and NBS continued without interruption from 1928, when the first ADA research associate, Norris O. Taylor, arrived. The productivity of the collaboration was outstanding.

Almost 50 years later, in 1977, there were nine NBS employees working as members of the Dental and Medical Materials Section of the Polymers Division, 22 research associates of the ADA Health Foundation Research Unit, and individual associates from the U.S. Navy, the Air Force, and the National Association of Dental Laboratories. Funding was provided by the ADA foundation, by NBS, and by agencies such as the National Institutes of Health.

During its first half-century, the collaboration produced 25 standards for dental materials and more than 600 scientific papers. Among the items of apparatus commonly used in 1977, the high-speed-turbine hand drill and the panoramic x-ray machine were developed at NBS. Composite restorative dental materials were developed at the Bureau as well.

During World War I, Wilmer Souder, an NBS physicist working in conjunction with the U.S. Army, began evaluating the properties of dental amalgams. In 1926 the work led to the first dental specification by the ADA.

George Paffenbarger was the Senior Research Associate in 1977; with Nelson Rupp, chief of Clinical Research for the ADA foundation, he updated the amalgam specification to eliminate from common use those amalgams that tended to produce inferior results. The goal of amalgams research, to make the restoration last the entire lifetime of the patient, was near, said Rupp; only slight differences in dental handling limited the service life of amalgams.

A 1956 collaboration, led by Ray Bowen—in 1977 still part of the research team at NBS—developed silica-resin composites that became standard materials for filling pits and fissures in teeth.

[222] M. Reite, J. Edrich, J. T. Zimmerman, and J. E. Zimmerman, "Human magnetic auditory evoked fields," *Electroencephalogr. Clin. Neurophysiol.* **45**, 114-117 (1978). A simplified discussion of this work can be found in *Dimensions/NBS*, February 1978, pp.19-21.

In 1974, Walter Brown published a new theoretical discussion of tooth decay; his idea was that decay initiated slightly below the tooth surface with a process of demineralization. [223]

Richard Waterstrat, chief of Dental Metallurgy, sought an effective substitute for gold in dental restorations. Gold constituted one of the principal components of restoratives that involved the fusing of porcelain to metals. The high cost of gold provided the motivation for Waterstrat's efforts. His work led him to become an expert on the phase diagrams of alloys of noble metals with less expensive elements. Properties such as toxicity and response to the chemistry of the mouth complicated Waterstrat's metallurgical problems.

In 1977, Curtis Mabie was chief of dental ceramics. His work focused on porcelain and other ceramic restoratives. An example of this effort was an attempt to render ceramic fillings opaque to x rays, so as to distinguish them from cavities.

Gerhard Brauer of the NBS dental group prepared a review of the use of polymers in dentistry for the construction of dentures, plastic teeth, and impression materials. He pointed out the advantage of liners that bonded securely to teeth, and discussed research in progress.[224] Brauer received the Department of Commerce Gold Medal award in 1975 for his work in dental research.

Bonding dental resins to dentin was an objective of research by Joseph M. Antonucci. He sought to replace the "acid-etch" process with monomers that co-polymerized with dentin.[225]

Crystallographer Leroy W. Schroeder, an American Dental Association Research Associate, was photographed with models of glaserite, used in studies of the crystalline structure of the apatites found in teeth.

[223] W. E. Brown, "Physicochemical mechanisms of dental caries," *J. Dent. Res.* **53**, No. 2, 204-216 (1974).

[224] G. M. Brauer, "Polymers in dentistry," Chapter 5 in *Dental Materials Review*, R. G. Craig, editor (Ann Arbor: University of Michigan Press, 1977), pp. 78-111.

[225] "New technique for dental restorations," *Dimensions/NBS*, April 1977, p. 22.

*Medical Diagnosis With Ultrasound*

High-frequency sound waves were used in many ways at NBS. Some of these involved non-destructive evaluation. A special category of non-destructive evaluation turned out to involve ultrasonic medical diagnosis, a new field that came into its own during the tenure of Ernest Ambler as director of NBS.

During May 1975, an international seminar on ultrasonic characterization of tissue was held at the Gaithersburg campus of NBS. The seminar was chaired by Melvin Linzer of the Bureau's Inorganic Materials Division.[226] It was co-sponsored by NBS, the National Institutes of Health, and the National Science Foundation. Some 22 papers were given during the meeting; they focused on experimental methods. Participants represented research hospitals, universities, government agencies, and private firms. In a keynote talk, G. B. Devey of the National Science Foundation traced the beginnings of NSF support for research on medical ultrasonics and progress towards the goal of bringing the techniques to clinical medicine. The seminar played an important role in disseminating new information on the status of the field.

A *Second International Symposium on Ultrasonic Tissue Characterization*, again co-sponsored by NBS, NIH, and NSF, and held at NBS from June 13-15, 1977, brought forth further instrumental details of ultrasonic techniques. Included among the 50-odd papers were specifics on some of the medical uses of ultrasound. These included the fact that, properly administered, ultrasound did not damage tissue during diagnostic use. Birth defects, brain disorders, heart disease, tumors of the breast, liver anomalies, and bone composition, all of these were diagnosed using ultrasound.

One contribution to the second symposium was offered by Melvin Linzer in collaboration with Stephen I. Parks, S. J. Norton, F. P. Higgins, and R. W. Sheidler, and their colleagues from NIH, T. H. Shawker and J. L. Doppman. Their paper described progress in developing at NBS a comprehensive analysis system for tissue, based upon the use of ultrasonics. Techniques considered for the system included computer-assisted tomography, opto-acoustic testing of imaging, transducer calibration, and sensitivity enhancement through signal averaging. Portions of the new system were tested and found satisfactory in the Clinical Center of the National Institutes of Health.

*Safe Use of Ionizing Radiation*

Lauriston S. Taylor took advantage of an opportunity to lecture on one of his specialties, radiation safety, on March 1, 1976. Taylor was a veteran member of NBS (his service to the Bureau began in 1927 and extended to 1965) and a national spokesman for radiation-related public safety problems. He was chief of the Bureau's radiation physics activities from 1950 to 1962, he served the National Academy of Sciences for 4 years in emergency planning, and during 1976 he was President of the National Council on Radiation Protection and Measurement. As keynote speaker

[226] "Ultrasonic Tissue Characterization: Proc. of a seminar held at NBS, May 28-30, 1975," Melvin Linzer, editor, *NBS Special Publication 453*, 288 pp., October 1976.

for the NBS-sponsored symposium on Measurements for the Safe Use of Radiation, Taylor reminded his audience of a few facts from the history of radiation safety, as well as some of his own thoughts on the topic.

First to be mentioned was the idea of traceability of measurement standards; it would be of little benefit to patients at a hospital if the radiation-measurement capability of NBS could not be transferred at an acceptable level to that hospital. Taylor was involved in inter-laboratory comparisons of x-ray standards as early as 1931.

Early medical x-ray dosimetry involved color-change chemicals, photosensitive films, and ionization chambers. Taylor traced the history of x-ray standards activities to the mid-70s, noting the availability of 5 % accuracy for patients in hospitals with the best measurement practices.

Taylor suggested continuing maintenance of basic radiation-safety measurements, continuing measurement assurance with organizations that place people in radiation situations, and continuing development of accurate and reliable field instruments.[227]

### *A New Mercury Monitor*

Industrial workers encountered mercury less frequently during the mid-70s than they did in earlier times,[228] but NBS nevertheless found a ready audience for its development of an improved mercury monitor.

National Institute of Occupational Safety and Health (NIOSH) safety standards limited exposure to mercury vapor to 0.05 mg/m$^3$ during an 8-hour workday. Eugene P. Scheide and John K. Taylor developed a sensitive, portable, inexpensive device that measured the total amount of mercury exposure over a workday.

The device was based upon the principle of the microbalance. It employed frequency measurement to indicate the amount of mercury encountered in its active components. The two scientists found that they could evaporate a gold layer on the surface of a piezoelectric crystal of quartz. Gold amalgamated easily, absorbing mercury as room air was drawn past the crystal; as the mercury accumulated, the natural frequency of vibration of the quartz changed. A simple formula related the amount of mercury absorbed to the change in resonant frequency of the dosimeter.

Perhaps best of all, a simple baking procedure could remove as much as 90 % of the mercury from the dosimeter after it was read. The sensor/air-pump system could readily be worn on a worker's clothing.[229]

[227] Lauriston S. Taylor, "A saga of radiation safety," *Dimensions/NBS,* May 1976, pp. 7-9, 21.

[228] Madeleine Jacobs, in "NBS develops new mercury monitor, *Dimensions/NBS,* January 1976, pp. 3-5, noted that the "Mad Hatter" of Lewis Carroll's "Alice in Wonderland" derived from the visible symptoms exhibited by workers in the hat industry when felt and fur processing involved the use of mercury in large quantities.

[229] E. P. Scheide and J. K. Taylor. "Piezoelectric sensor for mercury in air," *Environ. Sci. Technol.* **8**, No. 13, 1097-1099 (1974).

NBS chemists John K. Taylor (left) and Eugene P. Scheide discussed the portable mercury monitor that they developed to help public health officials determine whether a worker was exposed to hazardous levels of mercury.

### *Safety From Burning Metals*

Metal combustion studies at NBS/Boulder had as their goal the elucidation of the basic mechanisms involved in the burning of metals in the workplace. A research team of John L. Moulder C. C. Runyan, and Alan F. Clark undertook the project at the suggestion of a triplet of agencies—the Department of Transportation, the National Aeronautics and Space Administration, and the U.S. Air Force Office of Scientific Research.

Metals of special interest were involved in the transport of liquefied or gaseous oxygen. Any tendency for metal to burn—to oxidize, usually—would be enormously speeded up by the presence of oxygen in large quantities. One example of such a disaster was the explosion of a liquid oxygen tank truck in Brooklyn, which killed or injured more than 30 people.

The research team prepared a test fire by igniting 100 g samples of steel in an oxygen pressure tank, then dropping them on other metals. All experiments were conducted by remote control, with video monitors. Filming at a rate of 500 frames per second, they followed the details of combustion. Reaction rates could be monitored by weighing the samples during combustion. Radiation thermometers and spectrometers provided temperature and spectral data, showing the presence or absence of intermediate species.[230]

[230] A. F. Clark, J. C. Moulder, and C. C. Runyan, "Combustion of bulk titanium in oxygen," paper in *15th International Symposium on Combustion* (Pittsburgh: The Combustion Institute, 1974) pp. 489-499.

### *Medical Thermometry*

From the hand on the fevered brow, to the mercury thermometer under the tongue, to the electrical thermometer encased in a throw-away protector, medical and clinical thermometry gained both speed and accuracy.

In 1973, the NBS Heat Division initiated a program in Medical Thermometry, headed by Billy W. Mangum. At that time, the most accurate thermometer available to the medical profession was uncertain by 0.3 °C in terms of the International Practical Temperature Scale of 1968. Standard thermometers and a temperature reference point based on the melting point of purified gallium, subsequently developed in the Medical Thermometry program, reduced the previous uncertainty level by a factor ten. The new thermometers were made part of the Standard Reference Materials program and given the designations SRM 933 and SRM 934. They were used primarily to calibrate new, miniature electrical-resistance thermometers—thermistor thermometers or tiny platinum resistance thermometers. While they were very sensitive, the new thermometers needed re-calibration on a regular basis.

Working with thermistor manufacturers, Mangum and his co-workers helped to develop types of thermistor thermometers of exceptional stability—some showing drift rates as small as 0.005 °C per year.

To provide thermometry for body tissue under high-frequency irradiation, the group studied the use of ordinary radiation thermometry or non-metallic thermometers. A birefringent-crystal thermometer, $LiTaO_3$, connected to its power source and readout device by optical fibers, showed promise for contact thermometry in irradiation experiments.[231]

### *New Body Parts for Old*

In 1975, about 1 million foreign objects (implants) were surgically inserted into human patients. These consisted of nails and screws, plates and joints, heart valves and synthetic blood vessels. Since the implants were inserted into younger and younger patients, questions about their long-term biocompatibility and service life became more and more pressing. In 1976, a Medical Devices Amendment required manufacturers of implants to meet stricter standards—in some cases, standards still in the developmental stage.

James M. Cassel, chief of the Bureau's Dental and Medical Materials Section, headed an NBS program on synthetic implants at that time. Collaborating with Cassel were Freddy A. Khoury, Anna C. Fraker, John R. Ambrose, and Arthur W. Ruff; they studied the two largest areas of implant medicine, orthopedic and cardiovascular devices.

Orthopedic implants were made of stainless steel, cobalt-chromium alloys, or titanium alloys. Leading the way in such devices were artificial hips, with about 40,000 insertions per year. Fatigue and wear in use limited the service life of the

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[231] B. W. Mangum, "Mercury thermometers—are they becoming antiques?" *Dimensions/NBS,* February 1976, pp. 12-17.

prosthetic hips. Another factor in the service life of hip joint prostheses was the use of high-density polyethylene in the socket portion of the joint. It was subject to severe pressure because of its configuration and thus its wear characteristics were vital to the service life of the joint. And the cement used to hold the components of the implanted hip joint in place similarly was subject to extreme wear. Stephen S. Haas, Gerhard M. Brauer and George Dickson developed a polymethylmethacrylate bone cement that was effective with prosthetic implants.[232]

## Energy Conservation

Research and other activities in support of energy conservation, created as a major thrust of NBS work during the tenure of Richard Roberts, continued as an active program under Director Ambler. Following are brief notes on some of these projects.

### *ETIP Initiates the Modular Integrated Utility System Study*

Jordan Lewis, head of the Bureau's *Experimental Technology Incentives Program*, announced during 1976 the selection of the University of Florida, at Gainesville (UF), to test a new concept in energy generation and conservation that was given the name "Modular Integrated Utility System" (MIUS). The announcement was made jointly with Gerrit D. Freemouw of the Department of Health, Education, and Welfare, and Robert Q. Marston, President of UF.

The sub-systems comprising MIUS at UF included the generation of a fraction of needed power on the site of the project; the creation of a heating, ventilating, air conditioning, and hot water system; systems for disposal of liquid and solid waste; and the conservation of potable water.[233]

Clinton Phillips of the Office of Housing and Building Technology, Department of Housing and Urban Development was the lead technical advisor for the MIUS project. John Schaefgen was the leader of the MIUS demonstration project at the Bureau. One of the major goals, they stated, was the conservation of energy used within the demonstration community through recovery of waste heat, typically discarded into ponds or streams by electrical utilities. Other goals included protection of the environment, cost minimization, and maintaining high system reliability.

Besides the University of Florida project, a second contract was let for a project to be centered on the construction of a new town, St. Charles, Maryland, located 40 km southeast of Washington, DC. The town was planned to incorporate one high-rise apartment building, 205 apartments in four-story units, 200 townhouses, a shopping mall, offices, and a high school.

At the time of the award of the project, it was hoped that energy savings as large as 40 % could be realized by the new approach. A bonus would take the form of reduced environmental pollution.

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[232] S. S. Haas, G. M. Brauer and G. Dickson, "A characterization of polymethylmethacrylate bone cement," *J. Bone J. Surg.* **57A**, No. 3, 380-391 (1975).

[233] "University of Florida, Gainesville, Selected to Test Integrated Utilities System Concepts," *Dimensions/NBS*, March 1976, p. 19.

The MIUS experiment provided a useful model for a national utility program rooted in energy conservation and environmental protection.

### *Energy-Efficient, Automatic Control of Furnaces*

A new furnace-testing facility was completed in 1980 by the NBS Center for Mechanical Engineering and Process Technology. It was designed to improve the energy efficiency of industrial furnaces using automatic controls and heat-recovery systems known as "recuperators."

Recuperators, heat exchangers that recovered energy from hot exhaust gas to pre-heat the make-up air prior to combustion, lent complexity to automatic furnace controls, explained Hratch Semerjian, project leader for the new installation. The efficiency of the recuperator depended upon the temperature of the incoming air, which in turn depended upon the temperature of the recuperator. Developing the procedures for balancing the control system in the presence of such feedback mechanisms presented a problem which industrial combustion engineers were happy to bring to NBS.

The furnace was a slot-forging type rated at 300 kW (1 million Btu/h), with a maximum air preheat of 850 °C. A mini-computer was dedicated to the development of the control algorithm.

The furnace project also enabled Bureau scientists to study the combustion characteristics of various fuels and evaluate diagnostic test methods for furnaces.

### *Insulating an Older Home*

NBS scientists showed the value of insulating homes against the heat and cold during 1978-79. Using the Bowman House, mentioned in Ch. 1, they measured the energy consumption of the poorly insulated home under simulated conditions of occupancy, then insulated it and installed storm windows. The energy consumption in the house dropped by nearly 60 %.[234]

### *Catching Energy Losses With Infrared Thermography*

The value of infrared thermography for detecting loss of energy from residential and industrial structures was convincingly demonstrated in 1978 by scientists from the Center for Mechanical Engineering and Process Technology.

As part of the EPIC publications series, Lawrence A. Wood, John F. Ward, and Kenneth G. Kreider described a specialized camera that produced images indicating the temperature distribution on the outside surfaces of industrial furnaces—for example, an iron-forging furnace. The information would allow an exact calculation of the rate of loss of energy, a growing expense at that time.[235]

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[234] "National Bureau of Standards, A National Resource for Science and Technology, Fiscal Year 1978," *NBS Special Publication 538,* July 1979, p. 35.

[235] L. A. Wood, J. F. Ward, and K. G. Kreider, "Energy management for furnaces, kilns, and ovens," *Handbook 124,* January 1978, 44 pp.

## Environmental Science

Many Bureau projects of this period influenced the welfare of man's environment. Of these, we highlight only a few: a sampling device for life deep in the ocean, ozone-layer chemistry, a study of smog, corrosion by the environment, and the polluting aspects of oil spills.

### *A Deep-Ocean Sampler Wins a Prize*

Heat Division physicists Max Klein, Meyer Waxman, and Harry A. Davis made a brief excursion into the high-pressure world of deep-sea biotechnology during the late 1970s and came away with an award for their trouble.

Rita R. Colwell and Paul S. Tabor, microbiologists at the University of Maryland, needed help in retrieving live microorganisms from the ocean depths. Study of the living microbes was important to understanding their roles—if any—in decomposing wastes at great depths, and in the deep-ocean life cycle. They came to NBS for aid in designing a specialized sampling device primarily because Colwell was married to a Bureau physicist, Jack H. Colwell, of the NBS Heat Division, who was well aware of the Bureau's capabilities in high-pressure physics.

Davis, Waxman, and Klein designed a sampling apparatus for use to depths of 10,000 m, where the pressure was about 1000 times atmospheric pressure. The design proved entirely suitable for its tasks: to pre-pressurize a sterilized interior sampling chamber; to capture a sample at the required depth; to maintain the sample at its deep-water pressure while allowing the scientists to study enclosed microorganisms in the laboratory; and to permit the extraction of small samples at will.

The device was relatively small, inexpensive to construct, corrosion-resistant, safe, and reliable. Trials in the Puerto Rico Trench at 6800 meters depth brought up live bacteria of unknown types in addition to species previously studied with great effort. The device was immediately commissioned by the microbiology team for routine use.

The deep-ocean sampler was cited by Industrial Research and Development magazine as a winner of its 1979 IR-100 award, given to the "100 most significant new technical products."

### *Chlorofluorocarbons vs the Ozone Layer*

The idea that chlorofluorocarbons, used extensively in refrigeration, air conditioning, and as propellants for bug bombs and paint, might absorb ultraviolet light, thereby freeing atomic chlorine to deplete the earth's protective ozone layer, led to a search for details of such a process.

The Bureau's Robert J. Celotta, Stanley R. Mielczarek, and Chris E. Kuyatt, members of the Optical Physics Division, collaborated with Russell H. Huebner and David L. Bushnell of the Argonne National Laboratory to establish a few relevant facts, using the technique of electron-loss spectroscopy.

In a laboratory at the University of Maryland (UM), Max Klein, an NBS physicist, and Rita R. Colwell, a UM microbiologist, looked at colonies of deep ocean micro-organisms cultured from water samples retrieved by the deep-ocean sampling device (on counter).

Key to the method was the ability to count electrons of a given energy. The team's spectrometer was designed so that electrons projected from a gun were made to pass through a monochromator that transmitted only those electrons moving within a narrowly defined range of energy. The transmitted beam then passed through the test gas where some fraction of the electrons lost energy by colliding with atoms or molecules of the test gas. From there, the electrons were accelerated and energy-analyzed before entering a detector. The group estimated that cross-sections for electron-molecule interaction could be determined by the device within about 15 %.

Two chlorofluorocarbons, $CFCl_3$ and $CF_2Cl_2$, were studied by the group. Their results agreed well with one of two sets of measurements that themselves differed by factors of two to four.[236] Because the NBS-Argonne experimental arrangement incorporated very different systematic errors than the other experiments, the results were seen as strong confirmation of data published by Mario Molina and Sherwood Rowland of the University of California at Irvine, who had proposed the ozone-breakdown theory.

More information came from Pierre J. Ausloos, Richard E. Rebbert, Michael J. Kurylo, and Walter Braun, all members of the Physical Chemistry Division.

[236] R. H. Huebner, D. L. Bushnell, R. J. Celotta, S. R. Mielczarek, and C. E. Kuyatt, "Ultraviolet photo-absorption by halocarbons 11 and 12 from electron impact measurements," *Nature* **257**, No. 5525, pp. 376-378 (1975).

University of Maryland microbiologist Paul S. Tabor guided the deep-ocean sampler from the deck of a research vessel.

Ausloos and Rebbert studied the photodecomposition of $CFCl_3$ and $CF_2Cl_2$ at several different wavelengths, using methane and ethane to intercept atomic chlorine. They derived values for the quantum yields of half a dozen molecular fragments resulting from the photodissociation. Near the lower limit for absorption, they found evidence that atomic chlorine was indeed released during the photodissociation process. At higher photon energies, it appeared that two chlorine atoms were produced from each reacting halocarbon molecule. [237]

Kurylo and Braun, meanwhile, simulated the effect of sunlight on the reaction of atomic chlorine with ozone, using the process of flash-photolysis resonance fluorescence. They obtained the rate constant for one of the sequential reactions that was predicted by Molina and Rowland to result in essentially catalytic conversion of ozone to ordinary oxygen in the presence of atomic chlorine and sunlight.[238]

NBS was well into the ozone-layer controversy.

### *A New Molecule, Born in Smog*

An entirely new class of chemical compounds was identified during research at NBS on the components of smog. The new molecule, called dioxirane, was discovered in reactions between ozone and ethylene. Predicted by theorists on the basis of the energetics of reactions, the molecule had defied detection until two Bureau research teams found it independently.

Richard D. Suenram and Frank J. Lovas of the Optical Physics Division identified the three-membered ring compound, which contained only carbon, hydrogen, and oxygen, using the technique of microwave spectroscopy at low temperatures (77 K). The two physicists carried out the ozonolysis reaction in a waveguide held at the temperature of boiling nitrogen.[239] The new molecule appeared to consist of a small ring in which two oxygen atoms were singly bonded to each other and to a $CH_2$ radical.

Working independently, John T. Herron, Robert E. Huie, and Richard I. Martinez found the molecule, too. They observed dioxirane as a product of the low-temperature reaction of ozone with ethylene, using the methods of photoionization mass spectrometry in the gas phase. They found that the molecule decomposed to form hydrogen and carbon monoxide.[240]

The following year, Suenram and Lovas expanded their study to provide information on the synthesis, structure, microwave spectrum, and dipole moment of dioxirane. They were able to synthesize several isotopic forms of the molecule involving $^{12}C$, $^{13}C$, $^{16}O$, and $^{18}O$, obtaining molecular constants for the resulting isotopes.[241]

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[237] R. E. Rebbert and P. J. Ausloos, "Photodecomposition of $CFCl_3$ and $CF_2Cl_2$," *J. Photochem.* **4**, pp. 419-434 (1975).

[238] M. J. Kurylo and W. Braun, "Flash photolysis resonance fluorescence study of the reaction $Cl+O_3=ClO+O_2$ over the temperature range 213-298 K," *Chem. Phys. Lett.* **37**, No. 2, 232-235 (1976).

[239] F. J. Lovas and R. D. Suenram, "Identification of dioxirane ($H_2COO$) in ozone-olefin reactions via microwave spectroscopy," *Chem. Phys. Lett.* **51**, No. 3, 453-456 (1977).

[240] R. I. Martinez, R. E. Huie, and J. T. Herron, "Mass spectrometric detection of dioxirane, $H_2COO$, and its decomposition products, $H_2$ and CO, from the reaction of ozone with ethylene," *Chem. Phys. Lett.* **51**, No. 3, 457-459 (1977).

[241] R. D. Suenram and F. J. Lovas, "Dioxirane, its synthesis, microwave spectrum, structure, and dipole moment," *J. Am. Chem. Soc.* **100**, 5117-5122 (1978).

### *Corrosion, an Expensive Problem*

When Congress directed NBS "to embark upon a study of the economic effects of corrosion," they got their money's worth. By early 1978, the first phase of the study, covering the year 1975, was complete. A report, *Economic Effects of Metallic Corrosion in the United States,* provided details based upon a carefully chosen economic model. The model included all identifiable cost elements, along with an error analysis. It was considered to be the most reliable estimate of the economics of corrosion ever produced.

The report placed U.S. corrosion costs at the level of $70 billion each year. Some $10 billion, according to the study, could be avoided by the use of corrosion-control technology already in existence. Substantial savings of energy and of raw materials would also result if appropriate steps were taken to reduce the likelihood of corrosion.

Jerome Kruger, Lawrence H. Bennett, Robert L. Parker, Elio Passaglia, Curt Reimann, Arthur W. Ruff, and Harvey Yakowitz of NBS were joined in the project by Edward Berman of Edward B. Berman Associates to form the study team. Bennett pointed out that the $400,000 undertaking verified with solid information what many suspected. Corrosion was a tremendously costly problem to the Nation.

The study targeted for special attention three sectors of American activity; the electric power industry, the Federal government, and privately owned automobiles. About $4 billion was lost to the electric power industry through corrosion, including approximately 50 % of all maintenance costs for power generators. As much as 2 % of the Federal budget paid for corrosion costs—about $2 billion for maintenance and a staggering $6 billion in capital costs. Corrosion-based costs to the owners of private automobiles were not so firmly identifiable, but estimates ranged from $6 billion to $14 billion per year.[242]

### *Preparing for Oil Development in Alaska*

Environmental dangers inherent in developing enormous oil reserves found near the Alaskan shore were obvious. As far back as 1971, sections of pipe were shipped to Prudhoe Bay, site of successful drilling on the northern coast of Alaska, to begin construction of a trans-Alaska pipeline all the way to Valdez, the southern pipeline terminus on Prince William Sound. Damage to the marine environment of both coasts could easily occur, along with degradation of the ecology of any state crossed by a line conveying as much as 2 million barrels per day of crude oil.

NBS became involved in the project during 1974 at the request of the National Oceanic and Atmospheric Administration (NOAA). Harry S. Hertz and Stuart Cram, chemists in the Bureau's Analytical Chemistry Division, and Herbert Bruce of NOAA led a team of investigators who were assigned the task of collecting baseline data on the marine environment of Alaska. The group was requested to pay particular attention

[242] L. H. Bennett, J. Kruger, R. L. Parker, E. Passaglia, C. Reimann, A. W. Ruff, H. Yakowitz, and E. Berman, "Economic Effects of Metallic Corrosion in the United States," *NBS Special Publication 511-1,* May 1978, 65 pp.

to existing levels of hydrocarbons. Stephen N. Chesler, Willie E. May, Stephen Wise, Dalmo P. Enagonio, Susan M. Dyszel, and Barry Gump, a visiting scientist from the California State University at Fresno, comprised the balance of the study group.

Because they were looking for extremely low levels of contaminants, the team sought especially sensitive collection and analytical techniques for the investigation. About 700 samples of sediment, water, and marine life were collected over a 2-year period. Flights in light aircraft, collection in whatever weather conditions prevailed, and extreme care to avoid contaminating the samples even as they were obtained, made the project challenging.

Back in the laboratory, the samples were immersed in specially purified water and the hydrocarbons removed by flowing nitrogen gas, to be analyzed later by the methods of gas chromatography, mass spectrometry, or liquid chromatography. The results, cross-checked in triplicate, were believed to be significant at the μg/kg (parts-per-billion) level.[243]

The precautions taken by NOAA and NBS proved prophetic on March 24, 1989, when the *Exxon Valdez,* an oil tanker, struck a reef in Prince William Sound. The largest oil spill in U.S. history resulted; some 10 million gallons of oil were released, with enormous damage to the coastal environment.

### *Oil in the Monongahela*

The collapse of a large oil tank on January 2, 1988, released nearly 1 million gallons of oil into the Monongahela River near Pittsburgh. The tank capacity was 4 million gallons. After nearly 40 years of service elsewhere, it had been re-installed at an Ashland Oil Company storage terminal. As the tank was filled for the first time in its new position, it ruptured.

An NBS team from the Structures Division, including John L. Gross, Felix Y. Yokel, Richard N. Wright, A. Hunter Fanney, John H. Smith, George E. Hicho, and T. Robert Shives, investigated the spill, identifying the cause of failure of the tank.[244] The Bureau work helped the American Petroleum Institute and the Environmental Protection Agency to reduce the probability of such failures in the future.

## Non-Destructive Evaluation

Consumer safety, energy conservation, and industrial productivity were expected to benefit from a new NBS program known as non-destructive evaluation. Initiated as an inexpensive means for quality control in manufacturing, the technique became something of a self-contained specialty as a result of its broad application.

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[243] S. N. Chesler, B. H. Gump, H. S. Hertz, W. E. May, S. M. Dyszel, and D. P. Enagonio, "Trace hydrocarbon analysis: The National Bureau of Standards Prince William Sound/Northeastern Gulf of Alaska baseline study," *NBS Tech. Note 889,* 73 pp., January 1976.

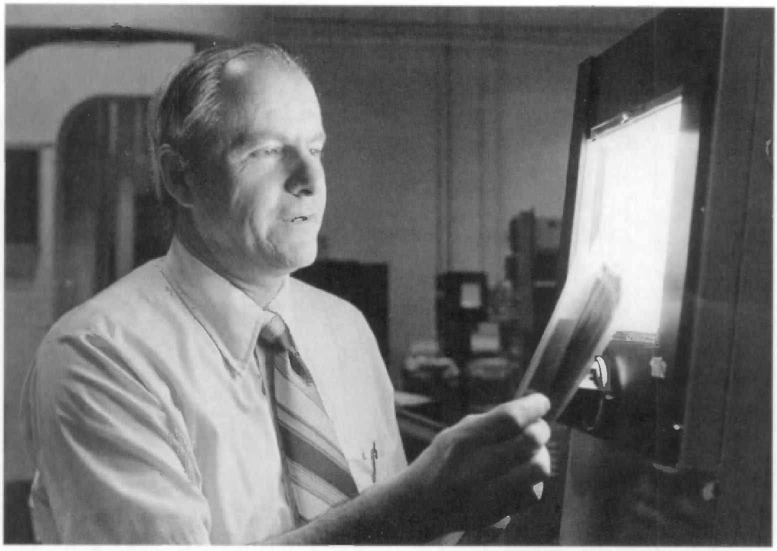
[244] J. L. Gross, F. Y. Yokel, R. N. Wright, A. H. Fanney, J. H. Smith, G. E. Hicho, and T. R. Shives, "Investigation into the Ashland Oil storage tank collapse on January 2, 1988," *NBSIR 88-3792*, June 1988, 202 pp.

Assisting in the Alaskan oil baseline study, NBS chemist Stuart P. Cram dug for samples of marine life in the early morning hours.

A variety of scientific methods found application as NDE techniques, according to Harry Berger, a physicist in the Reactor Radiation Division, who was selected to head the new program. These included ultrasonics, radiography, visual-optical, eddy-current, liquid penetrant, and magnetic particles. Each technique had the advantage that defects could be spotted without causing damage to the object under test; use of NDE methods to examine materials prior to manufacture could save considerable expense in processing costs. Most NDE methods could be used to find service-related failures in products or materials, saving repair costs or preventing failure-related accidents.

A symposium on NDE testing standards, co-sponsored by the Bureau, ASTM, and the American Society for Non-destructive Testing, was held at Gaithersburg on May 19-21, 1976.[245]

[245] H. Berger, "The National Bureau of Standards program in nondestructive evaluation," pp. 317-327 in *American Society for Testing and Materials Special Technical Publication 624, "Nondestructive Testing Standards*—A Review," H. Berger, editor, (Philadelphia: ASTM, June 1977).



Harold Berger inspected neutron radiographs as part of an NBS program to improve measurement methods used in the non-destructive evaluation of materials.

Berger himself offered one of many discussions of non-destructive methods—those used in nuclear science, his specialty.[246] He described gamma ray and neutron sources, as well as the techniques involved in non-destructive studies:

- Neutron and x-radiography.
- Scatter and secondary radiation, using x rays and neutrons.
- Activation analysis with neutrons.
- Radioactive tracers.

### *Testing Prosthetics With Vibration*

Piezoelectric polymers, discussed at some length in the next section, made possible a variety of non-destructive tests on as many types of materials. In the hands of Darrell H. Reneker, Seymour Edelman, Aime S. DeReggi, and David L. Vanderhart, the devices permitted the non-destructive testing of plastic prosthetic materials prior to their implantation. Making use of the high mechanical compliance of the piezoelectric polymers, the group found they could perform vibrational spectroscopy to detect hidden manufacturing flaws in the materials. The method involved synchronization of a mechanical shock to the test material and the computerized recording of the oscillatory

[246] H. Berger, "Nondestructive evaluation: A review of nuclear methods," pp. 427-437 in *22nd International Instrumentation Symposium*, B. Washburn, editor, (Pittsburgh; Instrument Society of America, 1976).

return signal from the piezoelectric transducer. On-line analysis of the return signal to produce Fourier transforms revealed the frequencies and intensities of the normal modes of vibration of the test piece; flawed materials exhibited spectra different from those of perfect samples.[247]

### *Inspecting Objects With Neutrons*

In a cooperative project with the U.S. Navy, the Reactor Research Division used the ability of neutrons to "see" through metal walls into the inner parts of Navy aircraft.

Using the method of neutron radiography, Donald A. Garrett was able to detect corrosion in the aluminum aircraft components with high sensitivity. Using specialized imaging techniques, Garrett found that he could provide visual evidence of the corroded parts on x-ray film. Quantification of the extent of the corrosion appeared possible.[248]

Garrett also was able to respond to a request for more accurate determination of levels of lubricating oil in a special jet engine. Early tests, using x rays, were not encouraging, but Garrett's use of thermal neutrons from the NBS high-flux reactor proved to be just the ticket. Oil levels were imaged by the neutrons using irradiation times as short as ten minutes.

Garrett produced many other images with the neutron radiograph technique as well, examining the quality of high-performance turbine blades, viewing activators for spacecraft solar panels for trouble spots, studying the interior of an ancient Chinese urn, and diagnosing the chemical activity of batteries in use.

### *X-Ray Magnifier*

X-ray images of industrial equipment often provided evidence of cracks, voids, or other imperfections. Frequently, however, it was desirable to magnify the image for more detailed examination. Ordinary photographic enlargement techniques could offer the needed enlargement with satisfactory resolution, but the technique was slow and cumbersome. A method was wanted that offered real-time analytical convenience.

Masao Kuriyama, William J. Boettinger, and Harold E. Burdette provided a solution to the problem—an x-ray magnifier built on the principle of successive diffractions of the x-ray beam from carefully prepared silicon crystals. Their device magnified the test image before it reached the detector.[249]

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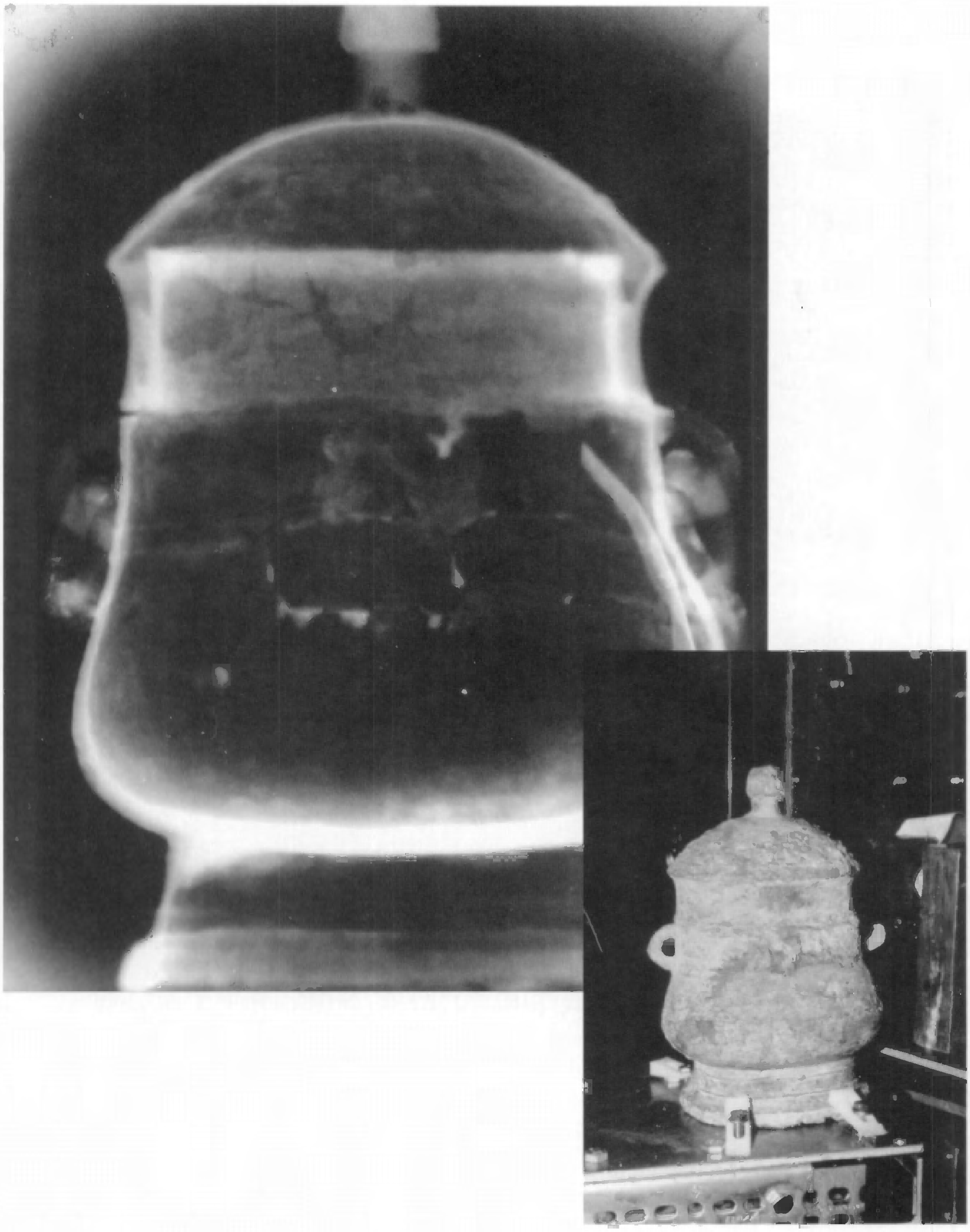
[247] D. H. Reneker, S. Edelman, A. S. DeReggi, and D. L. Vanderhart, "An ndt method using piezoelectric polymer transducers and computerized vibrational spectroscopy" *NDT Intl.*, pp. 15-16 (February 1978).

[248] D. A. Garrett, "The macroscopic detection of corrosion in aluminum aircraft structures with thermal neutron beams and film imaging methods," *NBSIR 78-1434*, December 1977, 42 pp.

[249] W. J. Boettinger, H. E. Burdette, and M. Kuriyama, "X-ray magnifier," *Rev. Sci. Instrum.* **50**, No. 1, 26-30 (1979).



In 1977, NBS researchers demonstrated a way to use neutron radiation in xeroradiography. In a successful application of this new tool for non-destructive evaluation, Bureau scientists analyzed a sealed ancient Chinese lead vessel for the Smithsonian Institution. Neutron radiograph from the collections of the Freer Gallery, Smithsonian Institution. Reprinted courtesy of the Hermitage Foundation Museum, Norfolk, Virginia. The inset shows the vessel waiting to be irradiated.

NBS Metallurgy Division scientist Masao Kuriyama with the x-ray magnifier that he developed. It won Industrial Research and Development magazine's IR-100 award in 1979.

The x-ray magnifier developed by Kuriyama's group improved the resolution of industrial x-ray imaging by a factor of 25, and furthermore could be used as the part was examined.

### *Gentle Tests for Bipolar Transistors*

Semiconductor switches called bipolar power transistors were used to power high-voltage and high-current devices, including such items as automobile ignition systems. Testing the transistors was a chancy enterprise, because of the risk of damage to the units owing to variability in their manufacture. As a result, untested units occasionally failed during use, to the chagrin of the new owner.

Researchers from the Center for Electronics and Electrical Engineering developed a non-destructive test circuit for the bipolar power transistors. The circuit placed a variety of electrical conditions on the transistors while monitoring the voltages in key locations. Any potentially damaging readings caused removal of the power within about 40 ns, before destruction of the device could occur. Use of the test circuit during manufacture gradually decreased the in-service failure rate of the transistors.

## Polymer Science

Studies in polymer science generally include theoretical studies, crystal and structure observations, properties information, and applications. Each of these is represented in the following accounts.

### *Crystal Growth in Polymers*

Fundamental studies in the nucleation and growth of polymers involved a number of scientists in the Polymer Science Division, as well as colleagues elsewhere.

Janice Breedon Jones and P. H. Geil, a visitor from Case Western Reserve University, experimented with the cracking of polyoxymethylene (POM) single crystals grown on Mylar film. Stretching of the Mylar film stressed the POM crystals to the point of rupture. Jones and Geil examined the areas containing the resulting cracks to gain insight into the mechanisms of deformation in polymeric substances. By the use of electron microscopy, they obtained detailed images of the broken surfaces. In one case they found indications that a very thin surface film might exist, and that it might be so lightly attached that it would slip under the stress of deformation.[250]

John D. Hoffman and G. Thomas Davis presented a model representing the surface of folded-chain polymer single crystals. They hoped to explain the experimental indications of the occasional existence of surface layers that exhibited different properties from the bulk of polymer crystals. Such "amorphous" layers, if present, could account for results such as those reported by Jones and Geil.[251]

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[250] Janice Breedon Jones and P. H. Geil, "Surface films on poly(oxymethylene) single crystals," *J. Res. NBS* **79A**, No. 5, 609-611 (1975).

[251] John D. Hoffman and G. Thomas Davis, "On the origin of the amorphous component in polymer single crystals and the nature of the fold surface," *J. Res. NBS* **79A**, No. 5, 613-617 (1975).

In a long discussion, Hoffman, John I. Lauritzen, Jr., Lois J. Frolen, and Gaylon Ross described the rates of growth of polyethylene crystals. They used the formalism of nucleation constants and observed the crystal growth in terms of the magnitude of undercooling and the molecular weight of particular samples, which spanned the range 3600 to more than 800,000. Particular stress was laid on the influence on crystal growth of the number of surface sites and on the morphology of the resulting crystals.[252]

Frolen and Ross each had served NBS for nearly 25 years by 1975; the two nearly always worked as a team. Ross, formerly a chemist in the U.S. Navy, joined the Bureau's Pure Substances Section in 1951. Frolen first came to the attention of the Bureau as a Westinghouse Science Talent Search winner at about the same time. Thereafter she became a summer-time student employee, assisting Harold F. Stimson in studies of benzoic acid and then joining Ross in the Pure Substances Section; in 1955, she became a full-time Bureau employee. In 1964, the two were transferred to the Polymers Division, where they continued their productive collaboration.

***Polymers—Sensors for Heat and Pressure***

Because of research accomplished at NBS, certain polymers joined single-crystal solids in providing useful electromechanical devices based upon the principle of piezoelectricity. Polymeric piezoelectrics brought advantages in flexibility, low density, toughness, size versatility, and low cost that were lacking in the generally brittle and relatively dense inorganic materials.[253]

The phenomenon of pyroelectricity generally accompanied piezoelectricity in polymers. The co-existence of the two properties presented problems if measurement times allowed the test sample to change temperature during piezoelectric measurements.

A number of Bureau projects featured the use of polymeric piezoelectrics and pyroelectrics, most undertaken by scientists in the Polymers Division, including Martin Broadhurst, Seymour Edelman, G. Thomas Davis, John McKinney, Steven Roth, Fred Mopsik, R. E. Collins, Aime DeReggi, and James Kenney.

One of the devices used in the program was used to monitor heart rates. The similarity of the polymer to human tissue permitted easy application to skin.

Another project involved the testing of piezoelectric polymers as pressure sensors for the U.S. Treasury Department, for use in presses that printed paper money.

Other uses of the devices include detonators, hydrophones for underwater sonar, underground tunneling sensors, and temperature detectors for radiometric instruments.[254]

[252] John D. Hoffman, Lois J. Frolen, Gaylon S. Ross, and John I. Lauritzen, Jr., "On the growth rate of spherulites and axialites from the melt in polyethylene fractions: Regime I and regime II crystallization," *J. Res. NBS* **79A**, No. 6, 671-699 (1975).

[253] S. Edelman, "Piezoelectric and pyroelectric polymer sensors," *Proc. Conf. on Sensor Technology for Battlefield and Physical Security Applications, Fort Belvoir, VA, July 13-15, 1977*, pp. 204-212.

[254] Detailed discussions of piezoelectric polymers can be found in *Dimensions/NBS*, February 1978, pp. 3-9; and *NBS Standard*, March 8, 1978, pp. 4-5.

NBS was sought out by manufacturers and other government agencies for assistance in the use of piezoelectric polymers because it was one of the few laboratories that supported its experimental work with continuing theoretical and analytical studies.[255]

Davis and Broadhurst, for example, developed a theoretical treatment for piezoelectricity and pyroelectricity in polymer electrets; it was based upon a model of molecular dipoles, aligned during the poling procedure and frozen thereafter. Their theory was able to account for experimental results on polyvinylchloride, a glassy polymer.[256]

Spectroscopy involving x ray, infrared, and Raman techniques were commonly used for analysis of the polymeric sensor materials.

### *Durability of High-Density Plastics*

During the early 1980s, John M. Crissman and Freddy A. Khoury began testing the durability of ultra-high-molecular-weight polyethylene. These polymers, with molecular weights as high as 4 million, were used in applications requiring exceptional durability and wear characteristics. Medical prosthetics was one of the most demanding of these applications; the lifetime of medical implants was determined, in the main, by the durability of the materials from which the implants were prepared. Creep, wear, and fatigue in use were the principal causes of failure. In turn, these mechanisms were related to crystallinity, orientation, size of spherulites, molecular weight, and molecular weight distribution.

By 1982, studies of the methods of preparation of the raw polymer powders, establishment of procedures for forming bulk and sheet materials, and elementary characterization of the formed materials were behind the two scientists. Work then focused on measurements of the morphology, density, viscosity, stress-relaxation, and fatigue of the highest-molecular-weight polyethylene. Its density ranged from 0.923 g/cm$^3$ for sheets quenched from the melt to 0.942 g/cm$^3$ for slowly annealed sheets.

As a check on the variability with molecular weight of the critical properties of this class of polymer, Crissman and Khoury prepared and tested sheets with molecular weight only half as large (2 million). The densities were only slightly different.

Both types of polyethylene retained memory of the granular texture of the raw polymer after forming, and both showed good recovery from strains less than those needed to break the materials.

Studies of the properties of the ultra-high-molecular-weight polyethylene polymers continued for some time. They served in a variety of applications that extended well beyond medical implants.

[255] One such study was performed by M. G. Broadhurst, G. T. Davis, S. C. Roth, and R. E. Collins, "Pyroelectricity and charge transport in a copolymer of vinylidene fluoride and tetrafluoroethylene," *Proc. Conf. Electrical Insulation and Dielectric Phenomena, Buck Hill Falls, PA, Oct. 18-21, 1976*, pp. 38-47.

[256] G. T. Davis and M. G. Broadhurst, "Piezoelectricity and pyroelectricity in polar polymers," *Proc. Intl. Symp. on Electrets and Dielectrics, Sao Carlos, Brazil, Sept. 1-6, 1975*, pp. 299-319.

### *Thermodynamic Properties of Macromolecules*

In 1983, Umesh Gaur, Suk-fai Lau, Brent B. Wunderlich, and Bernhard Winderlich, prepared the seventh, eighth, and ninth installments to complete a series of articles on the thermodynamic properties of linear macromolecules. The scientists, members of the Chemistry Department of the Renssalaer Polytechnic Institute, were finishing a project initiated several years previously in collaboration with the NBS Office of Standard Reference Data.

The series was published in the *Journal of Physical and Chemical Reference Data.*[257] A joint publication of the American Chemical Society and the American Physical Society for NBS founded in 1972, the publication provided an outlet for information that was critically reviewed by experts in the many topics treated in its pages. The strength of the Journal papers was the reliability of the information—mainly data, as implied by its name—contained therein. The first editor was David R. Lide; he was followed by Jean W. Gallagher in 1993 and Malcolm W. Chase in 1996.

With the completion of the series, the colleagues of the Polymers Division scientists had tabulated heat capacity data, enthalpies, entropies, melting and other transition temperatures, and a variety of other thermodynamic information for a large group of polymers. Much of the data originated with Bureau work, and the OSRD support made it available in coherent form for a wide audience.

### *Measuring Tiny "Space Beads"*

A measurement problem came to the Bureau from outer space during 1983, as the U.S. space shuttle "Challenger" landed. On board was a packet of several billion polystyrene beads, formed into nearly identical spheres about 10 μm in diameter during Challenger's flight.

The odyssey of the little beads began in a contract between personnel of Marshall Space Flight Center and the Emulsion Polymers Institute of Lehigh University. Lehigh Professor John W. Vanderhoff headed a small group who developed a novel technique for producing beads of approximately the desired size and shape, but found that—on earth—gravity caused the beads to take non-spherical shapes and to vary substantially in size. The National Aeronautics and Space Administration (NASA) was happy to design an apparatus to duplicate bead preparation in space, since NASA would acquire another payload item if the production experiment turned out to be a success. Already in the NASA records were successful production of two sets of smaller beads.

[257] Several papers written by U. Gaur, S. Lau, B. B. Wunderlich, and B. Winderlich appeared in the *Journal of Physical and Chemical Reference Data* **12**, No. 1, (1983):

Gaur, Wunderlich, and Wunderlich, "Heat capacity and other thermodynamic properties of linear macromolecules. VII. Other carbon backbone polymers," pp. 29-63.

Gaur, Lau, Wunderlich, and Wunderlich, "Heat capacity and other thermodynamic properties of linear macromolecules. VIII. Polyesters and polyamides," pp. 65-89.

Gaur, Lau and B. Wunderlich, "Heat capacity and other thermodynamic properties of linear macromolecules. IX. Final group of aromatic and inorganic polymers," pp. 91-108.

Two NASA engineers, Johnny M. Oddo and Jack E. Churchey, built the bead-producing equipment. Challenger astronauts and mission specialists operated the equipment during the April 1983 flight. Then came the "acid test:" deliver the beads to NBS for observation and measurement.

Investigation of the polystyrene beads was placed in the hands of Thomas R. Lettieri of the Mechanical Production Metrology Division by Lee J. Kieffer and Stanley D. Rasberry of the Office of Standard Reference Materials. With Arie W. Hartman, Gary G. Hembree, and Egon Mark, Lettieri found that the beads made in the weightless environment of space were extremely uniform in size and nearly spherical in shape.

The group had several different measurement methods at their disposal to study the beads. Using an optical microscope to view the beads under illumination from a collimated light source, Hartman was able to use a technique called "center distance finding." It utilized the light-refracting property of the tiny spheres to produce points of light; the distance separating two points could yield an average bead diameter. This method resulted in a value of 9.89 μm with a variance of only 0.04 μm.[258]

The new SRM, first space-produced beads to be offered for sale, was given the identification SRM 1960. Hembree, Lettieri, Kieffer, and Hartman shared a 1986 IR-100 award, given by *Research and Development* magazine for new technical products judged most significant.

Eventually, the list of polystyrene beads offered in the SRM program also included sizes of 30 μm (SRM 1961), 1 μm (SRM 1690) and 0.3 μm.

## Physical Science

In this section, we see surface studies, phase relationships, television captioning, gravimetry, aerosol physics, nuclear safeguards, cooled atoms, and cold-neutron research.

### *Surface Physics*

Theodore E. Madey, newly granted the Ph. D. degree in physics from the University of Notre Dame, and John T. Yates, with a fresh Ph. D. degree in chemistry from MIT, both arrived at NBS in 1963 as postdoctoral research associates. Within a year, they learned that they shared an interest in the science of surfaces. Soon they were trying to produce metal surfaces that were really clean and free of adsorbed atoms of any kind, let alone the grease and grime that covered the ordinary surface.

The studies of atomically clean metal surfaces by Madey and Yates led naturally to an interest in catalysis. In a 1977 report, they offered results that showed a high level of catalytic activity for an atomically clean tungsten surface, synthesizing methane

[258] Gail Porter, "New particles for measuring pigments, flour, blood cells," *NBS Research Reports*, October 1984, pp. 16-19.

molecules from hydrogen and carbon monoxide. This work, countering previous negative results for the same type of experiment, demonstrated the value of completely removing adsorbed material from catalytic surfaces.[259]

An effective method of looking closely as adsorbed gases were blasted from metal surfaces was developed by the two scientists. It was an apparatus that performed a procedure they called ESDIAD. ESDIAD offered a new way of looking at surfaces. It was the acronym for *Electron Stimulated Desorption Ion Angular Distributions,* a mouthful that referred to the phenomenon that occurred when an electron beam struck a metallic single crystal covered by adsorbed gas. In one example, oxygen and hydrogen gas atoms were emitted as positive ions from an otherwise clean (100) surface of tungsten. The angular distribution of the ions depended upon the positions which the oxygen and hydrogen atoms occupied with respect to the metal crystal atoms. The ions were detected with an image intensifier and displayed on a fluorescent screen. In other experiments, they were able to identify the way that water molecules bonded to single-crystal ruthenium surfaces.[260]

A National Academy of Sciences panel identified surface science as one of the most fruitful types of study in materials science. Madey and Yates, both staff members of the Physical Chemistry Division, helped make it so. The two scientists received the NBS Samuel W. Stratton Award in 1978 for their work in surface catalysis.

Many Bureau theoretical contributions to surface physics came from J. William Gadzuk, a solid-state theorist trained at MIT. He created models for the processes involved in spectroscopic measurements at surfaces, in the dynamic response to external perturbations of many-body systems, and in the dynamics of atomic and molecular reactions.

Gadzuk joined NBS in 1968 and immediately began to collaborate with E. Ward Plummer and Russell D. Young on electron tunneling to metal surfaces (see Ch. 3 Section on the Topografiner). His grasp of theoretical ideas helped make the group unusually productive in the physics of tunneling into clean metallic surfaces and through adsorbed atoms and molecules.[261] One brief paper, entitled "Resonance tunneling of field emitted electrons through adsorbates on metal surfaces,"[262] was the first report in which the electronic energy levels of atoms adsorbed on metal surfaces were observed experimentally and interpreted theoretically. By itself, it provided guidance

[259] R. D. Kelley, T. E. Madey, and J. T. Yates, Jr., "Activity of tungsten as a methanation catalyst," *J. Catal.* **50**, 301-305 (1977).

[260] T. E. Madey and J. T. Yates, Jr., "Evidence for the conformation of $H_2O$ adsorbed on Ru(001)," *Chem. Phys. Lett.* **51**, No. 1, 77-83 (1977).

[261] See, for example, J. W. Gadzuk, "Resonance-tunneling spectroscopy of atoms adsorbed on metal surfaces: theory," *Phys. Rev.* **B1**, No. 5, 2110-2129 (1970); E. W. Plummer and J. W. Gadzuk, "Surface states on tungsten," *Phys. Rev. Lett.* **25**, No. 21, 1493-1495 (1970); J. W. Gadzuk and E. W. Plummer, "Hot-hole—electron cascades in field emission from metals," *Phys. Rev. Lett.* **26**, No. 2, 92-95 (1971).

[262] E. W. Plummer, J. W. Gadzuk, and R. D. Young, "Resonance tunneling of field emitted electrons through adsorbates on metal surfaces," *Solid State Comm.* **7**, 487-491 (1969).

for later work on electron-energy-level spectroscopy of adsorbed species. A collaboration between Gadzuk and Plummer produced a lengthy review of the physics underlying the measurement of the energy distribution of field-emitted electrons.[263]

Gadzuk's theoretical studies at NBS/NIST continued apace for three decades, reaching into the areas of angle-resolved photoemission spectroscopy, core-level and vibrational spectroscopy, dynamics and chaos in surface processes, surface interactions at sub-picosecond time intervals (femtochemistry), and solid state tunneling.

Numerous honors came to Gadzuk for the quality and quantity of his work at NBS. He received the Arthur S. Flemming Award as one of the ten outstanding Federal employees of 1978. The award was given for Gadzuk's theoretical work on surface physics. Also in 1978, Gadzuk was awarded a guest professorship by the Nordic Institute of Theoretical Atomic Physics in Copenhagen. Gadzuk took advantage of the grant mainly for study at the Institute for Theoretical Physics in the Chalmers University in Sweden. The award provided for visits to the institute for two to three weeks at a time, several times each year.

### *A "Renaissance" Scientist Comes to NBS*

During 1977, John W. Cahn joined the NBS Center for Materials Science. A veteran of service as theorist to the General Electric Company and as professor of materials science at MIT, Cahn quickly became known at NBS for the depth and diversity of his knowledge of materials.

Already well-known for his work on the thermodynamic limits to phase stability, Cahn soon published discussions of interphase boundaries near the critical point of two-phase fluids[264] and antiphase boundary motion in alloys.[265]

By 1980, Cahn was heavily involved in materials research with NBS colleagues, including Michael R. Moldover, William J. Boettinger, Samuel R. Coriell, Gretchen L. Kalonji, and Frank S. Biancaniello.[266] One of these projects was a study of rapid solidification phenomena. By dropping the temperature of molten materials at rates of $10^4$ K/s or greater, scientists could produce microstructures of unusual compositional uniformity and high levels of supersaturation; in addition, metastable phases could be

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[263] J. W. Gadzuk and E. W. Plummer, "Field emission energy distribution (FEED)," *Revs. Mod. Phys.* **45**, No. 3, 487-548 (1973).

[264] J. W. Cahn, "Critical point wetting," *J. Chem. Phys.* **66**, 3667-3672 (1977).

[265] S. M. Allen and J. W. Cahn, "A microscopic theory for antiphase boundary motion and its application to antiphase domain coarsening," *Acta Metallurgica* **27**, 1085-1095 (1979).

[266] M. R. Moldover and J. W. Cahn, "An interface phase transition: complete to partial wetting," *Science* **207**, 1073 (1980). J. W. Cahn, W. J. Boettinger, and S. R. Coriell, "Rapid solidification," paper in *Laser and Electron Beam Processing of Materials,* C. W. White and P. S. Peercy, editors, (New York: Academic Press, 1980), p. 89. W. J. Boettinger, F. S. Biancaniello, G. M. Kalonji, and J. W. Cahn, "Eutectic Solidification and the formation of metallic glasses," *Proc. Second Intnl. Conf. on Rapid Solidification Processing: Principles and Technologies,* R. Mehrabian, B. H. Kear, and M. Cohen, editors (Baton Rouge: Claitor's Publishing Division, 1980), p. 50.

obtained, yielding materials with unexpected properties. In some cases, such as diamond, the natural conversion to the stable, equilibrium state (in the case of diamond, graphite) occurred at an immeasurably slow pace.[267]

A paper written in 1984 with colleagues from Israel and France attracted unusual attention even for Cahn, who, by that time, possessed honors and awards from many parts of the globe for his scientific research. The new communication described a startling discovery; "quasicrystals," a metastable phase with icosahedral symmetry but the sharp x-ray diffraction patterns characteristic of crystals.[268] One of the characteristics of icosahedral symmetry was its inconsistency with lattice "translations." The new materials were formed by the rapid solidification of alloys containing 10 atomic percent to 14 atomic percent of manganese, iron, or chromium in aluminum. The publication sparked a furor in crystallography and the study of metastable materials.

Among the many awards earned by Cahn during his service to NBS were the Department of Commerce Gold Medal in 1984 and the NBS Stratton Award in 1986. In 1998, he was awarded the National Medal of Science by President William J. Clinton; it was the nation's highest scientific honor.

### *An "Emmy" For NBS*

"Emmy" awards, given for outstanding contributions to television by the Academy of Television Arts and Sciences, did not usually go to NBS—in fact, the Bureau never had received the prize until 1980. However, Dicky Davis accepted an Emmy on September 6, 1980. It was jointly awarded to NBS, to the Public Broadcasting Service, and to the American Broadcasting Company for the development of closed captioning for the deaf.

Closed captions were broadcast along with regular programs, but decoded only with the use of specialized equipment. Viewers with hearing defects could use the decoders to "see" the dialog accompanying the program.

The closed-caption technique originated with a system called TvTime, developed by Davis, James Jesperson, and George Kamas in 1971 as a means of disseminating time and frequency information to a large audience.[269] NBS collaborated with ABC to broaden the concept to include program dialog, and prepared decoding devices for the use of PBS. During 1979, three major networks, ABC, NBC, and PBS initiated regular broadcasts of captioned programs.

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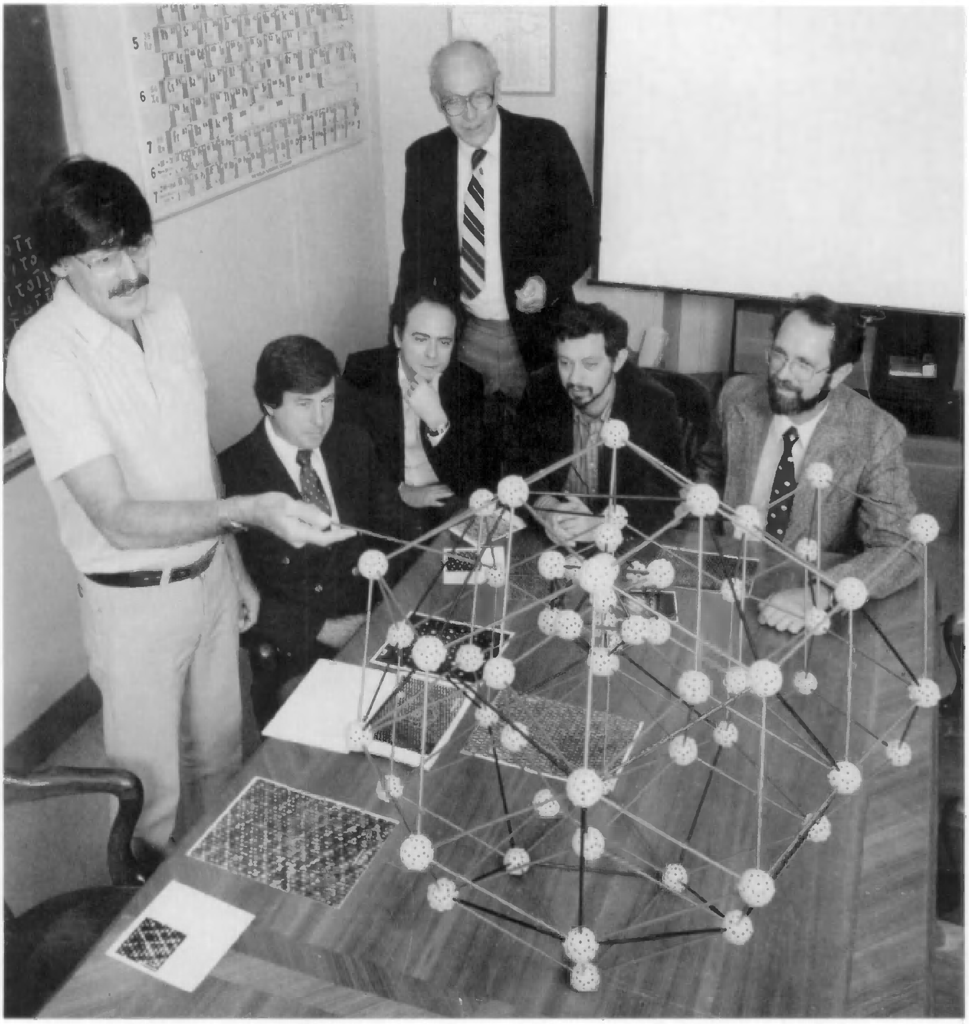
[267] See for example John W. Cahn and Denis Gratias, "Quasi-periodic crystals: a revolution in crystallography," chapter in *Advancing Materials Research,* Peter A. Psaras and H. Dale Langford, editors, (Washington, DC: National Academy Press, 1987) p. 157.

[268] D. Shechtman, I. Blech, D. Gratias, and J. W. Cahn, "Metallic phase with long-range orientational order and no translational symmetry," *Phys. Rev. Lett.* **53**, 1951-1953 (1984).

[269] See Ch. 2 for a brief description of the process. Details also are given in *NBS Standard* **25**, No. 19, p. 1.



A team of NIST scientists and visiting researchers led by John W. Cahn discussed quasicrystal structures in alloys. From left to right were Dan Shechtman of the Israel Institute of Technology, Frank S. Biancaniello of NIST, Denis Gratias of the National Science Research Center in France, John W. Cahn of NIST, Leonid A. Bendersky of Johns Hopkins University, and Robert J. Schaefer of NIST.

### *A Super Spring for a Super Gravimeter*

The isolation of experiments sensitive to very slight mechanical disturbances was a problem from the beginning of science. The use of heavy tables, for example for optical spectroscopy and laser work, reduced the response to all but building and earth vibrations. The addition of mechanical or pneumatic springs to a massive support further isolated sensitive equipment from all vibrations of frequency higher than the natural resonance frequency of the mass-spring system. But there the problem lay until James E. Faller and Robert L. Rinker of JILA took it up in the mid-1970s.

Faller and Rinker, eventually accompanied by a succession of colleagues including William A. Koldewyn, wished to measure the rise and fall of the earth's surface with a portable device in order to better understand the science of tectonics. The desire included a price. They needed an absolute means of measuring the acceleration due to gravity, previously measured at NBS by others, including Paul R. Heyl.[270] They devised an instrument—a gravimeter—based upon the notion of free-fall of a mass. It contained a drag-free, free-fall chamber; a stabilized laser; and suitable timing electronics. The trouble was that, in order to effectively isolate the instrument from the earth's natural microseismic vibrations using the mass-plus-spring technique, a spring about 1 kilometer in length would be necessary.

Faller and Rinker tackled the problem by designing a servo system to move the upper support for a 30 cm spring closely in rhythm with the experiment dangling from the spring. In this fashion the effective length of the support spring could be forced to respond as if it were as long as tens of kilometers!

By 1982 the gravimeter had been completed and tested. Results indicated its measurement uncertainty to be no more than 6 parts in $10^9$, providing an equivalent height sensitivity of about 2 cm.[271] Faller and two of his colleagues spent some time making measurements in California, New Mexico, Colorado, Wyoming, Maryland, and Massachusetts. The measurement accuracy indicated by the results: about 3 cm.[272]

### *Identifying Molecular Impurities*

During 1977, Edgar S. Etz and Gregory J. Rosasco reported the development of a new analytical tool, a laser-excited Raman microprobe that could be used to identify a variety of impurities, even those present only in tiny (micro-meter) particles.

Significant in use of the new microprobe for the identification of chemical species was a discovery by the two spectroscopists in collaboration with Wayne A. Cassatt[273] that the spectra produced by very small particles were analytically identical to those from macroscopic particles of the same composition. This discovery made it possible for them to use the Raman technique for fine aerosols, often necessary for air-pollution studies.

[270] P. R. Heyl, "A redetermination of the constant of gravitation," *J. Res. NBS* **5**, 1243 (1930).

[271] J. E. Faller, Y. G. Guo, and M. A. Zumberge, "Determination of absolute gravity," *Proc. Amer. Soc. of Photogrammetry, Amer. Cong. on Surveying and Mapping, Denver, Co*, Mar. 14-20. 1982, pp. 63-74.

[272] M. A. Zumberge, J. E. Faller, and J. Geschwind, "Results from an absolute gravity survey in the United States," *J. Geophys. Res.* **88**, No. B9, 7495-7502 (1983).

[273] G. J. Rosasco, E. S. Etz, and W. A. Cassatt, *Appl. Spectrosc.* **29**, 396 (1975).

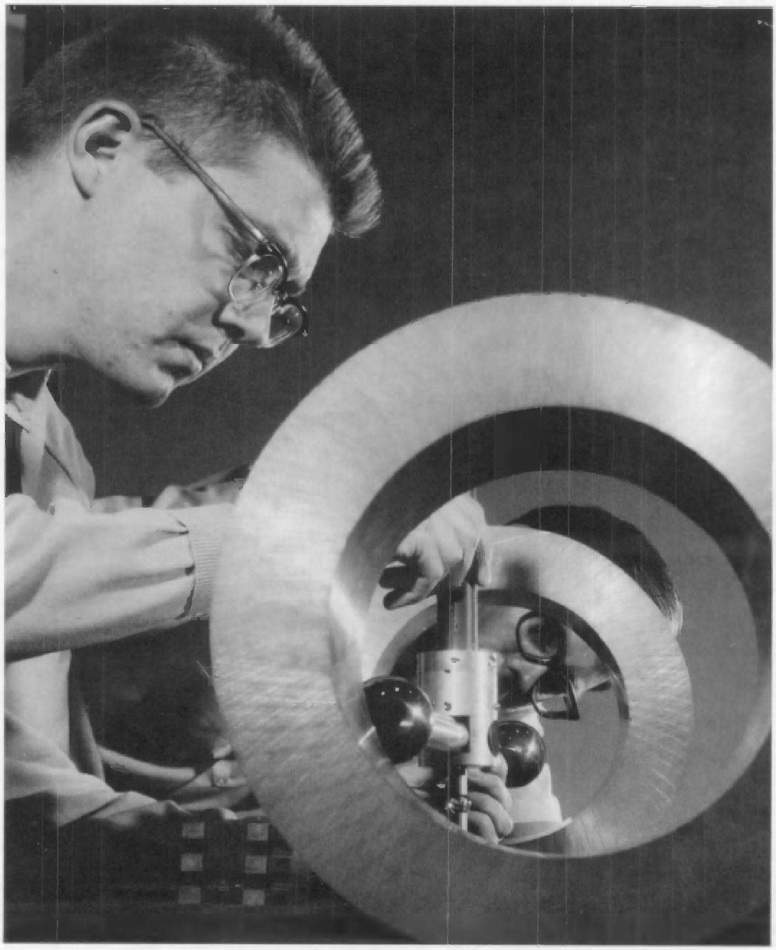
In 1930 and again in 1942, NBS physicist Paul R. Heyl redetermined the Newtonian constant of gravitation.

The Raman microprobe used an argon-krypton ion laser to irradiate the test samples in a carefully prepared irradiation chamber. A mechanism composed of a differential micrometer and a piezoelectric translator was employed to move the sample substrate in order to focus the irradiating beam on the chosen particle. A double monochromator provided the Raman-scattering spectrum for detection by a photomultiplier tube.[274]

Rosasco and Etz were able to balance inherent experimental conflicts: between maximizing beam power and minimizing sample damage from the beam; and between supporting the test sample in a rigid manner and avoiding intense background radiation from the substrate. The pair chose sapphire as the substrate material, taking advantage of its relatively weak Raman activity.

The versatility of the Raman microprobe was demonstrated by the observation of particles of thorium oxide, ammonium sulfate, "urban dust" (identified through its spectrum as calcium sulfate), cholesterol, and polyvinyl chloride. The new instrument became a potent tool for analytical chemists.

[274] G. J. Rosasco and E. S. Etz, "The Raman microprobe: a new analytical tool," *Research/Development* **28**, (June issue) pp. 20-35 (1977).

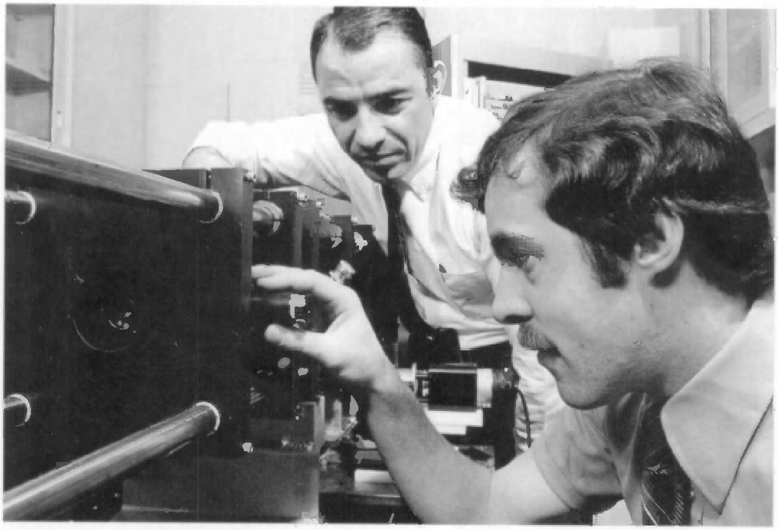


In 1977, James E. Faller (right) and William A. Koldewyn of the Joint Institute for Laboratory Astrophysics conducted an experiment to measure the acceleration due to gravitation even more precisely than Heyl did.

### *Measurements for Nuclear Materials*

Late in 1979, the NBS Office of Measurements for Nuclear Technology and the Institute of Nuclear Materials Management co-sponsored a conference on measurements for nuclear safeguards and control of nuclear materials. The 4-day meeting featured more than 60 papers on measurement methods, inventory techniques, assay of reactor materials, and management systems designed to keep nuclear materials safely. The proceedings were edited by T. R. Canada and by B. Stephen Carpenter of the NBS Reactor Radiation Division.[275]

[275] "Measurement technology for safeguards and materials control," T. R. Canada and B. S. Carpenter, editors, *NBS Special Publication 582*, 769 pp., June 1980.



Edgar S. Etz watched as Gregory J. Rosasco adjusted the eyepiece of a laser-excited Raman spectrometer that the two scientists developed to identify the composition of tiny particles.

Among the topics discussed during the conference by Bureau authors were the following:

- Role of NBS Standard Reference Materials in measurement accuracy, by William P. Reed.
- Mass-spectrometric determination of the half-life of $^{241}$Pu, by Ernest L. Garner and Lawrence A. Machlan.
- Resonance neutron radiography measurements for safeguards, by Roald A. Schrack, James W. Behrens, Charles D. Bowman, and Allan D. Carlson.
- Reactor track-etch power monitor, by B. Stephen Carpenter, Ivan G. Schroder, Lawrence J. Pilione, J. W. Roe, and S. Santani.
- In situ density of solutions, by Frank E. Jones, Randall M. Schoonover, and John F. Houser.

***Sharper Lines from Cooler Atoms***

By the early 1980s one of the principal impediments to improved resolution in high-precision spectroscopy and to improved frequency standards was the fuzziness of spectral lines incurred because of the thermal motion of the participating atoms. The Doppler effect—the increase or decrease of observed line frequency caused by motion of the atom towards or away from the observer—was an inevitable consequence of the temperature of the experimental species.

Two groups of NBS scientists attempted to minimize the Doppler effect by trapping ions or atoms in ingenious "cages" and reducing their velocities—and thus their temperatures—by various means.

An ion-storage group, working in the NBS/Boulder laboratories, numbered among its collaborators Robert E. Drullinger, Fred L. Walls, John J. Bollinger, Wayne M. Itano, Joseph S. Wells, James C. Bergquist, H. Hemmati, and R. G. Hulet. Leader of the group was David J. Wineland, a Harvard-trained physicist who joined NBS in 1975. One of the first successes of Wineland's group was the cooling of doubly ionized magnesium ions below 40 K during 1978. The ions were confined in an electromagnetic Penning trap, then irradiated with a dye laser tuned for resonant photon capture to slow their motion. Theirs was the first such observation.[276]

Wineland's group made spectacular progress during the next several years in their efforts to create a new frequency standard based on laser-cooled ions. By 1991, they had demonstrated a frequency standard using cooled beryllium ions, with a level of reproducibility comparable to that achievable with NBS-6, the then-current national frequency standard (8 parts in $10^{14}$).[277]

Finding that mercury ions were less susceptible to certain types of frequency shift than beryllium ions, the Boulder group explored a new area. They were able to cool mercury ions to the point where they existed 99 % of the time in the $n = 1/2$ state, creating a quantized-harmonic-oscillator system. This advance allowed resulted in a new frequency standard at 40 GHz with a reproducibility of one part in $10^{16}$—superior to that of NIST-7, the present national frequency standard.[278]

Joining NBS in 1978 was William D. Phillips, recently awarded the Ph. D degree in physics by MIT. Despite the spartan atmosphere at NBS dictated by presidential economies, Phillips was hired for his great promise in the fields of fundamental constants, atomic physics, and electrical standards.[279]

By 1983, Phillips and Harold Metcalf, a visiting scientist from the University of New York at Stony Brook, had assembled in Gaithersburg an experiment that demonstrated the use of counter-propagating resonant laser beams to decelerate neutral sodium atoms to about 40 % of their thermal velocities. A 500 °C oven produced a continuous collimated beam of sodium atoms directed along a decreasing magnetic

[276] D. J. Wineland, R. E. Drullinger, and F. L. Walls, "Radiation-pressure cooling of bound resonant absorbers," *Phys. Rev. Lett.* **40**, No. 25, 1639-1642 (1978).

[277] J. C. Bollinger, D. J. Heinzen, W. M. Itano, S. L. Gilbert, and D. J. Wineland, "A 303 MHz frequency standard based on trapped beryllium ions," *IEEE Trans.* **IM-40**, pp. 126-128 (1991).

[278] D. J. Berkeland, J. D. Miller, J. C. Bergquist, W. M. Itano, and D. J. Wineland, "A laser-cooled mercury ion frequency standard," *Phys. Rev. Lett.* **80**, pp. 2089-2092 (1998).

[279] Barry N. Taylor, Memo to Emanuel Horowitz, Deputy Director, National Measurement Laboratory, May 15, 1978. Subject; "Dr. William Phillips: Target of Opportunity." Taylor noted that Phillips, an outstanding young scientist, had an interest in NBS and enthusiasm for imaginative and careful measurements.

field. The changing Zeeman effect on the atomic levels of the sodium atoms tended to bunch atoms of like velocity-distribution as they met the oncoming laser beam. Despite some tricky problems with optical pumping of the atoms by the laser beam, deceleration was clearly demonstrated.[280] Within months, Phillips, John V. Prodan, and Metcalf had reduced the equivalent temperature of a neutral sodium beam to about 70 mK, only 4 % of its initial velocity.

In April 1983, a 2-day workshop was held at the NBS Gaithersburg laboratory on slow atomic beams. Some 20 participants presented papers on the methods and applications of cooled atoms. Both Wineland and his group and Phillips and his co-workers exhibited their latest results.[281]

The laser-cooling work continued with greater and greater success. By 1985, the Gaithersburg group learned how to build a magnetic trap to confine the neutral atoms for about a second so that measurements of their properties could be performed.[282] By 1988, the level of cooling reached 40 μK, far below the equivalent temperature limit supposed possible in then-current theories.

For participating in the development of experiments that opened a new field of study, Wineland, Bergquist, Bollinger, and Itano received the Department of Commerce Gold Medal in 1985. The same group shared the 1989 Stratton Award. In 1990, Wineland received the Davisson-Germer Prize of the American Physical Society and the William F. Meggers Award of the Optical Society of America. He was elected a member of the National Academy of Sciences in 1992.

For his part in leading the way to the use of lasers to cool and trap atoms, Phillips—by then a NIST fellow—was elected to the National Academy of Science in April 1997. Later that year, Phillips and two of his colleagues, Steven Chu of Stanford University and Claude Cohen-Tannoudji of the Ecole Normale Superieure of Paris, shared the 1997 Nobel Prize in physics. It was the first Nobel Prize for an NBS/NIST employee.

### *Cold Neutrons for Science*

On January 12, 1989, a *Cold Neutron Research Facility* was dedicated at NIST. It was the first such facility in America dedicated entirely to research. Before the new NIST facility opened, Bureau scientists performed cold-neutron experiments

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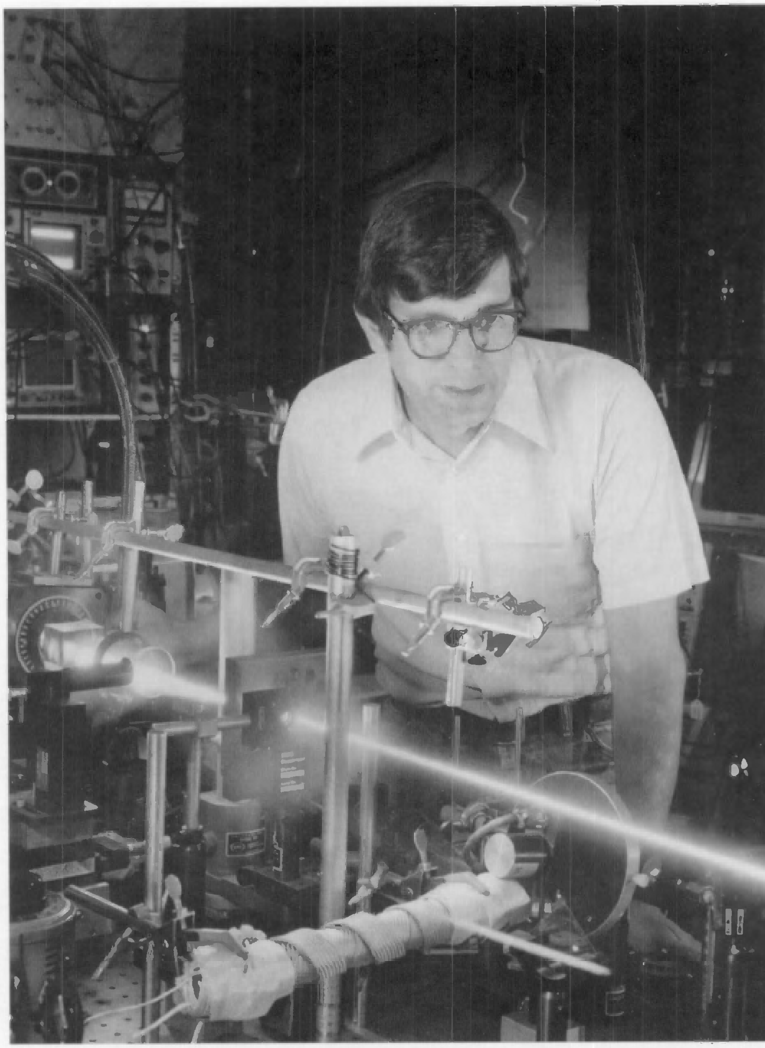
[280] William D. Phillips and Harold Metcalf, "Laser deceleration of an atomic beam," *Phys. Rev. Lett.* **48**, No. 9, 596-599 (1982).

[281] "Laser-cooled and trapped atoms," *NBS Special Publication 653*, W. D. Phillips, editor, June 1983, 172 pp. Papers included the following: pp. 1-8, W. D. Phillips, J. V. Prodan, and H. Metcalf, "Neutral atomic beam cooling experiments at NBS"; pp. 19-26, D. J. Wineland, W. M. Itano, J. C. Bergquist, J. J. Bollinger, and H. Hemmati, "Frequency standard research using stored ions"; pp. 137-141, J. V. Prodan and W. D. Phillips, "Chirping the light—fantastic? Recent NBS atom cooling experiments"; and pp. 142-153, R. Blatt, W. Ertmer, and J. L. Hall, "Cooling of an atomic beam with frequency-sweep techniques."

[282] A. L. Migdall, J. V. Prodan, W. D. Phillips, T. H. Bergeman, and H. J. Metcalf, "First observation of magnetically trapped neutral atoms," *Phys. Rev. Lett.* **54**, No. 24, 2596-2599 (1985).



NBS/NIST atomic physicist and Nobel Prize winner William D. Phillips with his laser cooling and trapping apparatus circa 1988.

wherever they could.[283] Cold neutrons, produced by a block of $D_2O$ ice held in the temperature range 30 K to 40 K by re-circulating helium gas, served some 15 experimental stations in the NIST research reactor by the time the installation was

[283] See, for example, R. M. Lindstrom, R. Zeisler, and M. Rossbach, "Activation analysis opportunities using cold neutron beams," *J. Radioanalytical and Nuclear Chem.* **112**, No. 2, 321-330 (1987).

fully completed in 1993.[284] The new facility incorporated a *Small Angle Neutron Scattering* capability, a depth profiling instrument, prompt-gamma-ray activation analysis, and a variety of other instrumentation designed to take advantage of the greatly reduced thermal energy of the cold-neutron beam. J. Michael Rowe was designated as the NIST contact for the new facility.

### *New Radius for the Carbon Nucleus*

A group of radiation physicists including Lawrence S. Cardman, John W. Lightbody, Jr., Samuel Penner, Sherman P. Fivozinsky, and Xavier K. Maruyama of NBS and their colleagues W. P. Trower of Virginia Polytechnic Institute and S. E. Williamson of the University of Illinois used the Bureau linear electron accelerator to measure the elastic electron scattering cross-section from $^{12}C$ atoms. Analysis of the new data along with the results of an earlier experiment involving lower momentum transfer allowed them to determine the shape of the ground-state charge distribution and the charge radius with substantially improved accuracy. The new value of the charge radius of the carbon nucleus was determined with an uncertainty estimated at 0.6 %.[285]

### *New Classifications for Critical Data*

Writing in the journal *Science* during 1981, David R. Lide, Jr., chief of the NBS Office of Standard Reference Data (OSRD), called attention to the avalanche of scientific data that by then was overwhelming the technical literature and suggested that there was a way to ease the increasingly tedious search for needed information.[286]

The solution to the scientific "information explosion," in Lide's view, was the omnipresent computer, itself source of much of the information flow. The development of computer-based bibliographic files that could be searched from remote terminals greatly increased access to documents for multitudes of researchers and technical workers. A second stage in bringing information directly to its users, Lide suggested, might be the provision of actual data on demand.

Providing data directly to those who needed the information carried certain risks, however. In many cases, the quality of the data was as important to the user as the actual numbers involved—and quality control in the production of scientific data was non-uniform at best.

Lide noted that even a vocabulary for information concepts was lacking in many areas—for example, the word "data" was used both to refer to documents and to numerical files of values.

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[284] A. Arif, R. D. Deslattes, M. S. Dewey, G. L. Greene, and I. G. Schroder, "Facilities for fundamental physics research at the NIST Cold Neutron Facility," *Nuclear Instruments and Methods in Physics Research* **A284**, 216-219 (1989).

[285] L. S. Cardman, J. W. Lightbody, Jr., S. Penner, S. P. Fivozinsky, X. K. Maruyama, W. P. Trower, and S. E. Williamson, "The charge distribution of $^{12}C$," *Phys. Lett.* **91B**, No. 2, 203-206 (1980).

[286] David R. Lide, Jr. , Critical data for critical needs," *Science* **212**, June 19, 1981, pp. 1343-1349.

The classification of scientific data was addressed by the International Council of Scientific Unions as early as 1975. Through its Committee on data for Science and Technology, the Council provided a detailed scheme that recognized three broad classes of data:

- Repeatable measurements on well-defined systems. These data constituted much of the traditional output of experiments in physics and chemistry laboratories.
- Observational data, in which any values quoted depended on transient conditions that, in general, prevented checking by remeasurement.
- Statistical data on such subjects as demographics, materials production, health, and energy use.

Each of the classes of data were necessary for particular individuals in the pursuit of their goals, noted Lide, although the efforts of the OSRD lay principally in improving the quality of the information contained in the first-named class.

Lide reviewed computer-based methods still under development to improve the dissemination of information—methods that finessed the increasingly large costs of printing handbooks and journals. These included electronic data bases on interactive computer networks, use of magnetic tapes and other computer-compatible storage media, and on-line data-retrieval services.

### *Optical Fibers and the Information Age*

What properties should optical fibers possess, and why would anyone particularly want optical fibers? As this history was written, the question sounded silly, given the intense effort today to stretch optical fibers around the world to speed communications. In the mid 1970s, however, few people understood the potential impact of optical fiber communications on telephone networks. Still fewer imagined the Internet, or other magic now worked by computer links.

It seems surprising, therefore, that the first significant proposal for telecommunications over fiber networks was published as long ago as 1966. And that two key advances—the reduction of attenuation of radiation below 20 dB/km in fibers, and the development of cw semiconductor lasers capable of room-temperature operation—occurred in 1970.

Fortunately for NBS, Harold S. Boyne, then chief of the Electromagnetics Division in Boulder, had friends in the telecommunications industry who helped him understand the potential benefits of optical communications:

- Far greater carrying capacity for information than copper wire.
- Better signal-to-noise properties than copper wire.
- Longer distances between repeater stations than copper wire.
- Effectively free of interference.

In the fall of 1975, Boyne took a member of his staff to the First European Conference on Optical Communications, held in London. There they heard researchers from the British Telecom Research Laboratories and elsewhere advocate the immediate deployment of optical fibers in the telephone networks, though only laboratory experiments had been conducted at that time.

A year later, Boyne called Douglas Franzen, Bruce Danielson, and Gordon Day to his office. Boyne told the trio to begin work on optical fibers.

> "What kind of work should we do?" they asked.
> "That's for you to find out," Boyne replied.
> Thus began NBS work on optical communications.

It soon became apparent to the three scientists that one could buy similarly-specified fiber from two different manufacturers and receive two very different products. The attenuation of an optical fiber produced in that era was in the range of several dB/km (two decades later, the best value was about 0.2 dB/km). The group showed by interlaboratory comparisons that the uncertainty of measurements among the various manufacturers was at best $\pm 1$ dB. They demonstrated in the laboratory that it was possible to make more accurate measurements and they worked with standards groups, especially the Electronics Industry Association and the Telecommunications Industry Association, to help them develop standard measurement procedures.

There were similar problems to be solved for bandwidth measurements and many other fiber parameters. By 1980, the group had doubled in size, adding Robert Gallawa, George Chamberlain, and Matt Young.

In 1980, Franzen and Day initiated a biennial *Symposium on Optical Fiber Measurements*. It still provides a principal forum for reporting the results of research on optical fiber characterization.

The pattern of organizing interlaboratory comparisons to quantify measurement problems, working in the laboratory to understand measurement techniques, and collaborating with standards groups to develop standard procedures became a familiar one. As more instrumentation became available commercially, the work shifted toward the development of artifact standards—Standard Reference Materials—to serve as calibration references for the commercial devices.

The effectiveness of the NBS/NIST group was recognized by a large group of colleagues. The President of the Telecommunications Industry Association wrote, "Without the NIST assistance and leadership, the U.S. fiber optics industry would not be in the competitive position it enjoys today." The Department of Commerce, too, recognized the high quality of the group's effort with Bronze, Silver, and Gold Medal Awards.

### Electronics and Electrical Engineering

Examples of contributions in the areas of electronics and electrical engineering include a new automated test facility, methods for flaw detection in integrated circuit manufacture, solar-cell materials, the evaluation of an interesting new device, and the measurement of contact resistance.

### *Automated Test Facility for A/D Converters*

During this period, the static transfer characteristics of high-performance converters for analog-to-digital and digital-to-analog signals were evaluated automatically by a new test set developed by T. Michael Souders and Donald R. Flach. The new facility provided measurements of gain, offset, linearity, and equivalent input noise with an uncertainty not exceeding 4 ppm. Up to 40 readings per second could be performed without degrading the instrumental accuracy. The two scientists used a 20-bit digital-to-analog converter as a comparison standard.[287]

### *Quick Checks of Integrated Circuits*

One problem that bedeviled manufacturers of integrated circuits during the late 1970s and early 1980s was circuit failure brought on by defects in manufacture. Tiny flaws in the semiconductor materials could result in equally small leakage currents, impairing the performance of the circuit. But these flaws were difficult to spot without extensive—and therefore, expensive—testing.

Center for Electronics and Electrical Engineering researchers Gary Carver and Martin G. Buehler attacked the problem by devising an integrated gated-diode electrometer that could be included in the manufacture of each semiconductor wafer. A tiny amplifier in the electrometer magnified any leakage currents and indicators of certain other quality defects, allowing the manufacturer to monitor the wafer by computer during processing. Wafers showing any indication of defects could be removed from the system. The electrometer also was used to monitor the fabrication and performance of charge-coupled detectors.[288]

Physicist David E. Sawyer and engineer David W. Berning of the Electronic Technology Division developed an instrument to test semiconductor devices. Called a "Flying Spot Scanner," the instrument could be used to map dc and high-frequency gains in transistors, reveal areas where non-linearities occurred, and detect the presence of "hot spots," all these in a non-destructive manner.[289]

The new apparatus was chosen for an IR-100 award in 1976.

### *Solar Cell Workshop*

Eighteen papers were presented at a 1979 workshop co-sponsored by the Bureau and by the Department of Energy on the stability of thin-film solar cells. Data pertained to all the major materials used in the cells. The papers discussed subjects ranging over the economics of solar cells, the reliability of various cells, materials problems, and measurement problems.

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[287] T. M. Souders and D. R. Flach, "An automated test set for high resolution analog-to-digital and digital-to-analog converters," *IEEE Trans. Instrum. Meas.* **28**, No. 4, 239-244 (1979).

[288] G. P. Carver and M. G. Buehler, "The development of test structures for characterization of the fabrication and performance of radiation-hardened CCD imagers," *NBSIR 79-1744*, May 1979, 54 pp.

[289] For a synopsis of the scanner, see *Dimensions/NBS*, November 1976, pp. 17-18.

David W. Berning (left), an electronics engineer, and David E. Sawyer, a physicist, of the NBS Electronic Technology Division, operated the laser flying-spot scanner they developed for testing semiconductor devices.

The workshop proceedings were published in the *NBS Special Publication 400* series entitled "Semiconductor measurement technology" and edited by David E. Sawyer and Harry A. Schafft.[290]

### *Evaluating an "Energy-Producing" Device*

One of the "hot potatoes" that arrived on the doorstep of the Center for Electronics and Electrical Engineering (CEEE) during the tenure of Ernest Ambler concerned the never-ending search for free power. One Joseph Newman had proffered a device which he claimed produced more power than it used. Neither the NBS Office of Energy-Related Inventions nor the U.S. Patent Office gave the device a second glance, since very basic laws of physics denied Mr. Newman even the possibility of success.

Mr. Newman held the opinion that his device should get a fair test, and said so in U.S. District Court. The judge in the case ruled that Mr. Newman had been denied due process, and he ordered that a technical review of the device be conducted forthwith. Patent Office officials negotiated with NBS officials, and responsibility for conducting the technical review fell upon Robert E. Hebner of the NBS Electrosystems Division of the Center for Electronics and Electrical Engineering.

[290] "Semiconductor measurement technology: NBS/DOE workshop, stability of (thin film) solar cells and materials," D. E. Sawyer and H. A. Schafft, editors, *NBS Special Publication 400-58*, August 1979, 181 pp.

For about 6 months during 1986, the Newman device resided at NBS. It was kept in a locked compartment throughout the examination except when it was actually under test. The District Court had ordered the production of a formal report on the test, with clear identification of the testing personnel and their credentials, full descriptions of the device, the NBS test equipment and procedures, and test results. More than one Bureau employee remembered the AD-X2 battery case and hoped for an early and satisfactory completion for the task.

The actual testing, done by Hebner, Gerard N. Stenbakken, and David L. Hillhouse, took some ingenuity. The machine contained a large coil of wire, a rotating permanent magnet, and a commutator that periodically reversed the connections from a battery-pack power supply. Its output consisted of a series of high-voltage pulses, so that some care was required to evaluate the output power.

Despite the problems, testing was completed with a few months. The testing team found that, once again, the laws of physics had triumphed over human ambition—the output power was less than the power used to run the machine.

The court-ordered report was carefully prepared, with a Foreword signed by Director Ambler, who stated:[291]

> Our results are clear and unequivocal. As the report states, "At all conditions tested, the input power exceeded the output power. That is, the device did not deliver more energy than it used."

Not a happy man, but at last the beneficiary of due process, Mr. Newman departed the scene. All the NBS participants in the case breathed sighs of relief and returned to more mundane matters.

### *Measuring Contact Resistance*

Stephen J. Proctor and Loren W. Linholm, researchers in the Electron Devices Division, developed a test method for the measurement of contact resistance in metal-semiconductor contacts. They employed a two-dimensional resistor network model to relate the specific contact resistance to the measured interfacial contact resistance with a homogeneous interfacial layer. The authors illustrated the technique with measurements of aluminum contacts on n-type silicon and of contacts with a 98.5 % aluminum, 1.5 % silicon composition, also on n-type silicon.[292]

## Computer Science

### *High Speed for the NBS Net*

The NBS Net received a boost in the speed of its data communication with new equipment developed by Robert J. Carpenter, Joseph Sokol, Jr. and Robert A. Rosenthal. The three scientists noted the need for improvement in the development of

[291] Robert E. Hebner, Gerard N. Stenbakken, and David L. Hillhouse, "Report of tests on Joseph Newman's device," *NBSIR 86-3405,* June 1986, 35 pp.

[292] S. J. Proctor and L. W. Linholm, "A direct measurement of interfacial contact resistance," *IEEE Electron Device Lett.* **EDL-3**, No. 10, 294-296 (1982).

local-area computer networks. Their innovation involved a new terminal design which allowed a wide variety of terminals, microprocessors, and larger mainframes to be fully interconnected by a common coaxial cable. The so-called *Terminal Interface Equipment* was partitioned to permit modular expansion and data encryption.[293]

### *Aid for Computer-Aided Design*

Computer-aided design became a popular tool during this period as smaller, dedicated computers appeared on the desks of the Nation's engineers. Plans for all sorts of projects, usually involving complex graphics programs used to design and portray new products on computer monitors, were speeded considerably by the use of "canned" data and procedures. One flaw in the CAD system, however, was a lack of digital transportability of the results to an installation manufactured by a different producer. In general, it was necessary for the operator to print out the results of the work and re-enter data in an unrelated CAD system.

The data transport problem was attacked by personnel from a consortium of industrial and government organizations, including Bradford M. Smith and Joan D. Wellington of the Bureau's Center for Manufacturing Engineering. Smith served as chair of the interface task group that represented the armed services, NASA, and more than forty large U.S. corporations. The group was successful in producing a mechanism that could solve the problem.

Completed in 1980 was a project called *Initial Graphics Exchange Specification* (IGES). The IGES enabled data originating on any CAD system to be transferred to any other CAD system, regardless of manufacturer. In addition, IGES provided an important link to Computer Aided Manufacturing systems, to robotic operations, and to other computer-assisted manufacturing activities.[294]

The task group noted that the IGES was not a panacea but a prototype. It was intended to alleviate then-existing data-exchange problems, which it did. But the concept embodied in IGES could be extended to other interface problems as the need arose.

When the improvement brought by the IGES became known, the American National Standards Institute, an organization supported by all areas of the Nation's technology sector, immediately commenced study of IGES as part of its program on industrial voluntary standards.

[293] R. J. Carpenter, J. Sokol. Jr. , and R. A. Rosenthal, "A microprocessor-based local network node," *IEEE Catalog No. 78CH 1388-8C* (New York: IEEE, 1978) pp. 104-110.

[294] "A technical briefing on the Initial Graphics Exchange Program (IGES)," J. C. Kelly (Sandia Laboratories, Co-Chair), Robert Wolf (Xerox Corp., Co-Chair), Philip Kennicott (General Electric), Roger N. Nagel (International Harvester), and Joan D. Wellington (NBS Center for Manufacturing Engineering, editor), *NBSIR 81- 2297,* July 1981, 128 pp.

### *Evaluating Computer Performance*

During 1983, the 19th meeting of the Computer Performance Evaluation Users Group was held in San Francisco. The 4-day meeting touched on a variety of problems associated with the utilization of supercomputers, microcomputers, and in-between sizes as well. Some of the topics were the following:[295]

- Local Area Networks—control of the flow of messages to buffered receivers, modelling a LAN.
- Statistical methods for computer evaluation.
- Improvement of software by modification and replacement methods.
- Sizing computer systems for particular applications.
- The Information Center concept for users of small systems.
- Automatic data processing—independent use *vs* organizational control.

### *Information Processing Standards*

During Ambler's term as director, the Institute for Computer Sciences and Technology continued as the source of *Federal Information Processing Standards,* intended to guide government employees in the use of computerized data processing. New FIPS publications of the era addressed the following problems:

- Passwords (FIPS publication 112), which specified basic security criteria for verification of personal identity and for access to restricted data.
- Graphical Kernel System (publication 120), which noted the adoption as a FIPS of an American National Standards Institute (ANSI) protocol of computer subroutines for handling two-dimensional graphics packages.
- Syntax for handling videotex and teletex information (publication 121), which described the formats, rules, and procedures for encoding alphanumeric text and pictorial materials in those applications.
- Data Descriptive Files (publication 123), which noted the adoption as a FIPS of an ANSI specification for information exchange between computer systems without loss of data integrity.
- Revision of *FIPS* on *FORTRAN* (publication 69-1), which updated a standard issued earlier to specify the form and interpretation of programs written in the FORTRAN language.

During 1987-88, two new FIPS were issued that built on the effectiveness of the *Initial Graphics Exchange Specification,* mentioned earlier in this section. Known by the acronyms POSIX and GOSIP, they provided additional means for the interconnection of computer hardware and software, regardless of manufacturer.

[295] D. Mowbray, editor, "Computer science and technology: Proceedings of the Computer Performance Evaluation Users Group, 19th meeting, October 25-28, 1983," *NBS SP 500-104,* October 1983, 236 pp.

POSIX, the *Portable Operating System Interface for Computer Environment* (publication 151), offered a standard for the transport of software from computer to computer. GOSIP, the *Government Open System Interface Profile* (publication 146-1), updated an international standard for data communications. The new standards encouraged computer vendors to offer products with enhanced versatility.

## NBS Radiometry Comes of Age

In chapter 3 we noted progress in optical radiation measurements. More can be added to that story at this point, covering advances made during the latter half of the 1970s and the 1980s.[296]

### *Electrical Substitution Radiometry*

The measurement of total radiant energy emitted by a variety of sources—for example, by lasers, by standard lamps, and by simulators of solar radiation—was eased considerably at NBS by the development of electrical substitution radiometry and by the development of electrically calibrated pyroelectric radiometers.

E. Dale West, a calorimetrist transplanted from the Gaithersburg Heat Division to the Boulder Quantum Electronics Division, joined colleagues W. E. Case, A. L. Rasmussen, and L. B. Schmidt to create an electrical substitution radiometer—basically a reference calorimeter—to evaluate the energetics of Boulder's new lasers. Use of the calorimeter allowed laser energy and power to be evaluated in terms of standard joules and watts, respectively.[297]

The operating characteristics of lasers made certain portions of the group's task particularly interesting. One such property was that of time variation in laser energy. Pulsed lasers delivered energy in short bursts; treated carefully, the pulsed outputs could be compared with those of continuous-wave lasers through calorimetry. In addition, transient variation in cw laser power could be averaged calorimetrically. West's group utilized the constant-temperature calorimetry method to develop a type of instrument designated the C-series calorimeter. The calorimeter accuracy was estimated as 1 % of the laser energy, with a range of 0.01 J to 20 J and with a limiting laser pulse intensity of 0.1 J/cm$^2$.

In the meantime, Jon Geist and Albert Crigler were working in the Heat Division on the measurement of incoherent radiant sources. They developed a versatile radiometer that could be used with lasers, standard lamps, and solar simulators.[298]

[296] Most of this material comes from an account kindly furnished by Jon Geist.

[297] E. D. West, W. E. Case, A. L. Rasmussen, and L. B. Schmidt, "A reference calorimeter for laser energy measurements," *J. Res. NBS* **76A**, No. 1, 13-26 (1972).

[298] J. Geist, "Fundamental principles of absolute radiometry and philosophy of this NBS program," *NBS Technical Note 594-1*, June 1972, 59 pp.

A comparison of the Boulder and Gaithersburg radiometers in 1973 produced agreement within 0.1 % in laser energy measurements, well within estimated uncertainties for the two devices.[299]

Use of the Geist-Crigler radiometer in a 1970 comparison of pyrheliometers—solar simulators—under the auspices of the World Meteorological Organization (WMO) of the United Nations demonstrated unexpectedly large errors in the international solar simulator calibrations. By 1979, however, the WMO, using the NBS information, was able to redefine its solar scale in terms of units consistent with the International System of Units.

Defoe C. Ginnings and Martin L. Reilly created a radiometer based upon the use of an electrical substitution calorimeter cooled to the temperature of liquid helium. The device was intended for measuring the temperatures of blackbody radiators,[300] and its advanced design provided a new level of accuracy in radiometric measurements. The principles developed by Ginnings and Reilly were subsequently incorporated by Terence J. Quinn and John E. Martin of the British National Physical Laboratory into a larger radiometer of extremely high accuracy.

### *Electrically Calibrated Radiometers*

The development of electrically calibrated pyroelectric radiometers, like their substitutional cousins, took place both in the Boulder laboratories and the Gaithersburg laboratories. Robert J. Phelan, Jr., A. R. Cook, Clark A. Hamilton, and Gordon W. Day produced at Boulder an electrically calibrated pyroelectric radiometer.[301] Jon Geist, William Blevin, a guest worker from the Australian National Measurement Laboratory, and Albert Crigler accomplished a similar development at Gaithersburg.[302]

The two efforts produced instruments that were more sensitive and easier to use than the forerunner in either laboratory, and almost as accurate. The Geist-Blevin device attracted the attention of a manufacturer and won an IR-100 award in 1975. Its availability allowed NBS to discontinue the calibration of several total-irradiance lamp standards and helped many user groups to trace their measurements to SI units.

While working on the radiometer problem with Geist, Blevin collaborated with Bruce W. Steiner of the Heat Division on a suggestion to redefine the SI base unit for photometry, the candela, in terms of a specified number of lumens per watt, thus effectively transforming photometric standards into radiometric standards.[303]

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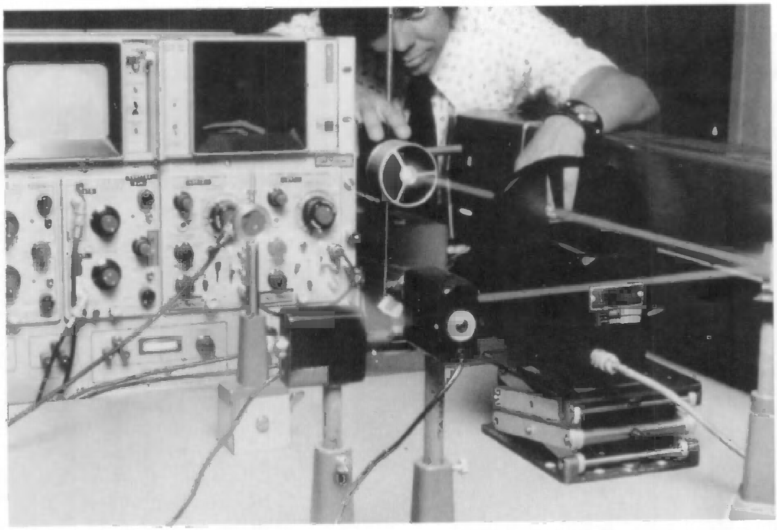
[299] J. Geist, L. B. Schmidt, and W. E. Case, "Comparison of the laser power and total irradiance scales maintained by the National Bureau of Standards," *Appl. Opt.* **12**, 2773-2776 (1973).

[300] D. C. Ginnings and M. L. Reilly, "Calorimetric measurements of thermodynamic temperatures above 0 °C using total blackbody radiation," *Temperature, Its Measurement and Control in Science and Industry*, **Vol. 4, Part 1**, H. H. Plumb, editor, pp. 339-348 (1972).

[301] R. J. Phelan, Jr. , and A. R. Cook, "Electrically calibrated pyroelectric optical-radiation detector," *Appl. Opt.* **12**, No. 10, 2494-2500 (1973). See also C. A. Hamilton, R. J. Phelan, Jr. , and G. W. Day, "Pyroelectric radiometers," *Opt. Spectra* **9**, No. 10, 37-38 (1975).

[302] J. Geist and W. R. Blevin, "Chopper-stabilized null radiometer based upon an electrically calibrated pyroelectric detector," *Appl. Opt.* **12**, 2532 (1973).

[303] W. R. Blevin and B. Steiner, "Redefinition of the candela and the lumen," *Metrologia* **11**, 97-104 (1975).



Robert J. Phelan used the electrically calibrated pyroelectric optical-radiation detector that he developed with colleagues at the NBS Boulder laboratories.

The success of the collaboration on the new radiometric instrumentation impelled Steiner, Geist, Russell Schaefer, and Edward Zalewski to form a research effort intended to improve the accuracy, reliability, and versatility of radiometric and photometric measurements. Eventually the project developed into a more formal collaboration called the Electro-Optical Radiometry Group.

### *Lasers and Photodiodes*

Some time after their introduction, photodiodes became known as highly stable detectors of radiation—more stable, in fact, than the lamps NBS used to calibrate them. Less happy features of the devices were large variation in response with source position, angle of incidence, and wavelength. Seeking to overcome these problems through the use of lamps, monochromators, and filters was tough going because the energy content of the resulting beam was too low for accurate measurement.

Having learned to measure laser energies accurately during their earlier experiments, Geist, Steiner, Zalewski, and Antonio Corrons, a guest worker from Spain, in 1975 adopted the use of lasers as sources for photodiode-response measurements. Their technique involved the use of an electrically calibrated pyroelectric radiometer for the calibration of the response of a silicon photodiode. The group irradiated the photodiode with a wavelength-tunable cw dye laser through an interference filter. The laser provided substantially more power than had the lamps tried earlier, improving substantially the accuracy of the measurements. A wedge-shaped beam splitter and a second photodiode used to monitor the laser beam proved satisfactory in compensating for the natural temporal variation in the beam intensity of the laser.[304]

The calibrated photodiodes became useful in measurements of the spectral irradiance of NBS lamp standards, used at the Bureau to reproduce the irradiance of the gold-point blackbody source at 602 nm. The uncertainty of the lamp standards, about 1 %, was degraded only to 1.3 % by the introduction of the photodiode detectors, demonstrating for the first time the suitability of the dye-laser approach to calibrations of spectral irradiance a well as the utility of lasers for radiometry.

Later, Michael A. Lind, Edward Zalewski, and Joel B. Fowler adapted the electro-optical modulator stabilizer, devised in the Boulder laboratories, to reduce the variation with time of laser energy emission. The technique—use of intensity-stabilized tunable dye lasers and discretely tunable ion lasers with electrical substitution radiometers to characterize photodiodes—proved successful and was still in use years later for measurements at the highest accuracy levels.

### *Self-Calibration With Silicon Photodiodes*

Continuing to advance the understanding of photodiode response, the NBS radiometry group assembled in 1977 a set of *Detector Response Intercomparison and Transfer* (DRIT) packages. Each package contained a photodiode-filter combination calibrated at the Bureau with ion-laser lines. NBS customers measured the photodiode response using their own instruments and reference standards, in accord with an NBS-prescribed protocol, then returned the results to the NBS radiometry group for analysis. The Bureau team examined the data, providing an evaluation of the customer's measurement capability and especially highlighting any apparent errors found in the customer's procedures.[305]

The new DRIT package nicely complemented the NBS calibration trend that passed beyond the calibration of reference standards towards analysis of a client's in-house measurement techniques—the procedure known generically as *Measurement Assurance Programs.*

In the course of studies of the physics of photodiodes, the NBS radiometry group discovered a method by which they could use the quantum efficiency of certain silicon photodiodes to create natural radiometric standards. In some cases, the uncertainty involved in the method was as low as 0.1 %.[306]

In 1984, Zalewski and Warren Gladden used the "self-calibration" method to calibrate a spectroradiometer with the 633 nm helium-neon laser line. The spectroradiometer was composed of an integrating sphere, a monochromator, and a photo-multiplier tube. The two then used the spectroradiometer to measure the

[304] J. Geist, B. Steiner, E. Zalewski, and A. Corrons, "Electrically based spectral power measurements through use of a tunable cw laser," *Appl. Phys. Lett*. **26**, 309 (1975).

[305] M. A. Lind, E. F. Zalewski, and J. B. Fowler, "The NBS detector response package: the instrumentation," *NBS Technical Note 950,* July 1977, 23 pp.

[306] J. Geist, E. F. Zalewski, and A. R. Schaefer, "Spectral response self-calibration and interpolation of silicon photodiodes," *Appl. Opt*. **22**, 3795 (1980).

spectral irradiance, at the same wavelength, of an NBS spectral-irradiance standard lamp. Since the lamp had been calibrated against a gold-point blackbody source, it was possible to compare the two methods directly; they agreed within 1.1 %. This was the first time such a comparison had been accomplished. It showed the value of the laser calibration of spectroradiometers.[307]

The self-calibration method was tested further in 1984 by Henry J. Kostkowski, J. L. Lean, Schaefer, Robert D. Saunders, and Lanney Hughey. Using a self-calibrated, filtered photodiode equipped with an integrating sphere, the group measured the spectral irradiance of a standard lamp, traceable to a gold-point blackbody source, and they measured the spectral irradiance of the radiation from the storage ring of the Synchrotron Ultraviolet Research Facility, version II (SURF-II), for which the spectral irradiance could be calculated. All of the measurements agreed within 1 %.[308]

The self-calibration method developed by Zalewski and Gladden proved so easy to use that it rapidly became a favorite within the international radiometry community. Only the cryogenic radiometer at the National Physical Laboratory in England was its equal in accuracy. A 1988 international comparison of measurements in 11 countries, 6 based on self-calibration and 5 on electrical-substitution radiometry, showed good agreement. Nine of the results agreed within 0.15 %, a distinct improvement over results obtained 20 years earlier.

## High-Temperature Superconductivity

The discovery that superconductivity, long thought to be a phenomenon restricted to temperatures below 20 K, could exist at much higher temperatures brought visions of lossless power transmission, revolutionary transportation systems, and exotic industrial and scientific devices during the late 1980s.

### *A Presidential Initiative*

President Ronald Reagan, generally skeptical about the value of non-military government activity, paid a surprise visit to a Federal Conference on Commercial Applications of Superconductivity on July 28, 1987. The Federal government, he announced, should strive mightily to develop and commercialize the field of high-temperature superconductivity.

Reagan proposed an 11-point initiative on superconductivity, partly legislative and partly executive. He requested legislation to expand the *National Cooperative Research Act* to encompass new joint industrial-governmental production avenues; to increase

[307] E. F. Zalewski and W. K. Gladden, "Absolute spectral irradiance measurements based on the predicted quantum efficiency of a silicon photodiode," *Optica Pura Y Aplicada* **17**, No. 2, 133-140 (1984).

[308] H. J. Kostkowski, J. L. Lean, R. D. Saunders, and L. R. Hughey, "Comparison of the NBS SURF and tungsten ultraviolet irradiance standards," *Appl. Opt.* **25**, No. 18, 3297-3306 (1986). See also A. R. Schaefer, R. D. Saunders, and L. R. Hughey, "Intercomparison between independent irradiance scales based on silicon photodiode physics, gold-point blackbody radiation, and synchrotron radiation," *Optical Engineering* **25**, No. 7, 892-896 (1986).

patent protection for manufacturing processes; and to exempt from the *Freedom of Information Act* commercially valuable scientific and technical information on high-temperature superconductivity.

On the executive side, Reagan proposed a number of steps:

- To establish an Advisory Group on Superconductivity, by which "Wise Men" could counsel the White House on research and commercialization policies.
- To establish several Superconductivity Research Centers to conduct basic research and serve as focal points for information on superconductivity. Four centers would arise within the Department of Energy—at the Argonne National Laboratory, at the Lawrence Berkeley Laboratory, at the Iowa Ames Laboratory, and in the DoE headquarters where a database would be created. The Department of Commerce was directed to establish a center devoted to electronic applications of high-temperature superconductivity at NBS/Boulder. Other activities in the program would take place in the National Aeronautics and Space Administration, in the National Science Foundation, and in the Department of Defense (the DoD was expected to invest $150 million in development of superconductive technology over a 3-year period).
- To urge all Federal agencies to help create and transfer to industry new technology based upon superconductivity.
- To establish accelerated processing procedures within the U.S. Patent and Trademark Office for superconductivity inventions.
- To urge NBS specifically to assist the program by the expeditious development of appropriate physical and reference standards and technical data, and to focus efforts on devices for the detection and measurement of low-level magnetic fields.
- To encourage all agencies to reallocate Fiscal 1987 funds to accelerate basic and applied superconductivity research.

Scientists at NBS responded enthusiastically to the encouragement of President Reagan, although they could accurately claim that the field of superconductivity had seen considerable action at the Bureau for more than a half-century.

Robert A. Kamper, chief of the Electromagnetic Technology Division in Boulder and himself a long-time student of superconductivity, gave his perspective to the topic:[309]

> The Bureau has been studying and measuring the properties of superconducting materials for more than three decades. While the new materials hold great commercial promise, the superconductor industry already registers annual sales of about $200 million. The measurement standards and methods that support

[309] Mark Bello, "Riding a Heat Wave: Researchers Take Another Look at Superconductivity," pp. 5-13 in "NBS Research Reports," *NBS Special Publication 733,* August 1987, 32 pp.

manufacturing and commerce in this industry were developed here. We also have developed several superconducting devices, including what is probably the world's largest working array of Josephson junctions—a series of 14,184 junctions that can produce a precise 10-volt standard of electricity.

Our expertise and measurement capabilities in areas crucial to exploiting this tremendous opportunity will support U.S. industry's efforts to surmount the many obstacles that must be overcome before the new high-temperature superconductors can be put to practical use.

Laboratory work on high-temperature superconductors followed several paths at NBS: study of the crystallographic phase relationships in the materials comprising high-temperature superconductors; measurements of the critical current densities of various high-temperature superconductors; and preparation of devices based on the use of high-temperature superconductors.

### *Phase Diagrams of High-Temperature Superconductors*

The new superconductor materials were brittle ceramics, generally polycrystalline. Forming such materials into wires, thin films, and bulky structures would not be an easy task. Francis W. Beech, Salvatore Miraglia, Antonio Santoro, and Robert S. Roth prepared a comprehensive phase diagram of one material, $YBa_2Cu_3O_{9-\delta}$, showing its structure to be orthorhombic. Their determinations were made by analyzing neutron-diffraction results from powder samples at the NBS nuclear reactor.[310]

Other phase transition studies, structure analysis, and observations of crystal growth were accomplished in several groups:

- Roger L. Stockbauer and Richard Kurtz of the Surface Science Division, in collaboration with David L. Ederer of the Radiation Physics Division.
- A group led by Robert Roth of the Ceramics Division.
- A group led by Hassel M. Ledbetter of the Fracture and Deformation Division.
- Stanley Block and Gasper J. Piermarini of the Ceramics Division.

In some cases, the chemical composition of the superconductor materials was uncertain, let alone the crystal structure.

### *Instruments and Machines*

The high-temperature superconductivity program in Boulder grew out of an older program which utilized "ordinary" superconductivity for the creation of new instruments and machines. The discovery of high-transition-temperature materials simply presented new options for the program.

[310] F. Beech, S. Miraglia, A. Santoro, and R. S. Roth, "Neutron study of the crystal structure and vacancy distribution in the superconductor $Ba_2YCu_3O_{9-\delta}$," *Phys. Rev.* **B35**, No. 16, 8778 (1987).

Soon after the announcement of superconductivity in yttrium barium copper oxide (YBCO) by Wu and Chu in 1987, James E. Zimmerman re-thought an earlier decision to retire. With some of his old colleagues, he devised a mechanical method to form the superconducting weak link required for a superconducting quantum interference device (SQUID). The resulting instrument was a sensitive magnetic sensor. When President Reagan paid his visit—mentioned earlier in this section—to the Federal Conference on Superconductivity, he attended a demonstration of the new device.[311]

Impressive as it was, the new magnetic sensor needed an important modification. For routine use, such an instrument should be constructed with a more stable thin-film link. Ronald H. Ono and a group of colleagues subsequently developed a practical junction consisting of two YBCO films sandwiching a thin barrier of normal conductor. The new SQUID proved operable at frequencies up to 9 THz.[312] The advance merited a Department of Gold Medal Award, presented to the entire team in 1993.

Another early application of YBCO to instrumentation was a bolometer for radiation detection.[313]

Soon after the discovery of superconductivity in YBCO, Jack W. Ekin investigated its current-carrying properties. He found that "weak links" existing between the grains of the polycrystalline material controlled the current flow. This discovery led to a world-wide effort to characterize the phenomenon and, if possible, to mitigate its effect.[314] The paper describing that work received many citations in subsequent superconductivity publications. The investigation led directly to new approaches to electronic and power applications. Robert L. Peterson and Ekin contributed to the theoretical understanding of the "weak link" model.[315]

Ekin and his colleagues Panson and Blankenship of the Westinghouse Research Laboratories also learned how to use noble metals to decrease the resistance of electrical contact in the new materials, enhancing their ability to transport large currents.[316]

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[311] J. E. Zimmerman, J. A. Beall, M. W. Cromar, and R. H. Ono, "Operation of a Y-Ba-Cu-O rf SQUID at 81 K," *Appl. Phys. Lett.* **51**, pp. 617-618 (1987).

[312] R. H. Ono, J. A. Beall, M. W. Cromar, T. Harvey, M. Johansson, C. Reintsema, and D. Rudman, "High $T_c$ SNS Josephson microbridges with high resistance normal metal links," *Appl. Phys. Lett.* **59**, p. 1126 (1991).

[313] J. C. Brasunas, H. W. Moseley, B. Lakew, R. H. Ono, J. A. Beall, J. E. Sauvageau, and D. G. McDonald, "Fabrication and operation of a high $T_c$ composite bolometer," *J. Appl. Phys.* **66**, p. 4551 (1989).

[314] J. W. Ekin, A. I. Braginsky, A. J. Panson, M. A. Janocko, D. W. Capone, N. J. Zaluzec, B. Flandermeyer, O. F. Delima, M. Hong, J. Kwo, and S. H. Liou, "Evidence for weak link and anisotropy limitations on the transport critical current in bulk polycrystalline YBCO," *J. Appl. Phys.* **62**, pp. 4821-4828 (1987).

[315] R. L. Peterson and J. W. Ekin, "Josephson junction model of critical current in granular $YBa_2Cu_3O_7$ superconductors," *Phys. Rev.* **B37**, p. 9848 (1988). See also R. L. Peterson and J. W. Ekin, "Airy pattern, weak link modeling of critical current in high $T_c$ superconductors," *Physica* **C157**, pp. 325-333 (1989).

[316] J. W. Ekin, T. M. Larson, N. F. Bergren, A. J. Nelson, A. B. Schwartzlander, L. L. Kazmerski, A. J. Panson, and B. A. Blankenship, "High $T_c$ superconductor/normal metal contacts with surface resistivities in the $10^{-10}\ \Omega\ \mathrm{cm}^2$ range," *Appl. Phys. Lett.* **52**, p. 1819 (1998).

The traditional role of NBS/NIST—development of definitive measurement and test methods—was filled for the new materials and devices by Ronald Goldfarb, who showed that ac susceptibility measurements were particularly advantageous for ceramic superconductors. Loren F. Goodrich and Steven L. Bray helped in this respect, too, describing at length the special measurement problems associated with the measurement of critical current, and recommending the adoption of specific methods as standard practice.[317] The efforts of Goodrich Bray and were incorporated into two international standards for high-temperature superconductors.

### *Other Properties of High-$T_c$ Superconductors*

Among the high-temperature superconductivity projects undertaken at the Bureau were the synthesis of samples and the dependence of the superconductive properties on magnetic fields using microwave absorption, by a group led by Lawrence H. Bennett;[318] critical currents, by Robert L. Peterson and Jack W. Ekin;[319] and electron tunneling in thin films and bulk samples, by groups led by Richard Harris and by John Moreland.[320]

Russell C. Casella pursued the theory underlying the new superconductors, which in many ways seemed not to follow the usual Bardeen-Cooper-Schrieffer theory of superconductivity.[321]

## Recycling to Save Energy and Materials

America knew in those days that it could extend the useful lives of many products to conserve natural resources and to save energy; for many families, recycling was a routine practice. At NBS, however, science undergirded recycling and resource recovery; staff members evaluated products and processes to maximize the conservation of energy.

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[317] R. B. Goldfarb, A. F. Clark, A. I. Braginski, and A. J. Panson, "Evidence for two superconducting components in oxygen annealed single phase Y-Ba-Cu-O," *Cryogenics* **27**, p. 475 (1987). See also L. F. Goodrich and S. L. Bray, "High $T_c$ superconductors and critical current measurements," *Cryogenics* **30**, pp. 667-677 (1990).

[318] F. J. Adrian, J. Bohandy, B. F. Kim, K. Moorjani, J. S. Wallace, R. D. Shull, L. J. Swartzendruber, and L. H. Bennett, "Magnetic field dependence of the superconductivity in Bi-Sr-Ca-Cu-O superconductors," *Physica* **C156**, 184-188 (1988).

[319] R. L. Peterson and J. W. Ekin, "Josephson-junction model of critical current in granular $YBa_2Cu_3O_{7-\delta}$ superconductors," *Phys. Rev.* **B37**, No. 16, 9848-9851 (1988).

[320] J. Moreland, R. H. Ono, J. A. Beall, M. Madden, and A. J. Nelson, "Evidence for the superconducting proximity effect in junctions between the surfaces of $YBa_2Cu_3O_x$ thin films," *Appl. Phys. Lett.* **54**, No. 15, 1477-1479 (1989).

[321] R. C. Casella, "Theoretical models for high-temperature superconductivity," *Il Nuovo Cimento* **10**, No. 12, 1439-1448 (1988). See also "Comparison of interplanar-boson-exchange models of high-temperature superconductivity: possible experimental tests," *Applied Phys. Lett.* **55**, No. 9, 908-910 (1989).

### *Recycling Oil to Save Energy*

The Bureau became involved in recycled oil as a result of the *Energy Policy and Conservation Act of 1975* (PL 94-163). This act called upon the Federal Energy Administration to direct NBS in the development of appropriate test procedures relating to energy conservation, including recycled oil. Federal Energy Administration officials estimated that oil re-use could reduce oil imports by about 70,000 barrels each day. At NBS, the mission of a *Recycled Oil Program,* formed in 1976 in the Institute for Materials Research with Donald A. Becker at its head, was to develop test procedures for the determination of the equivalency of re-processed oil and new oil.

In November 1976 NBS held a workshop on *Measurements and Standards for Recycled Oil.* Some 26 presentations by technical experts from both government and industry were divided among seven sessions. Nearly 70 attendees represented government agencies, engine manufacturers, petroleum refiners, heavy industry, and standards groups.[322]

A second workshop was held in November 1977. Considerable progress was reported in identifying the details of the recycling problem; for example, it was understood that the end use of the recycled oil—for fuel, for engine lubrication, for industrial use, or for hydraulics—dictated different levels of purification. Much of this progress resulted from NBS studies of recycled oil.

A third conference, co-sponsored by NBS, the American Society for Testing and Materials, and the Mechanical Failures Prevention Group, was held at the Bureau in October 1979. By that time, NBS had completed its study of recycled oil for use as fuel and had transmitted test procedures for that use to the Federal Trade Commission. The Bureau staged a fourth conference in 1982, which provided closure to the topic of recycled oil by 1984.

A new piece of legislation, the *Used Oil Recycling Act of 1980,* Public Law 96-463, provided new directions for NBS:

- The Bureau retained responsibility for determining the quality of recycled oil.
- NBS was forbidden to identify oil as recycled until the entire study was complete and the Federal Trade Commission had developed labeling rules.
- The new act also mandated assessment by the Bureau of environmental problems caused by improper disposal or reuse of recycled oil, analysis of the supply and demand for used oil, and comparison of energy savings associated with new or refined used oil.

During the lifetime of the recycled oil project, NBS was instrumental in forming a new technical division of the American Society for Testing and Materials. Bureau scientists also developed equipment and techniques for the chemical, physical, and thermal treatment and analysis of oils, and they contributed to the success of similar work in other laboratories.

[322] "Measurements and Standards for Recycled Oil," *NBS Special Publication 488,* D. A. Becker, editor, August 1977, 140 pp.

NBS contributors to the recycled oil program were many: Donald Becker (program manager); Reenie M. Parris, Franklin R. Guenther, Willie E. May, Charles S. Ku, Ronald F. Fleming, and Stephen N. Chesler (chemical analysis); Stephen J. Weeks and Stephen M. Hsu (mathematical analysis); Arthur L. Cummings and Patrick Pei (test methods); John J. Comeford, James A. Walker, Wing Tsang, Laszlo E. Szegvary, and David B. Clark (thermal analysis); Lewis K. Ives, Richard S. Gates, Paul A. Boyer, and Arthur W. Ruff (physical analysis).

### *NBS Opens an Office of Recycled Materials*

During its discussion of the *Resource Conservation and Recovery Act of 1976* (PL 94-580), members of Congress voiced the idea of locating in the Department of Commerce some or all of the research and development work connected with the act. This they did, calling upon the Secretary of Commerce to provide guidelines for specifications for recovered materials, to stimulate markets for recovered materials, to promote proven recovery methods, and to generate a forum for the discussion of technical and economic information on resource recovery. In turn, the Secretary delegated much of the responsibility to NBS.

By November 1976 the Bureau had established a *Resource Recovery Program.* In 1978 the activity was expanded to include the *Recycled Oil Program.* The new entity was given the name Office of Recycled Materials (ORM); located in the National Measurement Laboratory, it was temporarily placed under the command of Donald R. Johnson. In 1979, a Technical Advisory Center was created within the ORM to determine suitable market locations for recycled materials and to establish a database for technical and economic resource recovery systems.

NBS had discharged nearly all of its responsibilities under the 1976 Resource Recovery Act by the end of Fiscal Year 1982. Accordingly, the Office of Recycled Materials was disbanded at that time. [323]

The major activities undertaken by ORM during its 6-year life included the following:

- Study of recycled oil.
- Study of the recycling of municipal solid waste.
- Study of the recycling of industrial wastes.
- Studies of the recovery and disposal of hazardous wastes.
- Probing markets for recovered materials.
- Evaluating the commercial feasibility of resource recovery facilities.
- Assisting in the formation of pilot resource recovery program for the state of California.

[323] "The National Bureau of Standards Office of Recycled Materials 1976-1982," Harvey Yakowitz, editor, *NBS SP 662*, September 1983, 634 pp.

### *Recovering Energy From Municipal Wastes*

American consumers generated about 150 million tons of solid waste per year during the period 1976-82. Another estimated 50 million tons of waste was designated as hazardous. The Bureau collaborated with other resource-recovery agencies in an effort to separate usable materials and energy from municipal solid waste. The effort extended to metals—aluminum and ferrous metals—and to glass. In addition, there were efforts to recover energy from the combustion of the organic waste fraction.

An eddy-current method proved useful in removing aluminum from the waste stream. Aluminum often was used to manufacture soft drink cans; the metal could be recovered at purity levels useful as feed stocks for aluminum refiners. Electromagnetic separation could be used to remove ferrous metals. Glass often could be recovered as a heavy fraction once the metals were removed.

Bureau scientists undertook the problem of determining the energy available from the combustion of the organic fraction of municipal solid waste. Duane R. Kirklin and Eugene S. Domalski built an oxygen bomb calorimeter to accommodate 25 g samples of *Refuse Derived Fuel,* pellets prepared by compressing pre-processed solid waste. In collaboration with David J. Mitchell, they found experimental values averaging 25 MJ/kg for the fuel. The results seemed not to depend upon processing methods.[324] With the assistance of Jennifer C. Colbert, P. Decker, H. Xiheng, and Stanley Abramowitz, the scientists verified the early results by examining more than 100 samples and calibrating the calorimeters.

Construction, testing and use of a large-scale flow calorimeter were accomplished in 1981-82 by Domalski, Kirklin, Colbert, Kenneth L. Churney, Martin L. Reilly, Albert E. Ledford, Russell V. Ryan, and Donald D. Thornton.[325] Four members of the group—Churney, Ledford, Reilly, and Domalski—received the Department of Commerce Silver Medal Award in 1984 for the development of the large-scale calorimeter.

## The Beginning of "Technology Transfer"

From its founding, Bureau scientists communicated results of their investigations to the American—and, in many cases, the foreign—public. Sometimes the communication took place through the publication process. Other times it arose from a collaboration with an outside organization. Frequently, industrial associations were keenly interested in the progress of NBS work in particular areas.

During the 1970s and 1980s, however, the idea began to take hold that there should be direct connections between NBS projects and American industry in ways that previously had not been considered. In this section we note the growth of that idea.

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[324] D. R. Kirklin and E. S. Domalski, "A 25-gram-capacity oxygen- bomb calorimeter," *Resources and Conservation* **10**, 177-187 (1983).

[325] K. L. Churney, A. E. Ledford, M. L. Reilly, and E. S. Domalski, "multi-kilogram-capacity calorimeter for heterogeneous materials," *J. Res. NBS* **91**, 277-298 (1986).

### *A Change in Emphasis*

It became clear to the Bureau's managers while Ernest Ambler was director that NBS should begin to express its output in terms of "technology transfer"—identifying directly those activities that allowed industry or other government agencies to make use of scientific or engineering advances.

Looking at itself with new eyes in the early 1980s, NBS found many projects and programs that fitted the definition handily. Among them were the following:

- *Calibration Services,* which allowed other organizations to measure their own capabilities in dozens of technical areas against those of the Nation's leading measurement laboratory. The Bureau, selling the calibration services at cost, realized millions of dollars annually from this program.

- *Measurement Assurance Programs,* developed by NBS as a means of verifying not only the reference devices used by outside organizations but the latter's measurement practices as well. These enabled users to compare their measurement results against those obtained by Bureau scientists.

- *Standard Reference Materials,* which allowed other organizations to obtain samples chosen from a list of 1000 well-characterized materials or devices for use in their own plants or laboratories as reference devices. During Fiscal 1980, NBS sold about 40,000 SRM units to more than 10,000 users worldwide.

- *Standard Reference Data,* which gave outsiders access to technical data evaluated by experts for its accuracy and reliability. More than 20 data centers, located at NBS or elsewhere, screened thousands of literature references for the most reliable information.

- *Standards Information Service,* a reference collection of more than 200,000 standards, specifications, test methods, codes, and recommended practices issued by U.S. technical societies, professional organizations, State standards offices, Federal agencies, and international organizations.

- *Energy-Related Inventions,* a program in which experts reviewed plans submitted by individuals or small businesses. The free service, arising from the *Federal Nonnuclear Energy Research and Development Act of 1974,* resulted in the examination of more than 3000 ideas in 1980; some 30 were referred to the Department of Energy for further study.

- The *Research Associate Program,* under which personnel sponsored by industry, professional, or trade organizations were accepted for cooperative study with NBS scientists. Bureau laboratories and other facilities were made available for use by the associates. In addition, they enjoyed daily contact with NBS scientists and engineers. Since 1921, more than 1000 individuals participated in the program.

- Liaison with State and local governments in the areas of weights and measures, construction, and environmental measurements led to other communication as well. The government officials learned of NBS ideas and practices in unexpected areas such as fire-fighting and fire prevention, energy conservation, computers, and resource recovery.
- The *Postdoctoral Research Associates* program, which brought to NBS for one or two years some of the Nation's most promising young scientists and engineers. The associates worked with the most senior project leaders at the Bureau under the auspices of the National Research Council.
- The *Guest Worker* program, which allowed visitors from U.S. or foreign laboratories to work on specific projects for periods as short as a few months or as long as 2 years.
- Conferences, tours, exhibits, and technical films, which carried information from NBS to citizens and non-citizens at all levels of scientific sophistication.

All told, technology transfer became identifiable as an integral part of daily life at NBS.

### *Automated Manufacturing Research Facility*

As the manufacture of machine tools, aircraft, and automobiles became—perhaps paradoxically—more automatic and yet more intricate, measurement of the component parts became more complex as well. In the United States, most of the companies involved in parts manufacture employed fewer than 50 people. As automated manufacturing became more necessary to meet growing competition for business, such companies found it increasingly difficult to cope with the demands imposed by short-run, automated operations. But the complexity of automated manufacturing was felt by government agencies and large companies, too. NBS provided help with automation to all comers.

In a new Bureau facility known as the Automated Manufacturing Research Facility (AMRF), located in the main instrument shop, researchers in the National Engineering Laboratory developed protocols for the standardization of automated, small-quantity manufacturing that addressed the use of numerically controlled metal machining, robotic parts handling, in-plant conveyors, and software compatibility. The AMRF[326] was one of the largest and most influential progams ever undertaken at NBS, rivaling in many ways the wartime efforts in proximity-fuse and guided-missile development.

[326] J. Simpson, R. Hocken, and J. Albus, "The Automated Manufacturing Research Facility of the National Bureau of Standards," *J. Manufacturing Systems* **1**, 17-31 (1982).

The AMRF involved dozens of innovative scientists and engineers under the capable leadership of John A. Simpson. Protocols developed in the AMRF allowed the small manufacturer to compete with larger firms that employed process-development staffs, and they allowed large companies and government agencies to undertake automation projects that otherwise would have been beyond their reach.[327]

In developing new manufacturing measurement methods, Bureau experts initially worked with representatives of a dozen companies, using equipment lent by the firms and involving their personnel in the development through the research associate program. Equipment located in a Turning Center work station could be used to produce in half an hour parts that took as long as 17 hours with manual methods. In some cases, the need for spare-parts inventory could be entirely eliminated.

The AMRF also included a test bed to solve problems associated with interconnecting components used in computer-aided manufacturing systems and connecting those systems to design, planning and control operations. The most significant problems arose from the need to develop the software used to interconnect devices made by different companies. The interfaces had to be effective without exposing proprietary software. Continuous contact with industrial standards bodies permitted the development of such standards as the Initial Graphics Exchange Specification, mentioned earlier, that enabled all manufacturers to utilize computerized processing.

Eventually the AMRF became a $50 M technical research program that directly involved Industrial Research Associates from 50 firms and produced 18 patents and dozens of technical papers.[328]

According to a 1990 report of the National Academy of Science, the AMRF "catalyzed" the transition of NBS into NIST:[329]

> The AMRF has for years served as a platform to develop needed technology for flexible, integrated, and automated manufacturing of discrete parts. It has played a significant role in the identification and development of emerging technologies in manufacturing. It has had considerable influence on various private efforts throughout the nation. It was also the catalyst in the legislative process that resulted in the Technology Competitiveness Act.

[327] For a general discussion of the AMRF, see Michael A. Baum, "Manufacturing Technology for the Second Industrial Revolution," pp. 16-21 in "NBS Research Reports," *NBS Special Publication 721*, April 1987, 32 pp.

[328] P. N. Nanzetta, "Technology transfer from the Automated Manufacturing Research Facility at the National Institute of Standards and Technology," in *Control and Dynamic Systems: Advances in Theory and Applications*. Vol 45, Manufacturing and Automation Systems (Academic Press, 1992).

[329] "An assessment of the National Institute of Standards and Technology Programs, Fiscal Year 1990," *National Academy Press*, Washington, DC, 1991.

### *Measurements for Chemical Processing*

During the early 1980s, Bureau researchers developed new methods for measurements involving the flow of multi-phase materials. Many chemical processes involved mixtures of solids and fluids; techniques for the determination of properties such as composition, viscosity, temperature, and density were necessary for effective process design and control.

Calibration of instruments used in process-control measurements presented special problems because of the complex nature of many of the process streams. With the American Petroleum Institute, for example, scientists in the National Engineering Laboratory (NEL) prepared a database for use in evaluating the performance of orifice meters—used in gas pipelines to measure flow rates and establish equity in the transfer of metered gases.

In a related activity, NEL scientists developed a predictive model that incorporated properties such as density, thermal conductivity, and viscosity of whole classes of industrial mixtures—chemicals such as alcohols, ethylene, vinyl chloride, both natural and synthetic gases, and even such complex mixtures as those derived from tar sands, coal, and oil shale. The model was immediately adopted by the Gas Processors Association. The NBS Office of Standard Reference Data assisted in its distribution to interested firms.

To broaden the database used in the design of pumps, heat exchangers, compressors, and pipeline architecture, other NEL scientists designed and built an apparatus for the direct measurement of thermodynamic properties of hydrocarbon, chemical, and petrochemical fluids at temperatures up to 900 K and pressures as high as 35 MPa. Materials of special interest to particular industry groups could be studied in the facility, yielding key design data.

### *Sharing NBS Facilities*

NBS management became more conscious in the mid-1980s of a new trend in the U.S. government with respect to Bureau interactions with private companies. No longer—as was the case during the 1960s—were NBS scientists required to beware of charges of favoritism if they collaborated too closely with industrial colleagues. Gradually, as the effectiveness of the close government-industry cooperation in other countries—especially Japan—became clear, cooperation between NBS researchers and representatives of individual firms was tolerated, then encouraged. Eventually, Bureau laboratories were made available for proprietary industrial research.

Ernest Ambler recalled especially an admonition delivered in the 1983 Packard report (mentioned earlier in this chapter) encouraging increased access to Federal facilities for industrial and academic projects. The Bureau responded to that exhortation by expanding its programs for *Industrial Research Associates,* its cost-shared projects with industry, and the use of NBS facilities by industrial and government scientists and engineers.[330]

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[330] Ambler, *SP 825*, p. 33.

One example that illustrated the new trend in the use of NBS laboratories by outsiders was the issuance of *NBS Special Publication 682*, "Facilities of the National Bureau of Standards." In the foreword to the publication, Director Ambler stated:

> As the nation's foremost science and engineering laboratory, the National Bureau of Standards has some of the premier research and testing facilities in the United States. Many of the facilities are available for use by the scientific and engineering communities either on a cooperative or independent basis. Now, recognizing the strong challenges from abroad and the need for U.S. researchers to pool their resources, we have decided to make selected NBS facilities available to U.S. researchers for proprietary work on a cost-recovery basis, when equal or superior facilities are not otherwise readily available.

In this first venture into uncharted waters, the Bureau listed two dozen of its strongest experimental installations, along with the names of appropriate contact personnel. These included:

- The NBS Research Reactor, providing a peak thermal neutron flux of $4 \times 10^{14}$ neutrons per $cm^2$ (contact person, Robert S. Carter), along with a neutron depth profiling facility (Ronald F. Fleming), a high-resolution neutron diffractometer for use with powder samples (Edward Prince), and a small-angle neutron scattering facility (Charles J. Glinka).
- The 140 MeV Electron Linear Accelerator, providing electron beam power of 50 kW (Sam Penner).
- The Synchrotron Ultraviolet Radiation Facility-II, a 280 MeV electron storage ring providing photons of wavelengths 60 nm to 120 nm (Robert P. Madden).
- A metals-processing laboratory, with capabilities for inert gas atomization, electrohydrodynamic atomization, melt spinning, electron-beam and laser surface melting, hot isostatic pressing, and plasma-transferred arc coating (John R. Manning).
- Toxic chemicals handling laboratory, with the capability for safe use of dangerous materials (Willie E. May).
- High-voltage measurement facility, with capabilities for direct voltages up to 300 kV, 60 Hz alternating voltages up to 175 kV, and lightning pulses up to 500 kV (Robert E. Hebner).
- Transverse electromagnetic cells (Mark T. Ma, NBS/Boulder).
- Electromagnetic anechoic chamber, for field strengths up to 100 V/m at frequencies from 200 MHz to 18 GHz (Norris S. Nahman, NBS/Boulder).
- Ground-screen antenna range, enclosed by an air-inflated non-metallic cover for all-weather use (Norris S. Nahman, NBS/Boulder).
- Near-field scanning facility for antenna measurements, (Allen C. Newell, NBS/Boulder).

Robert P. Madden checked a connecting flange on the Synchrotron Ultraviolet Radiation Facility-II

- Outdoor extrapolation range for antenna measurements, featuring 6 m towers with separation variable up to 60 m (Allen C. Newell, NBS/Boulder).
- Automated Manufacturing Research Facility, with three machining centers, a coordinate-measuring machine, a cleaning/deburring station, and robotic handling system (Philip N. Nanzetta).
- Fire research facilities with heat-release calorimeters, a room/corridor smoke-and-gas station, a 2.4 m by 3.7 m by 2.4 m burn room and smaller subsidiary rooms, two pilot furnaces, reduced-scale physical models, and a two-story structural steel facility (Jack E. Snell).
- Plumbing Research Laboratory, a five-story plumbing stack (Lawrence S. Galowin).
- Large Environmental Chamber, with static and dynamic temperature and humidity profile capability (Tamami Kusuda).
- Line heat-source guarded hot plate, with a temperature variable over 200 °C (Thomas K. Faison or Douglas Burch).
- Acoustic Reverberation Chamber, 9 m by 7.6 m by 6 m with controlled environment (Simone L. Yaniv).

- Acoustic Anechoic Chamber, 6.7 m by 10 m by 6.7 m, with controlled humidity (Daniel R. Flynn).
- Network Protocol Testing and Evaluation Facility, for testing network protocols, satellite communications, high-speed and multi-processing networks, videotex, public data networks, network security, local area networks, and computer-based office systems (Robert P. Blanc).

It was an extensive list, containing facilities available nowhere else in America. The "arms-length" relationship formerly existing between U.S. industry and government was changing rapidly into an "arm-in-arm" relationship.