CHAPTER THREE

A NATION IN TROUBLE; AN AGENCY IN CHANGE
(May 1972–June 1975)

Early in 1972, while Lewis Branscomb and his colleagues were eagerly contemplating excellent prospects for a large funding increase for NBS, Richard Nixon and his colleagues were eagerly contemplating excellent prospects for his re-election to the presidency of the United States. For both groups, joy would be short-lived.

At NBS, Branscomb's success in revising the image of the Bureau gave promise of greater importance for the agency and the prospect of enough operating and equipment funds to work in something like the circumstances enjoyed in other major scientific laboratories. The budget put forth in March reflected the largest peace-time increase ever requested for the Bureau, and most of it was appropriated by the Congress later in 1972.[1]

In the White House, President Nixon had every reason to expect re-election: by March, only 95,000 American troops remained in Vietnam—less than one-fifth the number there in 1969; a triumphant trip to Moscow in May, following an equally triumphant trip to China in February, burnished the image of the President as a powerful world leader; the economy was temporarily in fine shape, thanks in large measure to careful priming by the Administration; and best of all, the President's political opposition was in disarray.[2]

As the year wore on, however, unwelcome events clouded the bright prospects for both NBS and the President.

In April of 1972, almost before the ink was dry on the House Appropriations Subcommittee hearings transcript, NBS staff members learned that Branscomb would leave the Bureau at the President's earliest convenience. Not long after, some $13 million of the Bureau's new-found wealth went a-glimmering, a hapless victim of an Executive-Branch economy drive. Coping with these problems—at least until the elections were over—became the duty of Lawrence Kushner, who was designated Acting Director of NBS.

In June of 1972, a bungled burglary of the Democratic National Committee offices in the Watergate complex presented President Nixon with a small problem that he immediately turned into a major problem.

President Nixon's small problem was that the apprehended burglars had acted at the behest of G. Gordon Liddy and E. Howard Hunt, operatives for the Committee to Re-Elect the President; not only that, but they were "Plumbers," a group formed by the White House to stop information leaks by any means available.

[1] House Appropriations Subcommittee hearings, April 20, 1971, pp. 1117-1140; also the hearings on March 28, 1972, p. 1077; also the hearings on April 17, 1973, p. 772.

[2] James T. Patterson, *Grand Expectations* (New York: Oxford University Press, 1996), Ch. 24.

The Watergate burglary, as crimes go, was no big deal. The fact that the burglars could be connected with the White House, however, interested the Federal Bureau of Investigation. The President, worried about the effect on the coming elections of any unsavory revelations by the burglars, ordered H. R. Haldeman, one of his top aides, to instruct the Central Intelligence Agency to intervene in the case and to demand that the FBI drop its investigation.

This action, constituting obstruction of justice, transformed the small problem into a large one. As time went on, new illegal actions and the accidental revelation of unrelated misdeeds made the problem larger and larger.[3]

Seeking a New NBS Director

The resignation of Lewis Branscomb as Director of NBS after less than three years in that office surprised and puzzled the technical community both inside the Bureau and beyond. The bright future envisioned by the NBS staff suddenly became cloudy and uncertain. The eloquent voice and restless personality, so promising in terms of leadership within the Bureau and so visible in the Nation's scientific establishment and in Congress, passed like a shadow with Branscomb's letter of resignation to President Nixon on April 4, 1972.[4]

An editorial in *Science* magazine summarized Branscomb's role for NBS with the comments that he had ". . . aroused the low-profile and somewhat sleepy agency to eminence . . ." Branscomb, Nicholas Wade wrote, had brought ". . . recognition of its potential as the government's instrument for stimulating industrial technology. . . "[5]

Branscomb's departure was a great disappointment to Allen Astin. Astin had persevered as Director through trying and occasionally unpleasant times. He had accepted his problems as they came, always placing the welfare of NBS above any personal desire or need. It was galling to think that his carefully nurtured choice as successor might have been undone by the mere offer of more money—the type of temptation that confronted first-rank Bureau scientists continually.

The matter was not as simple as wages to be earned for a day's work, although the salary increase offered to Branscomb by International Business Machines, Inc. was indeed substantial. There was the job itself—technical direction of a $500 million research laboratory and the opportunity to serve as technical spokesman for one of the greatest of the high-tech corporations. At IBM, Branscomb could influence the course of technology at the highest level; certainly this was a challenge to his desire to make a mark on the technical life of the United States.

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[3] Stephen E. Ambrose, *Nixon, Volume Three: Ruin and Recovery, 1973-1990* (New York: Simon & Schuster, 1991), Ch. 1.

[4] *NBS Standard*, Special Edition April 20, 1972. The four-page issue contains a note on Branscomb's departure and his temporary replacement by Lawrence M. Kushner, Branscomb's letter to President Nixon, Nixon's letter of acceptance, and excerpts from Branscomb's announcement to Bureau division chiefs.

[5] N. Wade, "NBS Loses Branscomb to IBM," *Science* **176**, p. 147 (April 10, 1972).

Besides the pull of an influential, well-paid position, there was also the push of Branscomb's political mismatch with a Republican administration, which could have created problems at any moment. Branscomb knew that another promising Bureau leader, Edward Condon, had chosen earlier to resign the NBS directorship when his effectiveness was compromised by bad relations with Congress.[6] But whatever the why or wherefore, the end of Branscomb's short tenure left NBS without a director in May of 1972. *NBS Administrative Bulletin 72-25*, dated May 3, 1972, contains the single statement:

> Effective May 7, 1972, Dr. Lawrence M. Kushner, Deputy Director of the Bureau, will serve as Acting Director until a new Director is named.

"Until" turned out to be nearly one year, a delay that was occasioned in part by the coming Presidential elections, in part by the extraordinary distractions experienced during this period by the Nixon Administration.

No one would have been surprised had Kushner been named to succeed Branscomb as Director of NBS. A Princeton-trained physical chemist, Kushner had come to the Bureau in December of 1948.[7] He had been invited by James I. Hoffman to join the newly created Surface Chemistry Section of the Chemistry Division. Kushner soon had organized a small group, including Hoffman himself, Blanton C. Duncan, Willard D. Hubbard, Rebecca A. Parker, and A. S. Doan, that successfully investigated the fundamental properties of surface-active agents, primarily wetting agents and detergents.

Several years later, Kushner created a Metal Physics Section in the Metallurgy Division. In that effort and later as Chief of the Metallurgy Division, Kushner took steps to modernize the Bureau's scientific work in the area of metallurgy. He brought to NBS a group of scientists interested in the newer theories of alloying and dislocation, nuclear magnetic resonance in metals, and the use of the electron microscope. Some of the people initiating the new projects were Robert L. Parker (crystal growth), John R. Manning (diffusion), Arthur W. Ruff (x-ray and electron microscopy), Lawrence H. Bennett (nuclear magnetic resonance), and Roland DeWitt (imperfections in crystals).

In September 1964, Kushner was selected as one of the first 17 participants in a new Department of Commerce scientific exchange program. Dubbed the Commerce Science and Technology Fellowship, the program enabled budding technical leaders to view the department from new angles by working outside their own agencies.[8] During his fellowship, Kushner worked as a special assistant for legislation to J. Herbert Hollomon in the Office of the Assistant Secretary for Science and Technology. This experience gave Kushner an excellent perspective on the need for technological upgrading of U.S. industry.

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[6] Lauriston S. Taylor, Oral History, April 10, 1990.

[7] Lawrence M. Kushner, "An NBSer's Odyssey," *SAA Newsletter*, Vol. 98-2, June 1998, pp. 16-18.

[8] Press release, Office of the Secretary (Luther H. Hodges), U.S. Department of Commerce, September 9, 1964, issuance #G 64-140.

In 1969 Kushner became Deputy Director of NBS under Allen Astin. He remained in that post under Director Lewis Branscomb, accumulating more than three years experience in the position.[9]

Only one feature of Kushner's résumé could not particularly help him with the Nixon administration: although politically neutral, he was a registered Democrat.

Other reasonable choices as Branscomb's successor could be found among the senior managers at NBS, too. One was Ernest Ambler, Director of the Institute for Basic Standards, a scientist with two decades of service as a physicist in the field of cryogenics and in several management positions. Another was John D. Hoffman, Director of the Institute for Materials Research, who was a second-generation Bureau man (coincidentally, John's father, James I. Hoffman, had hired Lawrence Kushner). Hoffman had been a participant in the wartime Manhattan Project and, like Ambler, a staff member at NBS for 20 years. Hoffman was still active as a theorist in the field of polymer science. A third reasonable candidate for Director was Edward Brady, Associate Director for Information Programs. Brady, a physical chemist, had been recruited to NBS in 1963 expressly to become head of its then-new Office of Standard Reference Data. Prior to his Bureau tenure, Brady had served in the Manhattan Project and had spent 10 years devising nuclear programs for the General Electric Company. Yet another possibility was Howard Sorrows, Associate Director for Programs. Sorrows had been employed as an electronics scientist at NBS from 1941-52. Subsequently he had worked for the Office of Naval Research and the Naval Ordnance Laboratory and for Texas Instruments Corporation. In 1965 he had returned to NBS as Assistant to Gordon Teal, Director of the Institute for Materials Research.

In these scientists and in others not named here, there was breadth of scientific understanding, experience in management at NBS and elsewhere, and more than passing acquaintance with the national technical establishment. Leadership of the Bureau in the uncertain days ahead could logically have been placed in the hands of any of a whole group of senior NBS scientists.

Despite the ready availability of suitable leaders at NBS, the loss of Branscomb as Director was utilized by the Nixon administration as an opportunity to look elsewhere for a replacement. As an alternative to NBS career scientists, Arthur A. Bueche, a member of the Bureau's statutory Visiting Committee, suggested that NBS could benefit from a director who was an expert on technical communication—not necessarily an outstanding scientist, but someone who could "sell" the Bureau's programs to the Congress and to the technical public as well. Such a quality, which had been strong in Lewis Branscomb, was relatively rare among scientists.

Bueche had someone very specific in mind: Richard W. Roberts, Manager of Material Science and Engineering at the General Electric Research and Development Center in Schenectady, New York. Though he was a scientist (a physical chemist) by training, Roberts was known more as a good salesman. He was interested in technical management as a career. In 1973 Roberts was but 38 years of age. He had worked at NBS as a National Research Council post-doctoral associate during 1959-60,

[9] Lawrence M. Kushner, Oral History, June 7, 1988.

studying surface chemistry with Heat Division scientists Kurt Shuler, John McKinley, and Robert Ferguson. In 1960 he joined the General Electric Corporation. There he pursued studies of high vacuum and lubricants, publishing furiously for several years; then he turned to technical management with equal vigor. It was said by some that he had his eye on the position held by Arthur Bueche!

Bueche's efforts on behalf of Roberts were well-received at the Department of Commerce and at the White House. President Nixon apparently discussed the directorship of NBS with Roberts prior to the national elections in November 1972, although the formal nomination announcement was not made until December 20, 1972, after Nixon's re-election to the Presidency. The Senate Committee on Commerce held nomination hearings on January 29, 1973, and Roberts was confirmed on February 1.[10] He was sworn in on February 5, 1973.

Ernest Ambler later amplified the circumstances surrounding the selection of Roberts as NBS Director:

> Dick Roberts came to NBS because of Art Bueche. Bueche was head of the General Electric Company's Central Research Laboratory in Schenectady, and Roberts was one of his senior people. Bueche was also a member and ultimately Chairman of the NBS Statutory Visiting Committee.
> Bueche prided himself on his ability to communicate to top management the nature of the work of his laboratory and its importance and ultimate utility to the company. Roberts was a 'whiz' at the kind of 'show and tell' that Bueche's method demanded. By comparison Beuche thought we at NBS did an absolutely lousy job in marketing our wares to our bosses in the Government and thought Roberts was just the man to come down and show us how to fix this deficiency.[11]

A Second Term For Richard Nixon

One feature of 1972 went well for President Nixon; he and Spiro Agnew were easily re-elected, besting by a heavy margin their opponents, Senator George McGovern and Sargent Shriver. Shriver was a former head of the Peace Corps; he replaced Senator Thomas Eagleton as the Democratic vice-presidential candidate when revelations of the latter's history of mental illness caused McGovern to drop him from the ticket.

The Democratic Party, however, retained control of both houses of Congress. When the time came to question the legality of certain actions by President Nixon, the Democrats in Congress possessed the necessary power to pursue all the ramifications of the Watergate affair.

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[10] Nomination hearings for Roberts were held by the Committee on Commerce, 93rd Cong., First Sess., January 29, 1973, *Richard W. Roberts, to be Director of the National Bureau of Standards.* See also *Congressional Record—Daily Digest,* February 1, 1973, p. D-36.

[11] 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. 31.

Thanks to Nixon's practice of tape-recording White House conversations, we know a great deal about how he was able to perform his presidential duties while at the same time pursuing his enemies with no regard for the law. It is instructive—nay, necessary—to take note of both facets of this interesting President.

"Watergate" and the Loss of a President

By the time that a replacement for Lewis Branscomb was nominated, the Nixon presidency had already been damaged seriously by the Watergate affair. Always suspicious, always determined to be decisive and tough, President Nixon had ensured himself at least a small problem by creating the "Plumbers," whose original charter was expanded as necessary to further the Administration's political goals. As noted above, Nixon also installed eavesdropping equipment to tape conversations and meetings in the White House.

Unfortunately, Nixon fell into the trap of denying all while failing to destroy tape-recorded evidence, which he presumed he could keep with impunity for later "historical" use. On February 7, 1973, a seven-member select committee of the U.S. Senate was established to investigate political espionage, including the Watergate break-in.

In a painfully slow process which lasted until August of 1974, the unfortunate details of Nixon's schemes were gradually uncovered by the Senate committee. The results showed a President so consumed with distrust that he not only countenanced lawlessness within his administration but demanded it of his personal staff.

In October of 1973, Vice President Agnew resigned his office rather than face trial on charges of bribery, extortion, and income-tax evasion that dated back to his days as Governor of Maryland but also extended into his term as Vice President. Agnew's resignation was forced by Elliot Richardson, only months earlier named Attorney General by Nixon after the resignation of Richard Kleindienst. Richardson had acted quickly upon seeing the evidence against Agnew, in order to eliminate the possibility that Nixon might be succeeded by a man soon to be prosecuted on felony charges.[12] Required by the 25th amendment to the U.S. Constitution to quickly nominate a replacement Vice President for confirmation by a simple majority of both houses of Congress, Nixon nominated Gerald R. Ford of Michigan, Minority Leader of the House of Representatives, a man whom the Congress could happily confirm.

On the same day that Ford was nominated, October 12, 1973, the U.S. Court of Appeals ruled that the tape recordings made by Nixon—which contained direct evidence of criminality and obstruction of justice by dozens of Administration officials including Nixon himself—must be surrendered to the Senate investigating committee.

Given the deep troubles of the President, it was considered a real possibility by the members of Congress that Nixon might resign his office to avoid prosecution, as Agnew had done. That possibility made it urgent that Ford—or someone with his

[12] See, for example, James Cannon, *Time and Chance: Gerald Ford's Appointment With History* (New York: Harper Collins Publishers, 1994), pp. 186-199.

capabilities—be confirmed as Vice-President: in the absence of a sitting Vice-President, the Speaker of the House would succeed to the White House.

Only the most partisan of the Congressional Democrats wanted Carl Albert, then the Speaker, to bear the burden of the Presidency; it was widely supposed that Albert's best years were well behind him. Nevertheless, nearly two months passed before Congress considered the nomination of Ford as Vice-President, so involved was that body over the question of Presidential misdeeds and with the consequences of Nixon's firing of Archibald Cox, the Special Prosecutor who demanded that the President surrender his collection of incriminating White House tape recordings.

On December 6, 1973, however, both houses of Congress confirmed the choice of Gerald Ford as Vice President by overwhelming margins. Quickly Ford was sworn into office.

Despite desperate efforts by the administration over the following months to slow or stop the prosecution of the Watergate affair, the Senate Select Committee inexorably demonstrated that Nixon himself was involved in a large-scale program that broke a variety of laws and had attempted to conceal the facts by misuse of the Internal Revenue Service, the Federal Bureau of Investigation, the Central Intelligence Agency, and the Department of Justice.[13]

At 9 am on August 8, 1974, President Nixon addressed the Nation via television to state his intention to resign his office during the next day. He became the first U.S. President to do so. He thus avoided protracted impeachment proceedings on criminal charges and abuse of his office. He also preserved his pension, his lifetime Secret Service protection, and other perquisites of the Presidency.

The next day, August 9th, Alexander Haig delivered Nixon's letter of resignation to Secretary of State Henry Kissinger, "I hereby resign the Office of President of the United States." At 12:03 pm, as Nixon and members of his family flew to California, Gerald Ford became President. Ford had some work to do.

Searching for an End to the Vietnam War

President Nixon had a little more luck in extricating the United States from the Vietnam War than had Lyndon Johnson. There was no way to "win" any more, only the possibility of withdrawing from the war-torn country without the stigma of losing. With Henry Kissinger, his foreign-policy guru, continually at his side, Nixon sought to capitalize on the gains in popularity that followed his visits to Russia and to Peking during the election year of 1972..

Once the elections were over, President Nixon ordered the heaviest bombardment ever—more than 36,000 tons of bombs dropped over a 12-day period in December—of the populous Hanoi-to-Haiphong corridor. The North Vietnamese asked for a return to peace negotiations.[14]

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[13] Ambrose, *Nixon, Volume Three,* p. 386.

[14] James MacGregor Burns, *The Crosswinds of Freedom* (New York: Random House, 1990), pp. 479-489.

Cease-fire talks early in 1973 gave the President the opportunity to promise "peace with honor," although the United States—despite pledges to its allies in South Vietnam—already had given in to the demand that North Vietnamese troops would remain in South Vietnam. Despite the talks, it proved necessary for the United States to continue routine bombing, not only in Vietnam but in Cambodia.

The Congress expressed its distaste for Nixon's style of governing with the War Powers Act, passed in August of 1973. This Act demanded that U.S. troops be brought home within sixty days unless Congress was consulted on military policy and agreed with the President's decisions.

The Vietnam War was winding down, not as a result of victory or defeat but of simple fatigue—the Nation was tired of sending its sons and daughters to participate in an expensive and unwinnable conflict on the other side of the world.[15]

In April 1975, under the anguished supervision of President Ford, the last U.S. civilians were evacuated from Saigon as the North Vietnamese took command of the beleaguered city.

Returning Vietnam veterans, frustrated and scarred in mind and body in battles that made no sense, added to the disaffection that ran through the country during this era.

Stagflation

As a believing Republican, President Nixon had a natural aversion to government economic controls. Nevertheless, in August 1971, he issued a 90-day freeze on wages, prices, and rents. Nixon took this distasteful step because of high (5 %) inflation, the Nation's first balance-of-payments deficit, and rising unemployment. He urged corporations to hold the line on stockholder dividends. For his part, he promised to reduce government expenditures and to reduce Federal employment by 5 %. As we mentioned at the beginning of this chapter and shall again later, NBS felt the full impact of these economies.

Nixon's efforts were sufficiently successful by the time of the 1972 elections that he could cite a rebounding economy as evidence that he should be re-elected. However, the rebound was brief, for the Nation's economic troubles were deep-seated.

The economic controls were continued, but gradually eased, during 1972 and 1973. They were abandoned in 1974, when the U.S. economic downturn became more pronounced. A condition of stagnant consumer demand accompanying relatively severe inflation became the definition of a new word—"stagflation."

The so-called New Economic Policy, announced by President Nixon during his first term, failed to curb the spending—in both the public and private sectors—that led to pronounced price inflation during 1973. In the meantime, U.S. industry, hard-hit by low-priced imported goods, languished. During 1973, U.S. automobile sales fell 11 million behind the 1972 figures. During 1974, unemployment reached 7.2 %, a 15-year high.[16]

[15] James T. Patterson, *Grand Expectations* (New York: Oxford University Press, 1996), Ch. 24.

[16] Patterson, *Grand Expectations*, Ch. 25.

The House Committee on Science and Astronautics, inspired by Lewis Branscomb's vision of the Bureau of Standards, was seeking an expanded role and increased funding for NBS as one means to reverse the decline in U.S. technical productivity. At the same time, the House Committee on Appropriations, inspired by fears of profligacy, was seeking to reduce government expenditures. Could the Bureau staff not be nervous in this situation?

A Crisis in Energy

Shortages of energy, problematic for the United States since the mid-1960s, came into sharper focus during the presidency of Richard Nixon. Unhappily, energy woes had to share the attention of the Nixon administration with the Vietnam War and with the Watergate affair, which ripened and rotted during the same time interval.

For the most part, the energy crisis originated with the discovery of the "oil weapon" in the mid-East and in Libya.

In October of 1973, the Egyptians and the Israelis renewed their war, with the Egyptians gaining the early advantage via the time-honored technique of a surprise attack. The United States supplied Israel with enough ordnance to partially offset the early losses and create a stalemate. While the short Egypt-Israel war transpired, an oil cartel formed by the oil-exporting nations (the Oil Producing and Exporting Countries, or OPEC) decided unilaterally on an increase in the price of their product from $3 per barrel to $5, then to nearly $12. Overall, OPEC production was cut by 5 % per month; oil shipments to the United States from Libya were cut off entirely. Eventually the other OPEC nations joined the embargo to punish America for its assistance to Israel.

Almost immediately, gasoline and fuel-oil shortages and skyrocketing petroleum prices became a feature of the U.S. economic landscape.

The American standard of living had risen to a comfortable level in large measure because energy was available in abundance and at a low cost. The United States, with one-twentieth of the world's population, became responsible for a third of the world's energy consumption. And 30 % of U.S. oil use was made possible by foreign supplies in 1972. During the oil embargo, the American standard of living retreated somewhat. Energy costs contributed substantially to economic stagflation.[17]

The winter of 1973-1974 saw long lines of U.S. automobiles waiting for scarce gasoline from filling-station pumps. Many Americans wondered aloud why gasoline prices rose as strongly as they did, and whether price-gouging, rather than OPEC, was the real culprit. President Nixon, ordinarily opposed to controls by "big government," addressed the Nation with a call for conservation of energy.[18] Nixon asked his countrymen to respond to the shortage of oil by reducing consumption by 10-20 %. He suggested that occupants of homes, factories, offices, and stores lower the settings on their thermostats by several degrees. He advocated staggered working hours to take advantage of natural light and to avoid gasoline-wasting delays in traffic. And he urged

[17] Patterson, Ch. 25.

[18] *New York Times,* November 8, 1973, pp. 1, 33.

managers of utility companies to consider designing new power plants to burn U.S. coal rather than foreign oil. During his speech, the President also put forward "Project Independence," a program intended to permanently reduce the Nation's reliance on foreign oil. For a time, this initiative would involve several projects at the National Bureau of Standards.

By the end of 1973, the price of a barrel of oil rose to $11.65 by edict of OPEC. In only three months, this most common of energy sources had quadrupled in price; by the end of the decade, even this new price would triple.

NBS responded quickly to the president's request to conserve energy in homes. Working through the office of Virginia Knauer, the President's Special Assistant for Consumer Affairs, the Center for Building Technology produced two pamphlets as guides for saving energy in household heating (*Seven Ways to Save Energy in Household Heating*) and cooling (*Eleven Ways to Save Energy in Household Cooling*). Thousands of copies of the pamphlets were distributed nationwide by Knauer's office, and many of those were reproduced by private industry.

Science Loses Its Advocates[19]

In President Nixon's administration, admiration for the power of science warred with concern regarding scientists' never-ending demand for freedom and their continual need for money. Nixon demonstrated this ambiguity as he basked in the warm afterglow of achievements in the space program—culminating in the landing of Americans on the moon in 1969, 1971, and 1972— while gradually reducing support for the National Aeronautics and Space Administration as his need for economy in government spending became more acute.

The President's Science Advisory Council, the Office of Science and Technology, and the Presidential Science Advisor, monitoring the scientific and technological needs of the Nation since the days of Eisenhower, were consistently undercut by the Nixon administration. Ultimately they were discarded. Nixon's view was that the governmental science establishment should serve the constantly changing political needs of the administration. This view continually brought clashes with the scientists, whose logic was inevitably rooted in facts. A conscious program of eliminating positions altogether or replacing Kennedy-Johnson appointees with Republican loyalists went far towards producing the desired unanimity on science and technology issues.

The President periodically embraced crash programs in science that he thought could quickly solve technological problems—a view that perhaps had its origin in the success of the Manhattan project, which produced the atomic bomb and thereby quickly and decisively ended World War II. For example, in his first term, Nixon urged that large amounts of money be spent on the gasification of coal, on the fast breeder reactor, and in the pursuit of controlled nuclear fusion. Members of the scientific establishment,

[19] Much of the material in this section is derived from information given by James E. Katz, *Presidential Politics and Science Policy* (New York: Praeger Publishers, 1978) Ch. 9.

who had suggested no such list, were more than a little surprised at the presidential statement.

Toward the end of his first term, Nixon delivered to Congress a *Presidential Message on Science and Technology.* It contained a glowing endorsement of the scientific enterprise and an explicit reference to NBS as a key agency in the use of science for mankind. But it contained a caveat that advancements in science must be put to the service of civilian needs—the environment, health, energy, and transportation.[20] The President promised:

> To use the capabilities of our high technology agencies—the Atomic Energy Commission, the National Aeronautics and Space Administration, and the National Bureau of Standards—in applying research and development to domestic problems.

Nixon adopted a *National Technology Opportunities* program as one part of his announced plan. It ultimately involved NBS in an *Experimental Technological Incentives Program.* Remarkably, NBS suffered while it was being praised for its effectiveness. During Nixon's last years, the agency was asked to surrender 5 % of its full-time personnel, along with the funding to support them. The Bureau was also required to reduce the average grade level of its staff.

As the Watergate affair grew to dominate White House activities, Nixon's personal staff—particularly H. R. Haldeman and John Erlichman—took over more and more control of Nixon's appointment schedule. As one consequence of this change, even agency representatives charged with producing technical breakthroughs no longer could meet with the President to put forth their ideas.

President Gerald Rudolph Ford, Jr.

President Gerald Ford, biological product of a failed marriage,[21] was the political product of a failed presidency. Born in Omaha, Nebraska, to an abusive father, Ford took Grand Rapids, Michigan for his hometown and he took the name of Gerald R. Ford, his kindly stepfather, as his own name. From his mother and his stepfather, Ford learned well the virtues of honesty and hard work. From his high-school and college experience, both in academics and in athletics, Ford learned the value of scholarship and competition. A child of the Great Depression, Ford also knew the value of a dollar.

By the time he was 32 years of age—at the end of World War II—Ford had graduated from the Yale school of law and had practiced his profession in Grand Rapids. He also had held positions as assistant football coach at Yale, professor of business law at Grand Rapids University, and lieutenant in the U.S. Navy with four years' service—two of those years as a deck officer on an aircraft carrier in the thick

[20] *The Public Papers of the President: Richard Nixon, 1972,* U.S.G.P.O., 1974, pp. 416-425.

[21] James Cannon, op. cit., Ch 1.

of some eleven Pacific battles of World War II. A standout among his colleagues for his honesty, judgment, and hard work, and for his capability to excel at any assigned duty, Ford was ready to become a front-line player in post-war America.

Ford won the first political campaign he ever entered: Congressman, Fifth District, Grand Rapids, Michigan, 1948. During his first term, he became friends with Representative Richard Nixon and won a spot on the House Appropriations Committee—one of the three most coveted assignments in the House. By the time that John F. Kennedy had defeated Richard Nixon in the Presidential campaign of 1960, Ford had been elected to his sixth term in Congress and was the ranking Republican on the Defense Subcommittee of the House Appropriations Committee. Ford, his wife, and their four children were citizens of Alexandria, Virginia, as well as of Grand Rapids.

When Richard Nixon won re-election as President in 1972, Ford was elected Minority Leader of the House of Representatives for the fifth time, capping a 12-term Congressional career. To his regret, Ford's career stopped short of his ultimate political goal: to become Speaker of the House. As luck would have it, the Republicans never gained control of the House after Ford reached the top of his party's Congressional delegation, so that the position of Speaker would forever elude him.

For a long time, Ford could not understand why the Watergate affair presented such a problem for his friend Richard Nixon. If the burglary was the work of Republican zealots, thought Ford, simply disavow them. If White House operatives were involved, seek them out, fire them, apologize for the unwarranted affront to civility, and go back to work. He could not believe that Nixon was personally involved—until the fact was obvious. Even in October 1973, when Nixon nominated Ford to replace Agnew as Vice President, Nixon gave no indication to his old friend that his career as President was even in jeopardy, let alone doomed.

Faced with a full field investigation (by 350 agents of the Federal Bureau of Investigation!) as a preliminary to Congressional confirmation as Vice President, Gerald Ford reacted characteristically. "Hold nothing back," he said to his staff. "Anything that they want, if we have it, give it to them. I don't want any papers from the files destroyed, or hidden, or doctored up. We are not going to cover up anything, and we are not going to stonewall."[22]

A Short Acquaintance

Gerald Ford became President in August 1974. With no executive experience in his background, he was thrust immediately into the most demanding of circumstances—completing the term of a resigned Chief Executive.

Ford saw his first responsibility to be the restoration of America's faith in its leader—in his case not an elected leader, but one chosen by the very man whose presidency he sought to redeem. A step in this direction was his nomination of Nelson Rockefeller, the experienced governor of the Nation's largest State, as Vice President. Much of America viewed Ford's pardon of Richard Nixon as a step in the opposite

[22] Cannon, op. cit., p. 229.

direction. Other steps— against inflation and underemployment, trade deficits, and the war in Asia—occupied his full attention for the balance of his term as President.

Barely 10 months after his inauguration, President Ford received a letter of resignation from Richard Roberts, Director of NBS. Given Ford's necessary preoccupation with more massive problems, it seems likely that he left the selection of a replacement for Roberts in the hands of Rogers C. B. Morton, appointed in May 1975 as his new Commerce Secretary, and Betsy Ancker-Johnson, who continued to hold the office of Assistant Secretary of Commerce for Science and Technology. Richard Roberts and Gerald Ford were destined for only a brief acquaintance.

RICHARD WILLIAM ROBERTS

Richard Roberts was born in Buffalo in 1935. He was educated as a physical chemist, receiving the undergraduate degree from the University of Rochester in 1956 and the doctorate from Brown University in 1959.

Although Roberts had spent the year following receipt of his doctorate as a National Research Council Postdoctoral Research Associate at NBS, he was not well-known to the Bureau staff in the way that Branscomb had been—instead, his career had been built at the General Electric Company (GE).

Roberts was less interested in laboratory science per se than he was in the management of science. Within 5 years of his arrival at GE, Roberts was appointed Manager of the Physical Chemistry Laboratory. In 1968, he was made Research and Development Manager of Materials Science and Engineering, a four-laboratory group of more than 250 technical people. At 33 years of age, he was directing GE work in artificial diamonds, in machining tools for special alloys, in new composite materials—including new types of magnets—and in coal gasification.

Not particularly active in politics but a registered Republican, Roberts' nomination as the seventh Bureau director could be perceived as trouble-free for the intensely partisan Nixon administration.

An interview with the new director was featured in a special edition of the NBS Standard.[23] In it, Roberts was asked about his immediate plans for the Bureau:

> In terms of detailed plans, the first thing I've got to do is really learn what's going on. I asked Larry Kushner to set up with the Institutes program reviews during the first week so I could get, in that time framework, an outline of everything that's going on.

Program reviews would become a way of life at NBS during the 30-odd months of Roberts' tenure.

Roberts quickly showed a lively interest in the public appearance of all aspects of the Bureau. Within 10 days of taking office, he had made suggestions for improving the appearance and readability of NBS publications such as the *Technical News*

[23] "Roberts Takes NBS Reins," *NBS Standard,* Special Edition, February 1973, 4 pp.

Richard W. Roberts was the seventh director of NBS. Trained as a chemist, his chief interest was in technical management.

On November 27, 1973, First Lady Patricia Nixon came to Gaithersburg to view a townhouse equipped with solar panels under an agreement between NBS and the Department of Housing and Urban Development. Mrs. Nixon and NBS Director Richard W. Roberts were photographed while fielding questions from reporters.

Bulletin, he had requested that a presentation package be prepared for his own use with perhaps 80 color slides, he had requested that Kushner prepare a set of management seminars, and he had requested that his speeches be printed in "an attractive format" for distribution to the public.[24]

Old Bureau hands who worked closely with Roberts agree on several of his personality traits.[25] He was personally ambitious. He was driven to seek perfection, especially in the area of presenting descriptions of technical work, an area closely related to public relations. He came to work early and left late, and he expected those around him to do the same. He was demanding in his judgments of the quality of presentations, often finding flaws that no one else noticed. He was extremely sensitive to the impact on its "customers" of work done at NBS; he probed quickly and with vigor to determine the extent to which Bureau managers were familiar with their "client base." And he was preoccupied with making management "cost effective," a term that had a less precise meaning in government agencies than it did in the private sector.

Richard Roberts' leadership at NBS was recognized by the Downtown Jaycees of the District of Columbia when they presented the Arthur S. Flemming Award to him on February 27, 1975. The award, given to outstanding young Federal employees, had been given to 13 Bureau scientists since its establishment in 1948. Roberts was the first NBS staff member to win the award strictly for administrative work.[26]

A New Management Style

Roberts' predilection for communication with his constituency found ample room for exercise at NBS. Despite the fact that his predecessor, Lewis Branscomb, had pushed mightily in the same direction, there had not been time enough during Branscomb's short tenure to move the Bureau very far from its accustomed posture as a quiet purveyor of facts.

The new director took up his task with a will. His efforts to impose a new, higher-visibility management style on NBS appeared in the form of new and modified organizational entities, new leaders, intense reviews of Bureau programs, and a public face for NBS intended to convey a fuller appreciation of a capable agency.

[24] Note to W. Reeves Tilley, February 7, 1953, RHA; RG 167; Director's Office; Box 430; Folder Chron; Feb. 1-15, 1973. See also Memo, RWR to W. E. Small, February 12, 1953, RHA; RG 167; Director's Office; Box 430; Folder Chron; Feb. 1-15, 1973. See also Memo, RWR to L. M. Kushner, February 12, 1953, RHA; RG 167; Director's Office; Box 430; Folder Chron; Feb. 1-15, 1973. See also Memo, RWR to W. E. Small, February 12, 1953, "NBS Publication Covers"; RHA; RG 167; Director's Office; Box 430; Folder Chron; Feb. 1-15, 1973. See also Memo, RWR to W. E. Small, February 15, 1953; RHA; RG 167; Director's Office; Box 430; Folder Chron; Feb. 1-15, 1973.

[25] Howard E. Sorrows, Oral History, December 10, 1986. See also Ernest Ambler, Oral History, November 7, 1986. See also Arthur O. McCoubrey, Oral History, November 3, 1986.

[26] *NBS Standard,* Vol 20, No. 6, March 12, 1975, p. 3.

On December 5, 1973, noted anthropologist Margaret Mead gave a talk entitled "Women—Oppressed and Unoppressed" in the NBS/Gaithersburg Red Auditorium. Mead was invited by the Standards Committee for Women to be the keynote speaker for the NBS observance of the Department of Commerce Federal Women's Program Week. In this photograph, Mead chatted with NBS Director Richard W. Roberts.

NBS Holds an Open House

Consistent with his desire for greater publicity and public awareness of the Bureau and its activities, Roberts scheduled an open house for October 26-27, 1973.

It was scarcely the norm for NBS to open its doors to the general public on the spur of the moment. Even during the 50th anniversary of the Bureau's founding in March 1951, visits to its laboratories were limited mainly to attendees of a large variety of celebratory scientific and technical symposia.[27]

The Roberts open house had a simpler objective than the "golden anniversary" in 1951: to advertise a major scientific laboratory to those who might not have been aware of its existence. A front-page article in the employee newsletter outlined plans for the event, which included some 118 tour stops at which Bureau staff members would explain their work.[28]

More than 20,000 students and other visitors crowded the grounds on Friday, October 26, many escorted by young tour guides who were the children of staff members. On Saturday, October 27, another 15,000 interested visitors came to NBS to see the types of projects that the Bureau supported.[29]

[27] Annual Report, 1951, p. 100. See also *Technical News Bulletin,* 1951 and 1952.

[28] "NBS Open House," *NBS Standard,* Vol. XVIII, No. 15, October 24, 1973, pp. 1-5, 8. See also NBS Admin. Bull. 73-67, October 18, 1973.

[29] "Dick Roberts Reviews the Open House," *NBS Standard,* Vol. XVIII, No. 16, pp. 2, 3, 7, 8.

The open house was judged to have been successful both in getting more publicity for NBS and in communicating to the public a better idea of the highly technical, yet often down-to-earth projects accomplished on a daily basis by Bureau staff members. It also served as a warm-up session for a larger celebration planned for 1976—the Nation's bicentennial and the Bureau's 75th anniversary.

Programmatic Center for Consumer Product Safety

Director Roberts continued Lewis Branscomb's efforts to create program management in consumer-related areas—both for better Bureau visibility and for better coordination with industry groups. During his first month on the job, Roberts formed a Programmatic Center for Consumer Product Safety.[30] This step consolidated in the Institute for Applied Technology oversight of all work in the Consumer Product Systems Section of the Measurement Engineering Division, the Product Flammability Section of the Fire Technology Division, and the Consumer Product Activities group of the Technical Analysis Division.[31]

Jacob Rabinow and Melvin R. Meyerson were appointed Director of the new Center and Associate Director for Consumer Activities, respectively. Their duties lay in coordinating NBS work in the participating sections with the new Consumer Product Safety Commission, headed by Lawrence M. Kushner, former NBS Deputy Director. As with most NBS programmatic centers, responsibility for funds, personnel actions, space, and equipment remained with the parent divisions of the participating sections.

On December 8, 1974, the name of the unit became "Center for Consumer Product Technology" and it became a line organization of NBS. Assigned to the new center as staff members were the Office of Consumer Product Safety under Walter G. Leight, the Law Enforcement Standards Laboratory headed by Jacob J. Diamond, the Product Systems Analysis Division led by Melvin R. Meyerson, and the Product Engineering Division, managed by G. Franklin Montgomery. No Center Director was chosen immediately; Marshall Isler was designated Acting Deputy Director.[32] Stanley I. Warshaw was later recruited from the American Standard Company as director of the Center.

More Change for NBS Programs

During his short tenure, Director Roberts continually modified the Bureau program structure. Among the changes were the following:

- Executive Board re-structured, March 1973. Roberts assembled a new membership roster and set up a new meeting format and schedule.

[30] NBS Admin. Bull. 73-11, February 15, 1973, "Programmatic Center for Consumer Product Safety Established."

[31] A subsequent NBS Admin. Bull. 73-40, June 20, 1973, assigned to the Center the coordination of all NBS work undertaken on behalf of the Consumer Product Safety Commission.

[32] NBS Admin. Bull. 74-81, December 30, 1974.

- Oversight of interagency collaboration, May 1973. A new NBS-Other Agency Board of Coordinators was established. Roberts charged the board with promoting and monitoring interagency programs.

- Oversight of energy programs, July 1973. David A. Didion, program analyst for the Institute for Applied Technology, was given the additional responsibility of generating and monitoring programs in the area of energy utilization and conservation.

- Office of Air and Water Measurement, December 1974. This office supplanted the former Measures for Air Quality and expanded its horizon. James R. McNesby continued to lead the newly expanded office.

- Office of Energy-Related Inventions (OERI), March 1975. In order to augment the Bureau's energy-conservation effort, Roberts established the OERI within the Institute for Applied Technology. It was formed to seek and screen energy-related inventions. George P. Lewett, formerly a staff member in the Technical Analysis Division, was designated Acting Chief of the office.

One of the first evaluators of energy-related inventions for OERI was, surprisingly, Jacob Rabinow. Rabinow retired from the Bureau just as OERI was created, but was enticed to return as a "rehired annuitant" to lead the evaluation team.

A New Management Team

Director Roberts made several changes in the senior management of the Bureau, including some that were mentioned in the preceding section. In most cases, new appointments came from within NBS ranks; in others, new managers were introduced to the Bureau:

- Ernest Ambler named NBS Deputy Director, June 1973. One of Roberts' first duties—though not one that he had expected—was to replace Lawrence M. Kushner as his deputy. Roberts had expected Kushner to stay on.[33] The latter's long experience with the Bureau and with external organizations such as the U.S. Congress could have eased the transition from industrial manager to Federal manager for the new director.

As senior members in the Nixon administration realized that Roberts would become NBS Director, Kushner was offered the position of Commissioner in the brand-new Consumer Product Safety Commission (CPSC), mandated by Congress in October 1972.[34] Richard O. Simpson, Deputy Assistant Secretary of Commerce for Product Standards, was appointed Chair of CPSC. The nascent organization especially wanted to name a Commissioner who was familiar with the evolution of product standards.

[33] "Roberts Takes NBS Reins," Special Edition, *NBS Standard,* February 1973, p. 1.

[34] Consumer Product Safety Act, Public Law 92-573, October 27, 1972.

Kushner had considerable experience in that area, and he accepted the offer of the new position.[35] Other commissioners included Constance B. Newman, Director of Volunteers In Service to America; Barbara Franklin, an expert on legislative politics; and David Pittle, a safety-minded engineer from Carnegie-Mellon University.

By May 1973, Kushner had left the Bureau. When Kushner departed, Roberts spent less than one month studying his subordinates in a search for a new deputy. He quickly chose Ernest Ambler, then Director of the Institute for Basic Standards (IBS). The appointment was made effective on June 11, 1973.[36] Roberts appointed David T. Goldman, Ambler's deputy, as Acting Director of IBS.

- Jordan Lewis to head the Experimental Technology Incentives Program (ETIP). By mid-1973, the funding level for ETIP was settled and a search was under way for a suitable manager for the new program. Roberts chose Jordan D. Lewis, former Director of Applied Technology Programs at the Battelle Memorial Institute in Columbus, Ohio.[37] Lewis had considerable experience in developing technologies in the areas of new products and processes.

- John Lyons to head the NBS Fire Program. At the behest of Karl Willenbrock, Director of the Institute for Applied Technology, John Lyons, an expert on certain features of fire research at the Monsanto Chemical Company, was brought to NBS in October 1973 to head the Bureau's fire program.[38] Lyons had been somewhat critical of the fragmented NBS program in fire research and safety, and it was hoped that he could bring a better focus to the work.[39]

In May 1974, a Programmatic Center for Fire Research (PCFR) was established to perform planning, coordination, and review of all Bureau work on destructive fires. Reporting to Lyons, the new Director of the PCFR, were an Associate Director for Fire Science and Information and an Associate Director for Fire Technology. Robert S. Levine was brought from NASA to fill the former position; Irwin A. Benjamin, chief of the Bureau's Fire Technology Division, was named to the latter post.

To facilitate the changes, the Fire Technology Division was reorganized into two branches, the Fire Science and Information Branch and the Fire Technology Branch. The former division administration retained responsibility for funds, personnel, equipment, and other resources.[40]

In 1974, the Department of Commerce, following the dictate of the Federal Fire Prevention and Control Act, mandated the creation at NBS of a Center for Fire Research.[41] The Bureau soon complied with the act, establishing the center with Lyons

[35] L. M. Kushner, Oral History, June 7, 1988.

[36] NBS Admin. Bull. 73-37, June 11, 1973.

[37] NBS Admin. Bull. 73-62, September 27, 1973.

[38] NBS Admin. Bull. 73-70, October 29, 1973.

[39] John W. Lyons, Oral History, June 1, 1993.

[40] NBS Admin. Bull. 74-39, May 17, 1974.

[41] The originating directive was DOO 30-2B dated April 28, 1975.

as Director, Levine as Chief of the Fire Science Division, and Benjamin as Chief of the Fire Safety Engineering Division.[42]

- Arthur O. McCoubrey to head the Institute for Basic Standards (IBS). Roberts selected Arthur O. McCoubrey, former Vice-President and Director of Frequency and Time Systems, Inc., as Director of IBS effective March 18, 1974. He succeeded David T. Goldman, Acting Director.

  As with other appointments from outside NBS, McCoubrey brought a wealth of understanding of the private sector to the Bureau's senior management. McCoubrey also had considerable experience in research in atomic time and frequency standards, both at Frequency and Time Systems and at Varian Associates.[43]

- Retirements. Several members of Roberts' management team retired during his tenure. Among these was Robert S. Walleigh, Associate Director for Administration under Astin, Branscomb, and Roberts; he had joined NBS in 1943. Roberts recruited Richard P. Bartlett, Jr., a former administrator in the Department of Agriculture, to succeed Walleigh.

  Another senior retiree was George R. Porter, chief of the Personnel Division for nearly a quarter-century. Mati Tammaru was named as his successor.

  Clarence N. Coates, Assistant to the Director for Congressional Relations and an NBS employee for twenty years, also retired. He was succeeded by Esther C. Cassidy, formerly a physicist in both the Heat Division and the Electricity Division and an expert in high-voltage measurements.

A New Secretary of Commerce

In February 1975, President Ford asked Frederick B. Dent to become his Special Representative for Trade Negotiations, a post that would bring Dent into the General Agreement on Tariffs and Trade.[44] Dent thus completed two years as Secretary of Commerce, during which he served and defended President Nixon with great vigor. Dent also was credited with inducing U.S. industry to pursue a policy of energy conservation.

Ford acted quickly to replace Dent, nominating Rogers C. B. Morton—Secretary of the Interior since 1971—for the Commerce post on March 27, 1975. Morton had served the State of Maryland in the House of Representatives from 1962-71, where

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[42] NBS Admin. Bull. 75-26, June 11, 1975.

[43] A. O. McCoubrey, Oral History, November 3, 1986.

[44] Edwin L. Dale, Jr., "President Names Dent Top Trade Negotiator," *New York Times*, February 28, 1975, p. 43.

NBS Congressional Liaison Esther Cassidy and NBS Director Richard W. Roberts spoke with Senator Claiborne Pell of Rhode Island (right) and a member of his staff, Bill Young (left), on the steps of the Gaithersburg Administration Building. Pell spoke at a Metric Education Conference held at the Bureau in May 1975.

In November 1974, members of the National Bureau of Standards (NBS) Executive Board posed for a photograph on the spiral staircase in the NBS/Gaithersburg library. From right to left were Arthur O. McCoubrey, Robert S. Walleigh, Ruth M. Davis, F. Karl Willenbrock, Richard W. Roberts, Ernest Ambler, Howard E. Sorrows, John D. Hoffman, and Edward L. Brady.

he had become a close friend of then-Congressman Ford. In an article describing the appointment, New York Times reporter B. A. Franklin stated:

> The move will also place Mr. Morton in a position where he could begin organizing the financial base for Mr. Ford's announced 1976 election campaign, a function for which the top Commerce post has long served.[45]

[45] Ben A. Franklin, "Morton, in a Cabinet Shift, Picked for Commerce Job," *New York Times*, March 28, 1975, p. 1.

Sure enough, Morton left his Commerce post in January 1976 to become White House counselor on economic and domestic policy matters, in close liaison with the chairman of Ford's Re-Election Campaign Committee.[46]

Betsy Ancker-Johnson, who had replaced Richard O. Simpson as Assistant Secretary of Commerce for Science and Technology (to whom the Director of the Bureau reported) in mid-1973, continued to occupy that position until the beginning of the Carter Administration in 1977.

Roberts Departs for the Energy Research and Development Administration

Despite his considerable abilities in the management of technical work and in the persuasive presentation of its results, several of his senior Bureau aides recall that Roberts never felt quite at home at NBS.[47] The preoccupation of many of its staff with extreme detail and meticulous care did not resemble the type of work that fitted his experience in an industrial laboratory. He also lacked experience with federal research and development and contact with public policy in science and technology. He found, he said, that NBS was not "his cup of tea." After a couple of years as director, Roberts developed the view that he could better realize his personal goals by becoming involved in the Nation's nuclear energy program.

On June 10, 1975, Director Roberts sent a letter to President Gerald Ford resigning from his office. In his letter of resignation, Roberts alluded to the many contributions of NBS to America's scientific and technical life, as well as to the increasingly central role that energy seemed destined to play in the country's progress. Roberts emphasized the importance of energy as "the major technical problem facing the nation in the years ahead." He further specified nuclear energy as offering "great potential," and "a great individual challenge in helping fulfill that potential."

As his principal reason for leaving NBS, Roberts stated his intention to accept a pending nomination to the post of Assistant Administrator for Nuclear Energy in the newly formed Energy Research and Development Administration. Roberts asked that his resignation become effective upon his confirmation in his new position.[48]

The Energy Research and Development Administration (ERDA) was created to focus the administration's energy-conservation efforts. Prior to the formation of ERDA, responsibility for energy programs was fragmented among several Executive-branch agencies, including the Atomic Energy Commission, the Federal Power Commission, and the National Science Foundation. Public Law 93-438, signed by President Ford on

[46] *New York Times*, January 14, 1976.

[47] See Oral Histories conducted by Karma Beal to compare the management styles of Branscomb, Roberts, and Ambler: Arthur O. McCoubrey, November 3, 1986; Robert S. Walleigh, November 5, 1986; F. Karl Willenbrock, November 7, 1986; Ernest Ambler, November 7, 1986; Edward L. Brady, November 10, 1986; and Howard E. Sorrows, December 10, 1986.

[48] Letter, RWR to President Gerald Ford, June 10, 1975, RHA; RG 167; Director's Office; Box 283; Folder RWR Chron; June 1- June 30, 1975.

October 11, 1974, dissolved the AEC, replacing it with the Nuclear Regulatory Agency and ERDA. Robert C. Seamans, Jr., former Secretary of the Air Force, was the first and only Administrator of ERDA—the agency was replaced by the Cabinet-level Department of Energy on October 1, 1977. President Jimmy Carter named James R. Schlesinger to the post of Secretary of Energy.

A week after receiving Roberts' letter of resignation, President Ford responded with abundant praise for his leadership in organizational development and program planning at NBS. Ford accepted the resignation on Roberts' terms. Roberts left his Bureau post on June 28, 1975.

Coincidentally, June 10, 1975 was not only the date of Roberts' resignation from the Bureau directorship; it also marked the beginning of the two-day formal Visiting Committee meeting at NBS. Although no inkling of his departure had been given to the committee, Richard Roberts greeted them with the announcement that on that very day he had tendered to President Ford his resignation as NBS Director.[49]

After Roberts' departure, a message from him to the NBS staff was published in the Bureau's employee bulletin issued July 16, 1975:[50]

> On June 30, 1975, I was sworn in as Assistant Administrator for Nuclear Energy in the Energy Research and Development Administration. This new assignment involves one of the most challenging technical problems facing the Nation—that of providing abundant energy for the years ahead.
>
> NBS is unique in mission, reputation, and quality of staff. The work done here is important to science, commerce, industry, government, in fact to all Americans. My leaving the Bureau does not mean an end to my interactions with you. ERDA, like all technical institutions, relies heavily on NBS output.

Like Seamans, Roberts remained at ERDA until its demise in 1977. Then he returned to the General Electric Corporation as a member of the Corporate Technology staff.

For the second time in succession, a newly appointed director of the Bureau had failed to reach his third anniversary. Five men had led NBS through its first 68 years; now two were gone in the space of another six years, leaving the staff to wonder whether change at the top was to become the new norm.

On June 30, 1975, Betsy Ancker-Johnson, Assistant Secretary of Commerce for Science and Technology, designated Ernest Ambler as Acting Director of NBS on behalf of President Ford and Secretary of Commerce Morton. Robert Walleigh, only a few months retired from his long-time position as Associate Director for Administration, was coaxed by Ambler to return to NBS as Acting Deputy Director.[51]

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[49] Transmittal letter of Visiting Committee verbal report to the Secretary of Commerce, RWR to Arthur M. Bueche, Committee Chair, June 18, 1975, RHA; RG 167; Director's Office; Box 283; Folder RWR Chron; June 1- June 30, 1975.

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

[51] Oral History, Robert S. Walleigh, November 5, 1986.

Roberts' Impact on NBS

Ernest Ambler, Roberts' successor as Director of NBS, recalled three features of his predecessor's leadership as having been especially useful to NBS in the increasingly political environment in which it operated.[52]

First, Roberts demanded from the Bureau staff a high level of "readability" for all management-level presentations—use of many colorful slides, persuasive references to user communities and minimization of arcane or tedious technical details. Adoption of a showy style to present topics that were really technical in nature engendered time, effort and—in the case of many old-time Bureau hands—grumbling, but Ambler was convinced that technical presentations became more effective as a result of the change.

A second Roberts initiative was to combine the NBS Program Office, the Budget Office, and the Accounting Division into a new unit known as the Office of Programs, Budget and Finance. Ambler himself was responsible for carrying out this change, which he felt provided much-needed streamlining of the Bureau's project administration.

The third significant feature of Roberts' leadership in Ambler's view was the elevation in importance of close liaison between NBS and Congress. Early in 1975 Roberts brought Esther Cassidy, an experienced scientist in the area of high-voltage measurements, to his staff as Assistant to the Director for Congressional Liaison. Among other activities, her responsibility was to ensure that Bureau programs were well understood by members of Congress and their staffs. Ambler stated:

> This last activity contributed to Congress holding 1977 Authorization Hearings,[53] the first held since 1971. This ended their reliance on a 'continuing authorization' and began regular annual authorization hearings starting in 1979 with a so-called 'field hearing' in the Red Auditorium at NBS with (Congressmen) George Brown and Don Fuqua attending.

An early consequence of Roberts' desire for improved presentation skills by NBS managers was the initiation of regular reviews of Division programs. These took on the appearance of "screen tests," with as much emphasis on style as on content. They were held in the Bureau's Green Auditorium with the Program Office staff and all NBS line managers down to section chiefs in attendance. As the ground rules became clearer, the presentations became more polished, occasionally with two projectors of color slides in operation at once. As was true in any organization, better performance in the reviews meant a happier life for managers at NBS.

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[52] Ernest Ambler, "Historical Perspective: 1973-1988" in *NBS/NIST A Historical Perspective, A Symposium in celebration of NIST's Ninetieth Anniversary, March 4, 1991*, NIST Special Publication 825, April 1992, pp. 31-42.

[53] The reader should recall that Authorization Hearings led to *permission* or to a *mandate* for Bureau activities, whereas Appropriation Hearings (see A Program in Technology Incentives later in this chapter) led to *funding* (or lack of funding) for them.

There is no doubt that Roberts wholeheartedly endorsed the energy-conservation, environmental-protection, and other consumer-oriented goals of the Nixon administration. One of his first actions as director was to change its scientifically oriented *Technical News Bulletin* into a popular-science format. Whereas the *Technical News Bulletin* was of interest mainly to scientific and technical workers in industry, government, and academia, its replacement, entitled *Dimensions/NBS,* was slanted towards the "man-in-the-street." In a leadoff announcement of the change, Roberts wrote:

> Since its founding at the turn of the century, the National Bureau of Standards has communicated the results of its work to the public. Initially, that public was largely the academic, scientific, engineering, and technical communities, and they are still in the forefront.
>
> In the last decades, however, a new pattern emerged. As the Bureau became more directly involved in immediate national problems and goals, its work also began to interest additional, broader audiences.
>
> At present our audience includes not only practitioners of the professional disciplines but also—very literally—the people who live down the block: the consumer, the student, the housewife, the homeowner.[54]

Roberts' view of the NBS constituency colored his whole approach to the Bureau's work. His efforts accelerated changes in the composition of its workforce and its mission that eventually would remake the National Bureau of Standards.

Technical Work of the Bureau, 1972-75

Despite the growing trend that eventually would take many of the Bureau's resources away from basic studies in physics and chemistry—and from fundamental standards work, too—most of the NBS technical work followed well-worn paths during the directorship of Richard Roberts. Projects attacking the energy crisis, environmental concerns, and public safety perhaps were better identified and more publicized than they might have been in earlier years, but a major swing in the Bureau's direction would have been hard to document.

As was the case in previous chapters, we offer in the following pages a few examples—chosen from a multitude of projects in dozens of laboratories—that provide glimpses into the minds of NBS scientists and evidence of the status quo in a unique institution.

A Program in Technology Incentives

The *Experimental Technology Incentives Program* (ETIP), created in concept during the directorship of Lewis Branscomb, began to produce results under Richard Roberts. The charter for the project was recorded in the House Appropriation hearings for Fiscal 1973:[55]

[54] R. W. Roberts, "to our readers," *Dimensions/NBS,* p. 179, August 1973.

[55] House Hearings for Fiscal 1973 (March 28, 1972) pp. 1085-1086.

> In partnership with the private sector, NBS will test the usefulness of various mechanisms and incentives to stimulate the generation and application of private research and development in ways that permit the private sector to further the Nation's productive capacity, industrial competitiveness, and our national well-being. The end product of this program is a better understanding of these mechanisms and incentives.

In creating ETIP, the Administration—mimicking successful foreign competitors—was seeking ways to make U.S. industry more effective in an effort to improve a dismal economy. It was not the usual type of request made of the Bureau, but a worthy goal nonetheless.

As noted earlier, Jordan D. Lewis, late of the Battelle Memorial Institute in Columbus, Ohio, where he headed applied technology programs, was selected by Richard Roberts to lead ETIP.[56] Lewis named Richard T. Penn, on the staff of the Institute for Applied Technology since coming to the Bureau in 1970, as his deputy for operations.

In concept, ETIP was similar to a project lodged in the National Science Foundation, called the *Experimental Research and Development Incentives Program.* Although a merging of the two efforts was considered during the planning stages, they remained separate because of the differing types of activity involved.

The ETIP experiments initially involved four program areas: procurement, regulation, civilian research and development, and small business.

In the procurement area, headed by Ralph Bara and Joseph G. Berke, a variety of ideas were tested by which the Federal Government, a mammoth customer for technical products, could pull U.S. industry towards innovation. Among the ideas were the use of performance specifications rather than design specifications as a means to spur innovative solutions to problems such as unwanted noise in appliances. As an example of this idea, the General Services Administration in 1974 advertised for bids on 10,000 lawn mowers with the proviso that they radiate 50 % less acoustic noise than the then-current average for that type of tool.[57] Later, NBS cooperated with the Consumer Product Safety Commission by measuring sound levels endured by operators of small, motorized lawnmowers.

The GSA bid also illustrated the principle of prototype purchasing, in which the government could acquire promising new products not yet on the market. Other procurement features included the use of multi-year procurement, value incentives, and cost contracting.

In the regulation area, four state public-utility commissions were selected for experiments applying computerized data and analysis techniques to improve utility rate-setting processes and regulatory practices. Philip J. Harter, chief of the ETIP regulatory programs, provided details of the experiments in an article in *Dimensions/NBS.*[58] It

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[56] "New ETIP Director at NBS," *Dimensions/NBS,* Vol 57, October 1973, p. 249.

[57] "ETIP on the move," *NBS Standard,* April 24, 1974, pp. 4-5.

[58] "ETIP, Utility Commissions and Policy Experiments," *Dimensions/NBS,* Vol. 59, May 1975, p. 112.

In a project undertaken with the Consumer Product Safety Commission, Jonathan Adler of the NBS Sound Section measured the sound level and thus the hearing-damage potential of a power lawnmower. The sound of the mower was picked up by microphone just below his right ear.

was hoped that elimination of delay and uncertainty among regulators would remove barriers to technological innovation.

In a third area, headed by James Kottenstette and Gregory C. Tassey, Federally sponsored research and development was used in an attempt to create new products for sale to the general public. In one experiment, the government issued a request that industry provide non-flammable cotton-polyester fabric. In response to the request, a group of yarn and textile manufacturers, university scientists, chemical companies, and other technical organizations formed a consortium to bring such a fabric to market.

In a fourth area, the impacts of regulatory compliance and the dearth of venture capital on innovation by small business were examined.

The ETIP experiments continued until 1977.[59] Evaluating the success of the program was not an easy task, inasmuch as the efficiency of whole industries was involved. But it was gratifying to NBS management to see the trust in the ingenuity of the Bureau that was implied by the request that NBS undertake the project. ETIP did not involve physical or chemical measurements or standards, or any of the other usual activities of NBS—only its capability for problem-solving.

[59] See "Evaluative Reports on the Experimental Technology Incentives Program for 1975, 1976, and 1977," National Academy of Sciences.

The Bureau Gets a New Fire Law and a New Fire Center[60]

America Burning

On May 14, 1973, the National Commission on Fire Prevention and Control issued a report entitled *America Burning*. The report had been mandated in the *Fire Research and Safety Act of 1968.*

America Burning was a powerful indictment of America's fire safety record. Among the major industrial nations of the world, the United States had the highest per capita death and property-loss rate caused by fire. In 1973, fires killed 12,000 people and injured 300,000. Of these, 50,000 were hospitalized for extended periods. The total economic cost of fire was estimated at $11 billion for that year.

Ninety recommendations intended to reduce by 50 % the level of American fire losses were included in the report: among these were suggestions that NBS and the National Science Foundation collaborate in sponsoring research on fire prevention, fire-fighting, and fire-service needs; that NBS and the National Institutes of Health collaborate in developing standards for combustion toxicology; and that NBS develop guidelines for a systems approach to fire safety.

The awful numbers in the Commission report immediately triggered new action in the Congress. Among some 173 pieces of legislation introduced in the 93rd Congress was a bill entitled *Fire Prevention and Control Act of 1973.* It was introduced jointly by Senator Warren Magnuson and Representative Wright Patman.[61] Utilizing many of the suggestions made by John Rockett and Alex Robertson of the NBS Fire Research and Safety Office, the committees crafted a new law, the *Federal Fire Prevention and Control Act of 1974,* Public Law PL93-498, 88 Stat. 1535-1549, enacted on October 29, 1974.

Federal Fire Prevention and Control Act of 1974

The new act called for the creation within the Department of Commerce of a National Fire Prevention and Control Administration (NFPCA) with the primary responsibility for public education on fire and for developing the "technology" of fire-fighting—equipment and equipment standards for compatibility. The NFPCA was to be directed by an Administrator whose duties would include supervising a National Academy of Fire Prevention and Control and a National Fire Data Center, as well as providing assistance to state and local fire programs.

The Academy was created to develop and offer training to state fire officials and to assist in developing training-certification criteria. The Data Center was to "gather, analyze, publish, and disseminate information related to the prevention, occurrence, control, and results of fires of all types."

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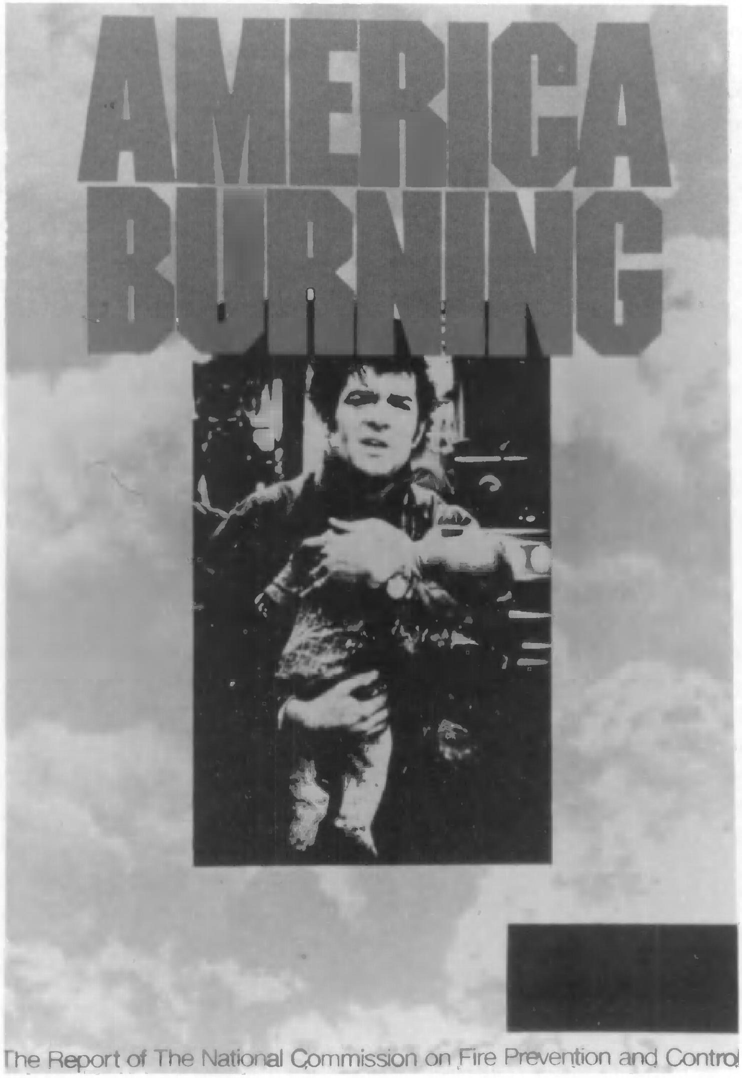
[60] Much of this material came from an excellent summary written by Daniel Gross; "Fire Research at NBS: The First 75 Years," an invited lecture at the *Third International Symposium on Fire Safety Science,* 1989, pp. 119-133.

[61] House hearings, FY 1975, p. 843, pp. 838 ff, April 9, 1974.



America Burning: The Report of The National Commission on Fire Prevention and Control (1973). The report contained fire statistics that showed the United States had one of the highest per-capita fire-loss rates in the world.

Center for Fire Research

One of the provisions of the Fire Prevention Act of 1974 established at NBS a Center for Fire Research (CFR), "To conduct basic and applied fire research, research into the factors influencing human victims of fire, and operation tests, demonstration projects, and fire investigations." The CFR would act independently of the NFPCA, but would consult with the Administration to assure that the two programs continued to be complementary. The Center was to be funded as a separate line item in the Bureau's budget, with support at the level of $3.5 million for Fiscal year 1975 and $4 million for Fiscal year 1976.

The Bureau's Center for Fire Research was finally to become a full-fledged, highly focused operation that would include an integrated research program as well as a University-grants-and-contracts collaboration with the National Science Foundation. As noted earlier, John W. Lyons, recently hired from the Monsanto Corporation to direct the NBS fire effort, became Director of the new organization.

The overall plan of PL93-498 offered a wide-ranging and useful effort, centered in the Department of Commerce, to reduce America's scandalous fire losses. Total Commerce budget requests for Fiscal years 1975 to 1977 were expected to amount to $6 million, $8 million, and $10 million, respectively, with the share for projects in the NBS Center for Fire Research scheduled for $2 million, $3 million, and $3.3 million.[62]

Shortly after enacting the Federal Fire Prevention and Control Act, the Congress decided to mandate the transfer of a set of fire-research grants from the National Science Foundation (NSF) to NBS. The program, funded at about $2 million per year, was part of NSF's *Research Applied to National Needs* activity. It supported a spectrum of fire-research studies at several universities and non-profit institutions. This assignment provided a valuable addition to the Bureau fire program, giving it direct access, either in-house or by contract, to much of the world's most advanced fire research.

Center Director Lyons took positive steps to ensure that the job of monitoring outside contracts would become a benefit to NBS fire research, not a detriment. Each grant was assigned to one or another of the Center's research groups, and the work of the grant was reviewed along with the in-house work of the group. That approach worked well—in later years, Lyons considered that the Center for Fire Research (CFR) experience was instructive in preparing NIST personnel for similar contract monitoring when he became Director. In addition, a number of future CFR employees became acquainted with the Bureau through the program.

At the request of NBS Director Ambler, Lyons and his senior staff prepared a detailed document, which they titled *Reducing the Nation's Fire Losses—The Research Plan,* that presented CFR proposals to fulfill the manifold requirements of the 1974 fire act. Ambler was pleased with the plan and circulated it both within and outside NBS.[63]

Law Enforcement Steps Forward at NBS

Work on law enforcement standards began at the Bureau shortly after President Johnson's Commission on Law Enforcement and Administration of Justice wrote a stirring call for safer streets.[64] The 90th Congress responded with the *Omnibus Crime*

[62] Senate hearings for FY 1977, p. 583.

[63] John W. Lyons kindly supplied the information on which much of the foregoing material was based.

[64] *The Challenge of Crime in a Free Society,* 1967.

Control and Safe Streets Act of 1968,[65] which created the Law Enforcement Assistance Administration (LEAA). The LEAA quickly turned to NBS for help in formulating standards that would be useful to state and local police organizations across the United States. Staff members of the Technical Analysis Division responded with new projects on computer-aided courtroom reporting and on the use of television in courtrooms to "get the ball rolling." Then in January 1971 the Bureau's Law Enforcement Standards Laboratory (LESL) became a reality.

Within four years of its founding, LESL had completed more than 45 projects and was pursuing twice that many for three outside sponsors. LESL performed three main types of activities: laboratory testing of equipment; development of equipment performance standards and user guidelines; and rapid-response advice to requesting organizations. LESL provided its many services without laboratories of its own—its managers issued contracts for the necessary laboratory work to capable groups elsewhere within the Bureau or outside. Administratively, LESL formed a part of the Center for Consumer Product Technology, Institute for Applied Technology.

The seven major project areas and their chiefs were: communications systems, Marshall Treado; security systems, Lawrence K. Eliason; investigative aids, Robert C. Mills; protective equipment, Ronald C. Dobbyn; courtroom equipment, Raymond L. Falge; vehicles, Jared J. Collard; and specialized systems, Avery T. Horton.

The lion's share of LESL support—more than 90 %—came from the National Institute for Law Enforcement and Criminal Justice. Smaller amounts came from the National Highway Traffic Safety Administration and the Defense Nuclear Agency. By 1975 LESL had produced on behalf of these sponsors more than two dozen reports, 18 performance standards, two Standard Reference Materials, and a user guideline.[66]

Communications Equipment

Laboratory work to improve police communications equipment or to develop more effective new units was centered in the Electromagnetics Division in Boulder. The effort, directed by Marshall Treado, focused on mobile and hand-held radios, base-station electronics, personal transceivers, transmitters for undercover use, vehicle-locating devices, and sensitive voice and broadcast receivers. In each case, field testing was used to prepare performance standards, thus allowing police units to write specifications addressing their particular needs rather than simply requesting items of existing equipment that might or might not satisfy their requirements.[67]

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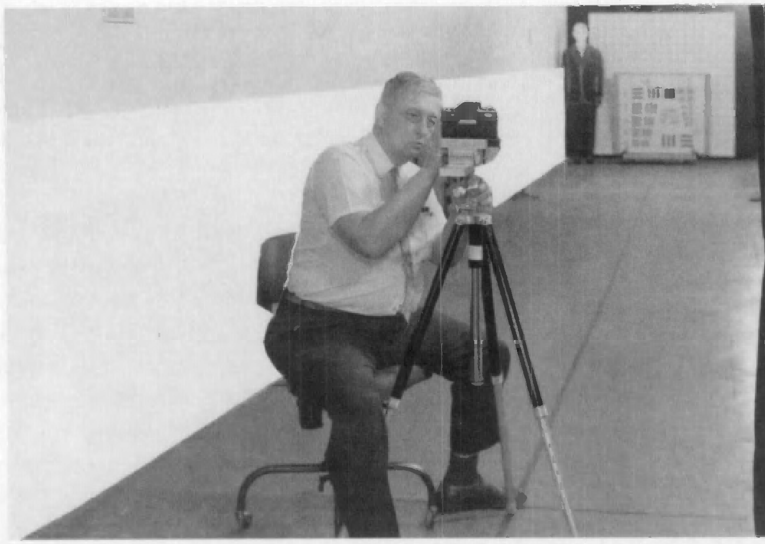
[65] Public Law PL 90-351, 82 Stat. 197, June 19, 1968.

[66] "NBS lab marshals Bureau know-how to help fight crime," *NBS Standard,* July, 1972, pp. 1, 10. See also Jacob J. Diamond, "The Law Enforcement Standards Laboratory," *Dimensions/NBS* **59**, March 1975, pp. 51-53.

[67] Marshall Treado, "Safer Streets Through Improved Communication," *Dimensions/NBS* **59** p. 54, March 1975.



In research for the National Institute of Law Enforcement and Criminal Justice, NBS scientist Joseph C. Richmond adjusted a passive night vision camera in order to photograph an optical chart and a dummy in the Law Enforcement Standards Laboratory.

Legal Record-Keeping

Scientists in the Boulder Electromagnetics Division, under the direction of Raymond L. Falge, studied courtroom use of tape recorders employing both audio and video signals, playback systems, and storage techniques. Much of this equipment was not in common use in U.S. courtrooms, which frequently relied on the older stenographic methods of recording and storage despite their unavoidable uncertainties and delays.[68]

A user guide to recording, replaying, and storage by electronic methods provided a means by which courtroom personnel could design systems to meet their individual needs. Performance standards describing the critical features of recording equipment were developed as well, providing specifications in terms that would satisfy local needs.

The objective of the record-keeping program was to provide the means for any courtroom to record testimony and other needed information in a durable format and to enable courtroom personnel to retrieve the information quickly and to store it efficiently without the danger of loss. In many cases, video recording equipment was found to satisfy courtroom needs far better than previously used methods, allowing

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[68] Raymond L. Falge, "Guidelines For Keeping Better Court Records," *Dimensions/NBS* **59** pp. 56-57, March 1975.

quicker and more accurate acquisition of testimony and preserving lifelike images of witnesses for use long after their departure or demise. Qualities of video images judged most significant were visual resolution, contrast, spectral sensitivity, and freedom from distortion.

Protective Gear

Developing improvements in protective gear for police use was the responsibility of a group operating under the leadership of Ronald C. Dobbyn. Its work encompassed a wide range of equipment. Body armor was one of the first items studied; it was followed by work on helmets, hearing protection, gas masks, face shields, handgun ammunition, and firing-range safety. As with other features of LESL work, the focus was on laboratory evaluation of existing equipment, the development of more satisfactory devices where needed, and the formulation of performance specifications to permit state and local police groups to buy the protection they needed. LESL examined 11 types of riot helmets; only two gave protection to the user that was considered adequate. In preparing typical examples of situations where such gear would be used, NBS scientists devised tests that would determine the forces exerted on helmets by particular objects likely to impact them. This information was then used to develop performance standards useful to many police departments.[69]

Forensic Standards

The increasing dependence of police upon physical evidence to amplify or replace statements of witnesses in turn increased the need for better physical standards for forensic use. Areas studied under the LESL Investigative Aids program, directed by Robert M. Mills, included composition and color of paint for automobiles, glass refractive index and composition, and gunpowder analysis, as well as alcohol detection and quantification.[70] A new Standard Reference Material for glass was developed and produced; a set of 140 automotive paint samples was collected, chemically analyzed, and cataloged;[71] and equipment was developed for use in gunpowder and alcohol detection, parcel screening, and bomb and narcotics detection.

Security Systems

Security systems, as applied to crime work, included an enormous variety of devices. Such mundane objects as doors resided in that group along with burglar alarms, handcuffs, window locks, night-vision viewers, and surveillance cameras. Lawrence K. Eliason led the Bureau effort in this area. One of the first investigations

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[69] Ronald C. Dobbyn, "Helping improve police protection," *Dimensions/NBS* **59**, p. 58, 67, March 1975.

[70] Robert M. Mills, "Toward more objective evidence," *Dimensions/NBS* **59**, p. 59, March 1975.

[71] Charles G. Leete, "Collection of auto paint colors prepared for forensic use," *Dimensions/NBS* **58**, pp. 200-201, September 1974.

Charles G. Leete, Research Associate from the Manufacturers Council on Color and Appearance and co-developer of the NBS Law Enforcement Standards Laboratory automotive paint reference collection, demonstrated the ease of visually matching a paint sample to a vehicle.

LESL performed in the security area involved the evaluation of the effectiveness of handcuffs. The staff found that as little as 27 newtons of force—barely 6 pounds—sufficed to open handcuffs in one shipment received by a state police force. Needless to say, the manufacturer was anxious to replace the entire shipment. LESL produced a draft standard for metal handcuffs based upon testing of actual sample devices.

Examining "thumbcuffs," under consideration as replacements for ordinary handcuffs, the staff found that, to be effective, the cuffs had to be applied so tightly that the prisoner was in danger of losing his thumbs because of severe restriction to the blood supply. A quickly drawn recommendation pointed out the danger in thumbcuffs and suggested that they not be used.

Burglary was estimated to cost the public $750 million per year. The LESL staff found, however, that typical burglar-alarm systems gave up to 99 % false-alarm rates, mostly as a result of improper operator procedures. Examining the detailed functioning of the alarms led quickly to a better understanding of the devices and the preparation of guidelines for their purchase and use.

Other security items under study included door and window locks, an analysis of the abilities of likely forced-entry burglars, and the selection and operation of surveillance cameras.[72]

[72] Lawrence K. Eliason, "Investigating the performance of security systems," *Dimensions/NBS* **59**, pp. 60-62, March 1975.

Vehicles

Jared J. Collard was charged with management of the LESL police vehicle program. He noted some of the many problems encountered in the use of vehicles by typical departments.[73] In compiling an experiential database, NBS surveyed nearly 1400 police agencies; patrol cars were identified as one of the two major equipment problems, not a happy circumstance considering that only police station operating costs and personnel expenses exceeded expenditures for vehicles. Robert G. Massey of NBS initiated a study of the details of police vehicles, including equipment normally carried therein. He found many instances in which departments purchased vehicles simply because of budget restrictions, even though they did not fit the anticipated mode of use.

Rosalie T. Ruegg, a Technical Analysis Division economist, collaborated with the LESL project. She prepared a report reviewing the costs and benefits of repairing or replacing police vehicles as functions of their age and service, basing her work on actual records of police departments. She addressed the advantages and disadvantages of fleet ownership by police units, as well as leasing methods. Ruegg's analysis offered helpful guidelines for hard-pressed police departments.[74]

Properties of Materials

Microbes and the Corrosion of Metals

In 1922, NBS set up a Corrosion Laboratory to augment even-earlier studies of underground corrosion of metallic equipment by stray electrical currents. The new laboratory staff began investigations of the corrosive action of soil itself on buried metal construction components. Utilities, especially gas line companies, were plagued at that time by economic losses arising from corrosion damage to their equipment.[75] Study of underground and underwater corrosion of metals continued apace, both at the Bureau and elsewhere, since that time.[76] Occasional discoveries of new corrosion mechanisms expanded man's understanding of this surprisingly complex phenomenon. One of the more interesting new mechanisms involved microbes, which were found to foster corrosion in as unusual a location as airplane fuel tanks, and, probably, to have hastened or caused the cracking of America's famous Liberty Bell.[77]

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[73] Jared J. Collard, "Patrol car performance and safety studied," *Dimensions/NBS* **59**, p. 63, March 1975.

[74] R. T. Ruegg, "The police patrol car: economic efficiency in acquisition, operation, and disposition," *NBSIR 75-961*, June 1976, 225 pp.

[75] Cochrane, *Measures for Progress*, p. 121.

[76] Warren P. Iverson, "Possible source of a phosphorus compound produced by sulfate-reducing bacteria that cause anaerobic corrosion of iron," *Materials Performance*, May 1998, pp. 46-49.

[77] Warren P. Iverson, private communication to the author.

In 1974, Warren P. Iverson, who was employed as a bacteriologist and microbiologist prior to joining the NBS Metallurgy Division in 1969, received both the Department of Commerce Silver Medal Award and the Charles Thom Award of the Society of Industrial Microbiology[78] for his studies of the role of microbes in underground and underwater metal corrosion. The awards followed a series of publications and talks by Iverson and his colleagues on certain mechanisms by which microbes greatly hastened the rate of corrosion of metallic materials in contact with the earth.[79]

Other members of the Corrosion Section of the Metallurgy Division, led at that time by Jerome Kruger, included Melvin Romanoff (just about to retire after nearly thirty years of corrosion work at the Bureau), William F. Gerhold, W. J. Schwertfeger, Benjamin T. Sanderson and Edward Escalante. Collaborators from the U.S. Army Corps of Engineers and the U.S. Naval Civil Engineering Laboratory included L. L. Watkins and R. L. Alumbaugh.

A microbe-free theory of metallic corrosion in marine environments that related chemisorption and passivity to alloy compositions with particular d-electron configurations was presented at the same time by Lawrence H. Bennett, Lydon J. Swartzendruber and Michael B. McNeil of the Alloy Physics Section of the Metallurgy Division.[80]

In a related microbe-vs-metal investigation, Iverson joined William R. Blair and Frederick E. Brinckman—colleagues from the NBS Inorganic Materials Division—in a collaboration with Rita R. Colwell of the University of Maryland to study the interactions between mercury and microorganisms found in the Chesapeake Bay.[81]

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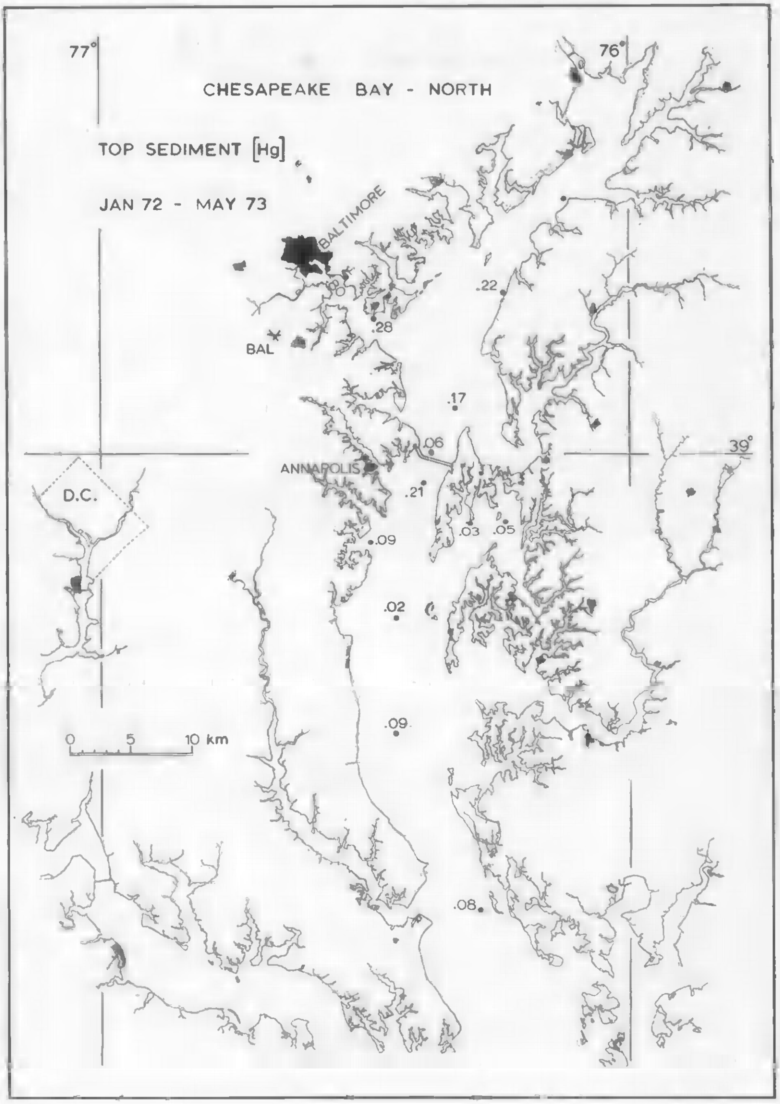
[78] W. P. Iverson, "Anaerobic corrosion: Metals and microbes in two worlds," *Dev. Ind. Microbiol.* **16**, 1-10 (1975).

[79] W. P. Iverson, *Biological Corrosion,* Chapter in *Advances in Corrosion Science and Technology,* M. G. Fontana and R. W. Staehle, Editors, **2**, pp. 1-42 (Plenum Press, New York, 1972). See also W. P. Iverson, "Tests in Soils," (Proc., Symposium on State-of-the-Art in Corrosion Testing, ASTM Annual Meeting, June 21-26, 1970, Toronto, Canada). Chapter 21 in *Handbook on Corrosion Testing and Evaluation,* W. H. Ailor, Ed., (John Wiley & Sons, Inc., New York, 1971) pp. 575-597. See also W. P. Iverson, "The corrosion of mild steel by a marine strain of *Desulfovibrio," Proc. 3d Int. Congress on Marine Corrosion and Fouling, Gaithersburg, Md, Oct 2-6, 1972,* Northwestern University Press, Evanston, Ill., Oct 1973, pp. 61-82. See also W. P. Iverson, "Microbial corrosion of iron," Chapter 19 in *Microbial Iron Metabolism,* Neilands, Ed., (New York: Academic Press, 1974) pp. 475-513.

[80] L. H. Bennett, L. J. Swartzendruber and M. B. McNeil, "On the electron-configuration theory of marine corrosion," *Proc. 3d Int. Congress on Marine Corrosion and Fouling, Gaithersburg, Md, Oct 2-6, 1972,* Northwestern University Press, Evanston, Ill., Oct 1973, pp. 410-426.

[81] W. R. Blair, W. P. Iverson and F. E. Brinckman, "Application of a gas chromatograph—atomic absorption detection system to a survey of mercury transformations by Chesapeake Bay microorganisms," *Chromosphere III,* No. 4, 167-174 (1974).

In 1949, Melvin Romanoff of the NBS Corrosion Section removed and inspected test specimens at a corrosion test site at Loch Raven, Maryland. Romanoff, an internationally known expert on underground corrosion, joined NBS in 1937; except for a year's military service during World War II, he worked at the Bureau until his death in 1970.



Map showing concentrations of mercury in top sediment of the Chesapeake Bay between January 1972 and May 1973. The element was most prevalent near population centers and industrial sites.

Cavitation in Mechanical Failure

The Mechanical Failures Prevention Group, formed during the 1960s under the sponsorship of the Bureau's Metallurgy Division to study ways of mitigating various types of failure in mechanical systems, met on Halloween in 1973 at NBS in Boulder.

It was the 19th meeting of the organization, sponsored by the Office of Naval Research, the National Aeronautics and Space Administration, and the NBS Institute for Materials Research.

The topic of the meeting was cavitation and mechanical failure. Sixteen papers were presented during the three-day meeting. They covered such topics as the physics of cavitation damage to materials, practical examples of cavitation erosion, cavitation in particular fluids, and coatings and other means to prevent cavitation damage.[82]

Fracture in Ceramics

A detailed analysis of slow crack growth in ceramics at temperatures up to 1400 °C was published by A. G. Evans. He discussed both cyclic and static loading conditions, using available data to account for and to predict failures. He discovered that purity of the ceramic was a key element in preventing failure, and that plasticity—leading either to motion of dislocations or to grain-boundary sliding—was a primary factor in the growth.[83]

Sheldon M. Wiederhorn performed a similar study of fracture in glass. Reviewing factors affecting the strength of glass—brittleness, surface flaws, and stress corrosion cracking—Wiederhorn applied the ideas of fracture mechanics to the physics and chemistry of glass strength. He expected that approach to aid in the design of glass structures.[84] The study relied heavily upon an earlier investigation by Wiederhorn and Leonard H. Bolz which employed the methods of fracture mechanics to stress corrosion cracking of glass.[85]

In the earlier work, Wiederhorn and Bolz measured crack velocities as a function of applied stress and temperature. They were able to determine activation energies for crack motion, which they found to be consistent with a universal static-fatigue curve for glass.

Ultra-Pure Materials

Recognizing that contamination of ultra-pure refractory materials by containers was a major problem in the preparation of ultra-pure materials, Alan L. Dragoo and Robert C. Paule considered the advantages of purification in a space environment. As an

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[82] "MFPG. The role of cavitation in mechanical failures," *NBS Special Publication 394,* 183 pp., April, 1974, T. R. Shives and W. A. Willard, editors.

[83] A. G. Evans, "High temperature slow crack growth in ceramic materials," *NBSIR 74-442,* 48 pp., February, 1974.

[84] S. M. Wiederhorn, "Strength of glass—a fracture mechanics approach," *NBSIR 74-485,* 24 pp., May 1974.

[85] S. M. Wiederhorn and L. H. Bolz, "Stress corrosion and static fatigue of glass," *J. Amer. Ceram. Soc.* **53**, No. 10, 543-548 (1970).

illustrative example they studied the advantages for the evaporative purification of molten alumina in zero gravity. They concluded that many thermodynamic criteria would still apply, but with modifications needed to account for weightlessness and reduced pressure.[86]

Stable Lasers, Frequency Standards, the Speed of Light, and New Laser Physics

The Elusive Speed of Light

How fast does light travel? This question fascinated mankind for centuries. Early attempts to measure the elusive quantity, such as the famous timing experiment proposed by Galileo in which lanterns on adjacent mountain tops would be unmasked in sequence, could only prove that light did indeed travel quickly.

Physicists found the speed of light to be an especially compelling constant of nature. Apart from its intrinsic interest, knowledge of the quantity was useful in many physical laws as, for example, when electromagnetic radiation was employed in "ranging" problems—determining distances, either between distant places on the earth or between celestial bodies such as the earth and the moon. An example of this use of the speed of light was presented in Chapter 2 (Lunar Ranging).

As of 1970, the speed of light was known with an uncertainty of a few parts in ten million. For example, a determination of the speed of light was performed in 1958 by K. D. Froome, a physicist at the National Physical Laboratory in England, using a radio interferometer. In his report, he gave as the uncertainty three parts in 10^7 at best. In a monograph summarizing the experiment, Froome and a colleague, L. Essen, stated the nub of the measurement problem succinctly:[87]

> The merits of the optical interferometer for the precision measurement of length or, conversely, the radiation wavelength, are well-known and require no elaboration here. But an interferometer operating with a radiation whose frequency *can be measured* offers an extremely accurate method for the determination of the velocity of this radiation.

To experiment with a form of radiation whose frequency and wavelength could readily be measured, Froome chose to use microwaves of 72 GHz frequency.

Given the difficulty of their measurements, it startled the scientific community when an announcement was made during a press conference in Denver, Colorado, on January 28, 1972 that Richard L. Barger, Bruce L. Danielson, Gordon W. Day, Kenneth M. Evenson, John Hall, F. Russell Petersen, and Joseph S. Wells, using a methane-stabilized laser of known frequency and wavelength, had derived a new value for the speed of light—one with an uncertainty of about three parts in 10^9. The new value was given as $(299{,}792{,}456.\ 2 \pm 1.1)$ meters per second.

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[86] A. L. Dragoo, and R. C. Paule, "Ultrapure materials; containerless evaporation and the roles of diffusion and Marangoni convection," *Proc. 12th Aerospace Sciences Meeting, Washington DC, Jan 30-Feb 1, 1974,* paper No. 74-209, pp. 1-8.

[87] K. D. Froome and L. Essen, *The Velocity of Light and Radio Waves,* (New York: Academic Press, 1969) pp. 136-137.

In 1972, Kenneth M. Evenson was photographed with the apparatus used to measure the frequency of an infrared helium-neon laser, the highest frequency measurement made to that time. Since the wavelength had already been determined in terms of the ^{86}Kr standard, knowledge of the frequency permitted calculation of the speed of light with greatly improved accuracy.

A news report of the Denver announcement was carried in the New York Times on January 31, 1972.[88] The German periodical Der Spiegel carried a similar report on February 14, 1972.

A brief publication of the new, high-frequency, speed-of-light measurement first appeared in the scientific literature late in 1972.[89]

The seven Boulder physicists shared the 1974 Department of Commerce Gold Medal Award for their work.

Key to the *tour de force* of the "Boulder seven" clearly was to devise an accurate measurement of both the wavelength and frequency of the radiation from the methane-stabilized laser.[90] Their success was an interesting example of the power of cohesive effort by a group of dedicated physicists. In a few short years they accomplished scientific work that could easily have taken more than a decade.

[88] Collier N. Smith, "NBS scores measurement breakthrough," *NBS Standard Vol XVII*, No. 3, April 1972, p. 1.

[89] K. M. Evenson, J. S. Wells, F. R. Petersen, B. L. Danielson, G. W. Day, R. L. Barger, and J. L. Hall, "Speed of light from direct frequency and wavelength measurements of the methane-stabilized laser," *Phys. Rev. Lett.* **29**, No. 19, 1346-1349 (1972).

[90] A short but informative account of this work is given by Wilbert F. Snyder and Charles L. Bragaw, *Achievement in Radio*, pp. 634-637.

In 1974, seven physicists from the NBS Boulder laboratories received the Department of Commerce Gold Medal Award for their work on frequency and wavelength standards and for a re-determination of the speed of light. Standing, from the left, are Richard L. Barger, John L. Hall, F. Russell Petersen, and Joseph S. Wells. Seated, from the left, are Kenneth M. Evenson, Bruce L. Danielson, and Gordon W. Day.

Laser Stabilization

One of the first problems to be faced was to stabilize a short-wavelength laser at a totally new level of reproducibility. Early in the project, John L. Hall, one of Lewis Branscomb's first colleagues in the Joint Institute of Laboratory Astrophysics, outlined the problem of deriving wavelength standards from lasers that periodically experienced frequency shifts as large as ten thousand times the theoretical bandwidth. Since the instability affected both the wavelength and the frequency, one could discuss the problem from either point of view. Hall also proposed a solution to the problem.[91]

In his paper, Hall noted that, while the intrinsic spectral bandwidth predicted for gas lasers might be as small as 10^{-13} of its wavelength or even less, the "resettability" of such lasers was typically one part in 10^9. The solution, he stated, was to incorporate

[91] J. L. Hall, "The laser absolute wavelength standard problem," Paper P-1 at the *1968 International Quantum Electronics Conference, May 14-17, Miami, Florida.* Published in *IEEE J. Quantum Elec.* **QE-4**, No. 10, pp. 638-641 (1968).

in the laser a servomechanism that would continually reset the oscillating cavity to some precise feature in the radiant spectrum of the system.

Hall mentioned several possibilities for stabilizing existing lasers: the Lamb dip associated with the 632 nm He-Ne laser, stable within perhaps one part in 10^9, except for pressure effects; dispersion stabilizers based on gain-modulation frequency shifts; and atomic or molecular lines in tag gases included in the laser. He mentioned work done with Harold S. Boyne on Lamb-dip stabilization on the 1 μm neon line, as well as work done elsewhere on an iodine line at 514 nm, which would appear later in a stabilizing scheme. Finally, he referred to work under way with Richard Barger on a 3.39 μm line in methane, which would figure directly in the redefinition of wavelength and frequency standards as well as help provide a greatly improved value for the speed of light.

Barger and Hall attacked the stabilization problem head-on. They showed in 1969 how to obtain a methane line with half-width-at-half-maximum-intensity of approximately 10^{-9} and how to stabilize to the center of the line within about one part in 10^{11}. This level of irreproducibility, the best found up to that time, was less than 1 % of the uncertainty of the then-primary length standard, the 605.7 nm line of ^{86}Kr.[92] The methane line showed exceptionally small shifts arising from changes in pressure or temperature. Furthermore, Barger and Hall found that only modest power densities and moderate laser-line pressure shifts were needed to make use of the line for stabilization of the helium-neon laser. Such a stabilized laser would provide a reproducible radiation source at 88 THz and 3.39 μm, very useful values if they could be measured accurately.

In 1971, Barger and Hall shared the NBS Stratton award for "extraordinary creativity in the application of lasers to the science of measurement."[93] Barger and Hall had utilized the methane-stabilized helium-neon laser for new length measurements. Their work was only part of the flood of laser-based physics that came from the Boulder laboratories in that period.

Frequency Measurement

Obtaining an accurate value for the frequency of the methane line presented a difficult hurdle. There was a large difference in frequency between the methane line and the existing cesium-beam standard. The high optical frequencies of laser lines seemed out of reach.

Evenson and his colleagues overcame the calibration problem by constructing a "chain" of overlapping frequency measurements. In February 1970, Evenson, Wells, Lawrence M. Matarrese, and Lyman B. Elwell reported measurements of the absolute frequencies of two water-vapor laser lines, at 3.8 THz and 10.7 THz.[94] They used a

[92] R. L. Barger and J. L. Hall, "Pressure shift and broadening of methane line at 3. 39 μ studied by laser-saturated molecular absorption," *Phys. Rev. Lett.* **22**, No. 1, 4-8 (1969).

[93] "Stratton and Rosa awards presented," *NBS Standard,* Vol XVI, No. 6, June 1971, p. 1.

[94] K. M. Evenson, J. S. Wells, L. M. Matarrese, and L. B. Elwell, "Absolute frequency measurements of the 28- and 78-μm cw water vapor laser lines," *Appl. Phys. Lett. 16,* No. 4, 159-161 (1970). The correct interpretation of the water vapor laser lines—and the HCN laser lines as well—was provided by David R. Lide, Jr. and Arthur G. Maki, "On the explanation of the so-called CN laser," *Appl. Phys. Lett.* **11**, p. 62 (1967).

"catwhisker diode" comprised of tungsten on nickel to achieve harmonic generation and mixing of the water-vapor laser lines with radiation from an HCN laser and from phase-locked klystron tubes. They found proper adjustment of the diode to be "onerous." However, the two frequency measurements made thereby were evaluated in comparison to the NBS cesium-beam frequency standard, with an estimated uncertainty of 1 ppm and 0.2 ppm, respectively. These were the highest frequency calibrations yet reported.

The new high-frequency record lasted only a few weeks. Using the same point-contact diode technique to detect beat frequencies, Evenson, Wells and Matarrese reported in March 1970 yet higher frequency measurements, this time of lines in the 28 THz branch of the CO_2 cw (continuous-wave) laser.[95] The measurement was made possible by use of the 3.8 THz and 10.7 THz lines of the water-vapor laser, and a klystron operating from 26 GHz to 28 GHz. The balky diode was even less stable at the higher frequency, but two lines were measured at 28.3 THz with an uncertainty of 1 ppm.

The next step in this frequency-measurement odyssey was completed in late 1971 by Evenson, Day, Wells, and L. O. Mullen, with measurements of the frequency of the 88 THz methane stabilization line in the helium-neon laser.[96] Once again, the Boulder team broke the record for the highest absolute frequency measurement. Radiation from a CO_2 laser and a 50 GHz klystron were used along with the He-Ne radiation to make the measurement, with harmonic generation and mixing again occurring in a tungsten-on-nickel diode. The resulting uncertainty was quoted as 0.6 ppm.

The accuracy of the frequency measurements reported thus far had been limited by the way in which the lasers were tuned. Evenson, Wells, Petersen, Danielson, and Day[97] were able to improve the accuracy of the measurements substantially—as much as 100 times—by tuning them to molecular transitions in CO_2 and CH_4. In the paper cited in the previous paragraph, the authors described the entire calibration chain, from the cesium-beam frequency standard as maintained by NBS to the 88 THz methane line. The frequency chain, a three-step process, had required the manipulation and careful measurement of five different lasers and five klystron sources. In step 1, an HCN laser was frequency-locked to a quartz crystal oscillator, using two klystrons; the H_2O laser was frequency-locked to the stabilized CO_2 laser and the beat frequency between the H_2O and HCN lasers was measured. In step 2, the difference between the two CO_2 lines was measured. In step 3, the frequency of the 3.39 μm line in methane was measured relative to one of the lines of the CO_2 laser. Values for each of the three measured molecular transitions were given, with uncertainties ranging from 1 to 1.5 parts in 10^9.

[95] K. M. Evenson, J. S. Wells, and L. M. Matarrese, "Absolute frequency measurements of the CO_2 cw laser at 28 THz (10.6 μm)," *Appl. Phys. Lett.* **16**, No. 6, 251-253 (1970).

[96] K. M. Evenson, G. W. Day, J. S. Wells, and L. O. Mullen, "Extension of absolute frequency measurements to the cw He-Ne laser at 88 THz (3.39 μ)," *Appl. Phys. Lett.* **20**, No. 3, 133-134 (1972).

[97] K. M. Evenson, J. S. Wells, F. R. Petersen, B. L. Danielson, and G. W. Day, "Accurate frequencies of molecular transitions used in laser stabilization: The 3.39 μm transition in CH_4 and the 9.33- and 10.18 μm transitions in CO_2," *Appl. Phys. Lett.* **22**, No. 4, 192-195 (1973).

Wavelength Measurement

The measurement of the wavelength of the stabilized methane line at 3.39 μm was the final piece of the speed-of-light accomplishment. Barger and Hall, who had demonstrated the stability of the line, also measured its wavelength.[98] They used a frequency-controlled Fabry-Perot interferometer for the purpose. It was necessary to compare the methane-line wavelength to the length standard, the line of ^{86}Kr defined to be 605.7802105 nm.

The uncertainty of the Kr standard was limited by an asymmetry in the standard line. This asymmetry was discovered only after the frequency of the line had been defined by international agreement. Because of the standard line asymmetry, the methane wavelength was given by Barger and Hall as 3.392231404 μm and 3.392231376 μm. The two values represented the wavelength of maximum intensity of the Kr line and the center of gravity of the line, respectively. The uncertainty of the measurement was estimated as ±3.5 in 10^9.

A New Value for the Speed of Light

The assumption underlying the entire project was that the product of the frequency and wavelength of an electromagnetic wave truly represented the speed of propagation of that wave. With absolute values available for both the wavelength and the frequency of the methane line used in the experiments, all that remained to provide a new value for the speed of light, in principle, was a simple multiplication. Evenson, Wells, Petersen, Danielson, Day, Barger, and Hall provided that final step in the letter to the Physical Review that was mentioned earlier.[99]

In their paper, the Boulder group referred to the utility of stable, reproducible lasers as references for both frequency and wavelength. They also noted that the methane-stabilized helium-neon laser operating at 3.39 μm and 88 THz could provide these references in the range where precision could be optimized, and they reviewed the methods used for calibration of both wavelength and frequency of the methane line. They called attention once again to the characteristics of the length standard that limited its accuracy. In order to minimize the uncertainty of the speed of light resulting from their measurements, the group selected one feature of the ^{86}Kr line—its center of gravity—which they found that they could identify within ±3.5 parts in 10^9. That uncertainty then dominated the overall determination of the speed of light, given as $c = (299\,792\,456.2 \pm 1.1)$ m/s.

The new determination of the speed of light agreed with the previous value, but carried a lower uncertainty by nearly a factor 100. Their result also agreed with a new value simultaneously presented by an NBS Gaithersburg group (see below). In order to

[98] R. L. Barger, and J. L. Hall, "Wavelength of the 3.39-μm laser-saturated absorption line of methane," *Appl. Phys. Lett.* **22**, No. 4, 196-199 (1973).

[99] K. M. Evenson, J. S. Wells, F. R. Petersen, B. L. Danielson, G. W. Day, R. L. Barger, and J. L. Hall, "Speed of light from direct frequency and wavelength measurements of the methane-stabilized laser," *Phys. Rev. Lett.* **29**, No. 19, 1346-1349 (1972).

make best use of the new results, the group recommended that consideration be given to revising the length standard by assigning a particular value to the wavelength of one of the optically stabilized lasers. As an alternative, they noted that the speed of light could be set by international agreement and the wavelength of the lasers set by experiment. Their paper provided a fitting and well-stated conclusion to a group project that was brilliantly conceived and carefully carried out.

A "Gaithersburg" Value for the Speed of Light

As happens frequently in science, while the NBS Boulder group was in the midst of its re-determination of the speed of light, a second re-determination—quite independent of the first—was in progress in the Bureau's Gaithersburg laboratory.

Zoltan Bay and Gabriel G. Luther of the Quantum Metrology Section of the Optical Physics Division, in collaboration with John A. White, a colleague from The American University, published a new value for the speed of light a few months before the Boulder group.[100] The Gaithersburg group used an ingenious scheme for modulating the light from the 633 nm line of a helium-neon laser by the use of microwaves. The technique produced the frequency difference between sidebands generated by the modulation process, as well as the ratio of the frequencies of the sidebands. The frequency of the laser line was thus calculated in terms of the microwave frequency, which could be measured directly in terms of the primary standard of frequency at 100 kHz.

The value given for the red-line frequency was $\nu = (473\ 612\ 166 \pm 29)$ MHz or slightly in excess of 473 THz. Using a value for the wavelength of the He-Ne red line given earlier by Christopher Sidener of the Bureau's Optical Physics Division, $\lambda = (632.991\ 47 \pm 0.000\ 01)$ nm, Bay, Luther, and White obtained for the speed of light the value $c = (299\ 792\ 462 \pm 18)$ m/s. This value, while not determined with the low uncertainty level claimed a few months later by the Boulder group, was entirely consistent with their result.

Thus it happened that, within the short space of a few months in 1972, two independent determinations of the speed of light shone forth from NBS, each providing an unprecedented level of uncertainty for one of the most prized of the fundamental constants.

The Task Group on Fundamental Constants, Committee on Data for Science and Technology (CODATA) of the International Council of Scientific Unions included in its report of August 10, 1973, the speed of light as evaluated by the Boulder group. Meeting in October of the same year, the Consultative Committee for the Definition of the Meter (the operative arm of the International Committee for Weights and Measures (CIPM) in the area of length) recommended that the CIPM consider adoption of the 3.39 μm methane transition studied by the Boulder group as a length standard.

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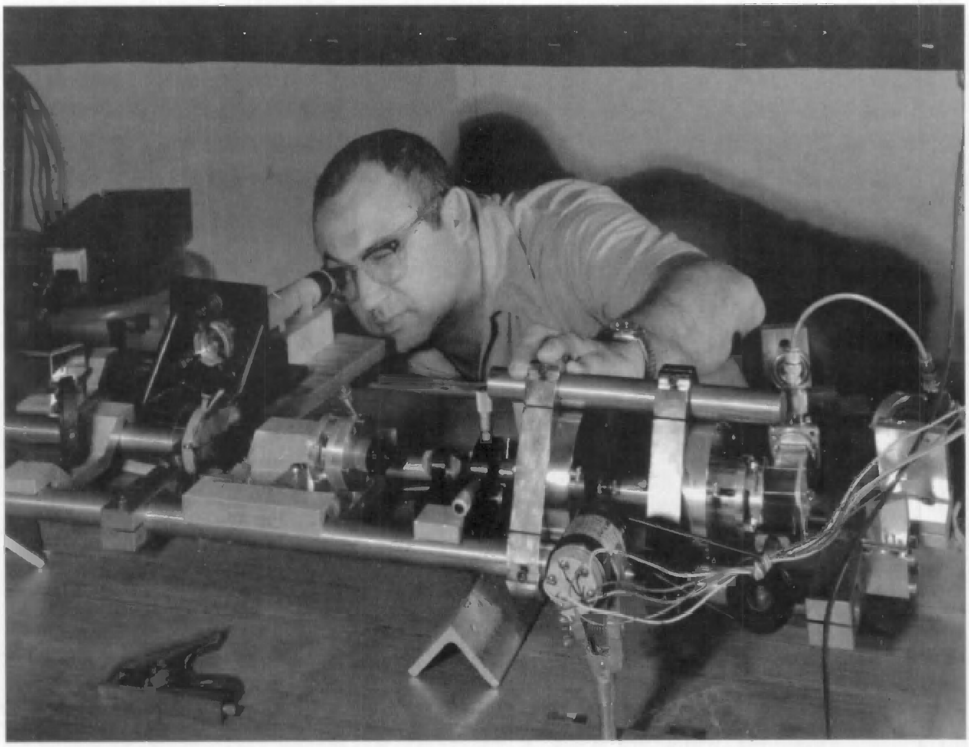
[100] Z. Bay, G. G. Luther, and J. A. White, "Measurement of an optical frequency and the speed of light," *Phys. Rev. Lett.* **29**, 189 (1972).



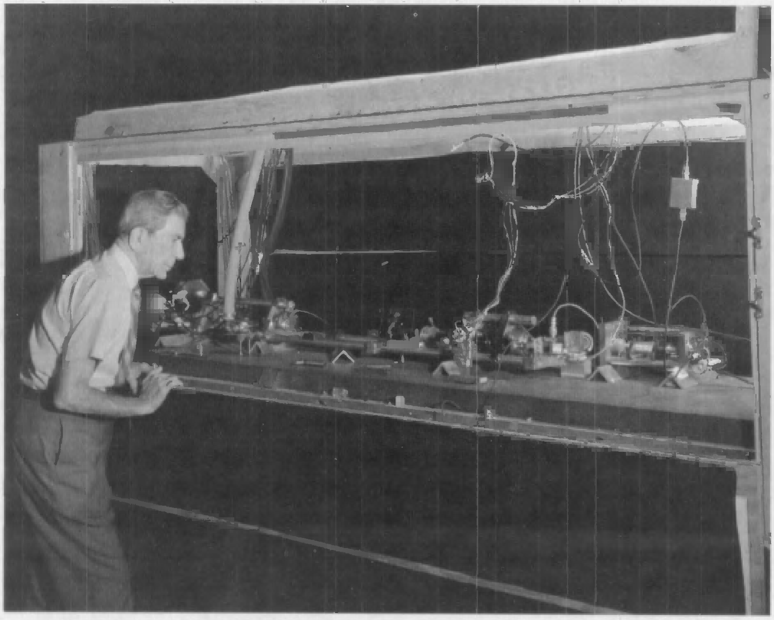
Fine optical adjustments were made by Gabriel G. Luther of the NBS Optical Physics Division during measurements of the optical frequency of the 633 nm red line of a helium-neon laser.

As might have been expected, development of new, more precise measures for length and frequency led to many new measurements and discoveries not directly related to the speed of light. It is interesting to highlight some of these to indicate the type of "spinoff" scientific results that nearly always accompanied advances in metrology.

Lasers and Magnetic Resonance

One of the first of these was the use of lasers in magnetic resonance. Evenson and Wells collaborated with Herbert P. Broida and Robert J. Mahler of NBS and with Masataka Mizushima of the University of Colorado in using an HCN laser to observe paramagnetic resonance absorption in molecular oxygen.[101] Mizushima had noted the coincidence between certain oxygen energy-level separations and the HCN laser frequency at 890 GHz, given the application of a magnetic field of the proper strength.

[101] K. M. Evenson, H. P. Broida, J. S. Wells, R. J. Mahler, and M. Mizushima, "Electron paramagnetic resonance absorption in oxygen with the HCN laser," *Phys. Rev. Lett.* **21**, No. 15, pp. 1038-1040 (1968).



Zolton Bay studied the apparatus used to measure the frequency of a helium-neon laser line.

The successful experiment provided the first observation of absorption between the oxygen levels. It opened a new window into molecular spectroscopy.

Acting on the results of their experiment, Wells and Evenson constructed an improved electron paramagnetic resonance spectrometer based on the use of the HCN laser.[102] The new spectrometer featured a sample cavity that was integral with the HCN laser, separated only by a polyethylene membrane. Its signal-to-noise ratio was higher than the earlier version by a factor of ten or more. Many investigators were attracted to the Boulder laboratory by the prospect of using it.

The new tool was soon put to use by Evenson and Wells in collaboration with Harrison E. Radford, a staff member of the NBS Heat Division until 1970 when he joined the Smithsonian Astrophysical Observatory. Evenson, Wells and Radford investigated the 79 μm electric dipole spectrum of OH, a free radical which they suspected might participate in stellar maser action.[103] Use of the technique enabled the authors to identify an energy coincidence between the OH lines and a line in water, confirming the possibility of maser pumping involving OH.

[102] J. S. Wells and K. M. Evenson, "A new LEPR spectrometer," *Rev. Sci. Instrum.* **41**, No. 2, p. 226 (1970).

[103] K. M. Evenson, J. S. Wells and H. E. Radford, "Infrared resonance of OH with the H_2O laser: a galactic maser pump?" *Phys. Rev. Lett.* **25**, No. 4, 199-202 (1970).

Evenson, Radford and M. M. Moran, Jr., another colleague at the Smithsonian Astrophysical Observatory, quickly investigated yet another interesting case. They identified the fundamental hydrocarbon radical CH, long since known to astronomers by its optical interstellar absorption lines. The radical was expected to appear in the microwave spectrum in the form of a 10 cm Λ-type doubling spectrum, but it had proved singularly elusive in the laboratory. The group was successful immediately with the technique of laser magnetic resonance, using an oxyacetylene flame burning within a water laser. They took advantage of the coincidence between the separation of rotational levels in the CH radical and the 118.6 μm line of the water laser, using a 2 T magnetic field to Zeeman-split the levels and permit the observation of some 14 lines in the CH spectrum.[104]

The lines appeared at the expected positions and with excellent signal-to-noise characteristics (250:1).

The HCN laser spectrometer was used again by R. F. Curl, Jr. of Rice University in collaboration with Evenson and Wells for study of the spectrum of NO_2. The NO_2 molecule, a paramagnetic asymmetric rotor, had Zeeman components at 337 μm and at 311 μm; four lines were quickly identified because their energies could be accurately predicted from previous work.[105] By the time that work was complete, the new technique of laser magnetic resonance was well established.

An interesting feature of the laser magnetic spectrometry was the initial difficulty encountered in interpreting the signals arising from spectrometry of polyatomic molecules. No general formalism existed for the treatment of such data.

Jon T. Hougen, theoretician in the Optical Physics Division, undertook to solve the problem. Using the methods of mathematical physics, he developed equations involving both Zeeman line positions and Zeeman line intensities for the molecular infrared spectra obtained by laser magnetic spectrometry.[106] On the basis of Hougen's work, experimenters could assign quantum numbers and determine spin-rotation interaction constants for the states involved in a given spectral line, without prior knowledge of the molecular structure or the energy levels.

Harmonic Generation

In another "first," harmonic generation up to frequencies of 8200 GHz and submillimeter wave laser detection and radiation mixing in superconducting Josephson junctions were demonstrated by Donald G. McDonald, Evenson, Wells, and J. D. Cupp of NBS, experimenting in collaboration with their colleague from the Physikalisch Technische Bundesanstalt in West Germany, Volkmar Kose.[107]

[104] K. M. Evenson, H. E. Radford and M. M. Moran, Jr., "CH free radicals detected by infrared laser magnetic resonance," *Appl. Phys. Lett.* **18**, No. 10, p. 426 (1971).

[105] R. F. Curl, Jr., K. M. Evenson, and J. S. Wells, "Laser magnetic resonance spectrum of NO_2 at 337 μm and 311 μm," *J. Chem. Phys.* **56**, No. 10, pp. 5143-5151 (1972).

[106] Jon T. Hougen, "The assignment of molecular infrared spectra from a laser magnetic resonance spectrometer," *J. Molec. Spectros.* **54**, 447-471 (1975).

[107] D. G. McDonald, V. E. Kose, K. M. Evenson, J. S. Wells, and J. D. Cupp, "Harmonic generation and submillimeter wave mixing with the Josephson effect," *Appl. Phys. Lett.* **15**, No. 4, pp. 121-122 (1969).

It was known at that time that a Josephson junction could function as a local oscillator and a harmonic generator. The magnitude of the maximum frequency achievable by harmonic generation could be determined by finding the maximum voltage at which a constant-voltage step occurred in the dc voltage-current curve.[108] The NBS/PTB group used a Josephson junction connecting two niobium point contacts to generate constant-voltage steps up to 17 mV (more than 100 steps) in response to an applied radiation at 70 GHz. They also noted that the technique could be used for the direct frequency measurement of infrared laser lines.

Harmonic mixing of klystron and laser radiation, using a Josephson junction, at orders as high as 100—at that time, an unprecedented level—was achieved in 1971 by McDonald, Cupp, Evenson, and their colleague Allan S. Risley.[109] In performing the experiment, they simultaneously irradiated a Nb-Nb Josephson junction with 10 GHz microwaves from a klystron and with 891 GHz laser radiation; a 60 MHz beat note was produced between the fundamental laser frequency and high harmonics of the klystron.

That type of experiment, coupling the properties of the superconducting Josephson junction with applied irradiation, quickly became a standard avenue of investigation.

Detecting Earth-Tides and Nuclear Explosions

Judah Levine, a member of the Quantum Electronics Division in Boulder, and John L. Hall of the Joint Institute for Laboratory Astrophysics constructed a long (30 m) laser strain-meter in an evaluation of the precision of long-path Fabry-Perot interferometry. They built the device underground, in a shaft of an unused gold mine in Boulder County, Colorado. Mounting long-focal-length mirrors on rock piers within a 30 m vacuum tube, they directed the light of a helium-neon laser oscillating at 3.39 μm into the interferometer. A second, similar laser, locked to a particular absorption frequency in methane, served as a reference.

The two scientists found, as expected, that the sensitivity of the system depended in part on the stability of the reference laser, about 1 part in 10^{11}. In part, the sensitivity depended also on the signal-to-noise ratio of the long-path interferometer, which turned out to be about 500 to 1 for a 1 ms integration time. They also had to consider the possibility that the geological response of the rock comprising the area in which the mine was located might exhibit unexpected behavior. They examined this possibility by creating artificial "seismic disturbances" with a sledge hammer. The response of the detector showed no resultant hysteresis or permanent offset, but it did display a directional sensitivity.

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[108] See, for example, W. H. Parker, D. N. Langenburg, A. Denenstein, and B. N. Taylor, "Determination of *e/h*, using macroscopic quantum phase coherence in superconductors. I. Experiment," *Phys. Rev.* **177**, 639 (1969).

[109] D. G. McDonald, A. S. Risley, J. D. Cupp, and K. M. Evenson, "Harmonic mixing of microwave and far-infrared laser radiation using a Josephson junction," *Appl. Phys. Lett.* **18**, No. 4, pp. 162-164 (1971).

The authors used their new, wide-bandwidth, stable, highly sensitive strain-meter to study long-term changes in the local earth strain field, the earth tides, and actual seismic events. They found the fact that the strain-meter output was a frequency rather than a voltage to be an advantage, as was its digital nature. The earth tide showed a strain of about 3 parts in 10^8, easily detected with their device.

Fortuitously, they also were able to detect a nuclear explosion. "Project Boxcar," one of a series of nuclear tests, took place in Nevada during their studies. Its transient disturbance of the local geology was readily detected by the Levine-Hall device.[110]

Progress in Physical Standards

Standards, as we have seen, take a variety of forms. Quantities that serve as benchmarks are standards, as are procedures adopted to produce specific results. Some of these we see in this section.

Fundamental Constants

Published in the second volume of the *Journal of Physical and Chemical Reference Data* was the 1973 version of the fundamental constants of physics. It contained the latest recommended values for the dozens of constants that defined the scientific world at that time. Prepared by Barry N. Taylor—a member of the staff of the director of NBS and soon to become chief of the Electricity Division—and E. Richard Cohen of Rockwell International, the summary represented critical reviews and analyses of all the available experimental and theoretical data. The project was carried out under the auspices of a panel of measurement experts operating under the aegis of the Committee on Data for Science and Technology (CODATA), an arm of the International Council of Scientific Unions.

One of the constants upgraded in the summary was the speed of light, determined with greatly improved accuracy by a group of NBS researchers as described earlier in this chapter. All older determinations were discarded in favor of the new value, which featured an uncertainty smaller by a factor of about 75.

In assessing the most probable values for the various constants, Taylor and Cohen used the method of "least squares," involving a comparison of different experimental determinations of the constants to minimize the overall uncertainties.[111]

Values of the 1973 Least-Squares Adjustment of the Fundamental Physical Constants were made available to the general public in a number of different forms, including a wallet card for handy reference.[112]

[110] J. Levine and J. L. Hall, "Design and operation of a methane absorption stabilized laser strainmeter," *J. Geophys. Res.* **77**, No. 14, 2595-2609 (1972).

[111] E. R. Cohen and B. N. Taylor, *J. Phys. Chem Ref. Data* **2**, No. 4, pp. 663-734 (1973).

[112] B. N. Taylor, "Fundamental physical constants," *NBS Special Publication 398,* card, August, 1974.

The National Measurement System

How important are measurements to America? Attempting to answer this question involved many Bureau scientists in a multi-year assessment project that covered nearly two dozen measurement areas.

The elements of a national measurement system were described in 1965-1966 by Robert D. Huntoon,[113] although his discussion dwelled mainly on the degree of sophistication of the various measurement standards in relation to use of atomic and molecular properties as compared to dependence upon artifacts such as the kilogram standard for mass.

During the tenure of Richard Roberts, the concept itself was sufficiently advanced that economists as well as scientists could contribute to answering the question that opened this section. The measurement tools and their accuracies were only one component of the question for specialists in measurement. Of equal interest were the numbers of Americans who themselves made measurements as part of their jobs, the value of the measurement tools employed by those workers, the amount of money spent in making measurements, and the portion of the gross national product resulting from the measurement activity.

Many measurement areas were involved in the study, including the following:[114] dimension; volume & density; temperature; pressure & vacuum; time & frequency; acoustics; vibration & shock; force; humidity; flow; optics; electricity; surface finish; vacuum ultraviolet radiation; spectrophotometry; radiometry & photometry; quantum electronics; x & nuclear radiation; dosimetry; cryogenic material properties; and electromagnetic radiation. The individual reports were published separately as they were completed.

The Bureau technical experts who performed the evaluations of their measurement disciplines and wrote the reports were assisted by several people and organizations. Directing the study was a Presidential Exchange Executive from the Dow Chemical Corp, James Seed, who was assigned to the NBS Director's office for the duration of his tour at the Bureau.[115] Economists from the NBS Programs Office participated, as did the U.S. Labor Department and member firms of the National Conference of Standards Laboratories (NCSL).

Officials of the Labor Department provided a wealth of statistics mainly valuable to the study in an overall way but also dealing in detail with certain of the study areas. Their figures indicated an economic impact of American measurement activities in 1973 in excess of $70 billion, all but about $7 billion reflecting labor costs. Measurement costs thus represented about 6 % of the Gross National Product. Annual sales of companies comprising the NCSL exceeded $300 billion; of that amount, it was estimated that NCSL company laboratories invested about $0.23 billion to produce about $20 billion of added value to America's goods and services.

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[113] R. D. Huntoon, "Status of the national standards for physical measurement," *Science* **159**, No. 3693, 169-178 (1965). See also R. D. Huntoon, "The basis of our measurement system," *Phys. Teacher* **4**, No. 3, 113-120 (1966).

[114] "Measuring the National Measurement System," *NBS Tech. News Bull.*, February, 1974, pp. 38-39.

[115] "NBS has presidential interchange executive," *NBS Standard,* March 1973, p. 13.

A fairly typical study, on flow measurements, involved some 200 contacts with trade associations, companies, universities, measurement laboratories, or agencies of the government. The contacts yielded estimates of the various types of flowmeters in use, their adequacy for the intended use, and the economic significance of flow uncertainties in various applications.

Publication of the individual studies generally appeared in NBS Interagency Reports, beginning in 1974. In all cases, the Bureau's measurement groups came to know their clients better. Generally, they also learned useful facts and clients' views about their own services.

A New Optical Radiation Calibration Service

Beginning July 1, 1972, the Heat Division's Optical Radiation Section, headed by Henry J. Kostkowski, offered a revised schedule of radiometric and photometric calibrations.

The new services were listed under "basic," "gage," and "special." NBS had found it necessary to augment its calibration service in the optical-radiation area to satisfy users who needed special arrangements or better calibration accuracy than they could obtain elsewhere. The "basic" calibrations were those considered of fundamental importance to measurements in the two fields—calibrations of spectral radiance, spectral irradiance, irradiance, luminous intensity, and luminous flux. The "gage" calibrations were provided for measurements in which official uncertainty levels had not been assigned, but for which NBS maintained reference standards. In certain "special" cases, the Bureau could offer calibrations of particular instruments or at especially low uncertainties by extra effort; these calibrations would be undertaken only when the results would benefit many users.

A Century of International Metrology

In 1975 the "Convention du Mètre" (Convention of the Meter, the oldest treaty of which the United States was still a signatory) reached the venerable age of 100 years. The original 1875 Convention was accepted by 17 signatory nations:

Argentina	Austria-Hungary	Belgium	Brazil
Denmark	France	Germany	Italy
Peru	Portugal	Russia	Spain
Sweden and Norway	Switzerland	Turkey	
United States	Venezuela		

The treaty consisted of only 14 Articles. These articles created an International Bureau of Weights and Measures (BIPM) in Paris, to be maintained at the common expense of the signatories; an International Committee for Weights and Measures (CIPM) with authority over the BIPM; and a General Conference on Weights and Measures (CGPM) with authority over the CIPM. The Articles also delineated briefly the responsibilities of the three organizations and placed a few conditions on the "contracting states." Regulations regarding financing, personnel, and operation of the standards apparatus were provided in an appendix to the convention.

The Convention proved to be surprisingly durable. Only minor modifications to it were adopted by a second Convention in 1921. As might be expected, the growing need for measurement standards throughout the world brought a multitude of new classes of standards under the purview of the Convention. These were included by simply expanding the activities of the participating organizations.

By 1975, the number of "member states" that had accepted the Convention had risen to 43—those listed above plus the following group:

Australia	Bulgaria	Cameroon	Canada
Chile	Czechoslovakia	Dominican Republic	
Egypt	Finland	German Democratic Republic	
Hungary (now separate from Austria)		India	
Indonesia	Ireland	Japan	Korea
Mexico	The Netherlands	Norway (now separate from Sweden)	
Pakistan	Poland	Romania	South Africa
Thailand	Soviet Union (replacing Russia)		
United Kingdom	Uruguay	Yugoslavia	

The most recent arrival had been Pakistan in 1973. The Treaty roster by then included nearly all of the industrially mature nations.

At NBS, the centennial was celebrated by exhibits on the Convention of the Meter and on the Metric System, which preceded the Convention and helped to give it life. The Bureau also hosted a conference of educators on the teaching of metric units in schools.

A lasting memento of the centennial was a translation into English of the official centennial volume, edited by Chester H. Page—at that time the Coordinator for International Standardization Activities for the Institute for Basic Standards—and Paul Vigoureux of the National Physical Laboratory in England.[116] Following a history of metrology, 10 chapters of the volume described progress in particular standards (mass, length, gravimetry, manobarometry, thermometry, electricity, photometry, radioactivity, x and gamma rays, and neutrons). Appendices contained the text of the Convention, a list of its member states, the membership and officers of the CIPM, the directors of the BIPM, the international system of units, a short history of the metric system, and a list of the publications originating in Convention activities.

[116] "The International Bureau of Weights and Measures 1875-1975," edited by Chester H. Page and Paul Vigoureux, *NBS Special Publication 420,* May 1975, 248 pp.

In recognition of the 1975 centennial, the 15th General Conference on Weights and Measures, held on the BIPM grounds just outside Paris from May 27 to June 3, became a celebration. Separate activities were held in several countries that participated in the work of the treaty, including the NBS festivities mentioned earlier.[117]

Delegates from 43 nations attended the 15th General Conference; they were treated to several commemorative activities. Valery Giscard d'Estaing, President of France, welcomed the delegates. Jean Terrien, head of the International Bureau of Weights and Measures, presided over the conference. The U.S. delegation to the General Conference consisted of Richard Roberts, Director of NBS, and Ernest Ambler, Deputy Director. Ambler, with long experience in metrology, was the official U.S. delegate. He also served on the International Committee for Weights and Measures (CIPM) and was head of the Consultative Committee for Ionizing Radiation.

Besides the Centennial memorial volume mentioned earlier, a second commemorative, a medal, was struck in honor of the occasion. It portrayed on one face the Pavillon de Breteuil, home of the BIPM, and on the other face the base units of the Systeme Internationale (SI, the international system of metric units).

In its regular proceedings, the 15th General Conference passed several resolutions noting progress in the areas of length, mass, time, electricity, and temperature. One such resolution suggested adopting the value 299 792 458 m/s for the speed of light in a vacuum, symbol c; that value was provided by NBS scientists in the landmark investigations described earlier in this chapter. Several delegates suggested that the value for the speed of light—perhaps the most important of the physical constants—might be fixed by definition, allowing the meter and the second to assume values consistent with a defined value of c.

Another resolution noted recent progress in laser science, advances that could be expected to lead to still more precise definitions of both time and length.

Time was the subject of yet another resolution. In that case, the General Conference recognized the many contributions to time standards made by the International Bureau of Time (BIH). Located at the Observatory of Paris during 1919, the BIH had coordinated international time signals ever since. After the adoption of the atomic clock, the BIH had initiated the International Atomic Time (TAI) scale and had begun the use of the "leap second" to synchronize the new scale with the Universal Coordinated Time scale, which was based upon astronomical observations. The resolution also suggested the abandonment of the Greenwich Mean Time Scale, which was no longer needed.

In a fourth resolution, the Conference praised then-current measurements of the gyromagnetic ratio of the proton, which connected electrical standards to atomic constants, and work on the development of a new volt standard based upon the superconducting Josephson effect.

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[117] These events and the history that preceded them were discussed briefly in articles in *Dimensions NBS*, successor to *The Technical News Bulletin of NBS*: "The Treaty of the Metre, 1875-1975," pp. 104, 105, 117, Vol. 59, May, 1975; "An International Meeting, A Century Celebration," p. 224, Vol. 59, October, 1975; and "World Conference Updates Vocabulary," pp. 225-227, Vol. 59, October, 1975.

A final resolution expressed approval of on-going studies of the relation between the International Practical Temperature Scale of 1968 and thermodynamic temperatures, and it adopted slight changes in the IPTS-68, which were embodied in a scale revision entitled "IPTS-68 (1975 version)."

During other deliberations of the 15th General Conference, a number of changes in the SI were adopted. These included:

- Two new prefixes as multipliers for units—peta (symbol P) for 10^{15} and exa (symbol E) for 10^{18}. [118]
- A name for the unit of activity of a weakly radioactive source, the becquerel, symbol Bq, with 1 Bq = 1 disintegration or other nuclear transformation per second.[119]
- A name for the unit of absorbed radioactive dose, the gray, symbol Gy, with 1 Gy = 1 joule per kilogram.[120]

Nearly all of the metrological activities discussed during the 15th General Conference on Weights and Measures involved work done at NBS.

Thermometry With Thermocouples

Specialized industries such as food processing, medicine, and steel-making required accurate thermometry at cryogenic temperatures. Thermocouple thermometers constituted a popular type of thermometer for use at low temperatures. To assist the users of cryogenic thermocouples, Larry L. Sparks, Robert L. Powell, W. J. Hall, and J. G. Hust provided reference tables for use with the International Practical Temperature Scale of 1968 for a variety of low-temperature thermocouples, as well as carefully evaluated uncertainty limits.[121]

Several types of thermocouple wires used to manufacture low-temperature thermometers received shorthand designations from the ASTM. These included copper-nickel alloys (type TN), nickel-chromium alloys (type KP), and nickel-aluminum alloys (type KN). Other popular types involved precious-metal alloys.

[118] An example of the use of these prefixes was to express the large amount of energy used in the United States each day; the amount could be expressed as 10^{17} joules, or alternatively as 100 petajoules (100 PJ), or as 0.1 exajoules (0.1 EJ).

[119] The previous unit, the curie (equal to 3.7×10^{10} Bq) would remain the unit of choice for highly radioactive sources such as those used to sterilize food.

[120] This unit was meant for use with quantities substantially larger than the rad (100 rad = 1 Gy).

[121] L. L. Sparks, R. L. Powell, and J. G. Hust, "Reference tables for low temperature thermocouples," *NBS Monograph 124,* June 1972.

The Cryogenics Division physicists tested samples of the various commercially available wires for homogeneity, both chemical and physical, and published reference tables for their use.[122]

Powell, Hall, Sparks, and C. H. Hyink assisted George W. Burns, Margaret G. Scroger, and Harmon H. Plumb of the Heat Division in constructing reference tables for thermocouple thermometers used in promulgating the International Practical Temperature Scale of 1968.[123] Their publication contained tables, analytic expressions, approximations, and explanations for the use of seven types of thermocouples recommended for use in thermometry by the American Society for Testing and Materials. Three noble-metal types, designated S, R, and B, were included, as were four base-metal types, designated E, J, K, and T.

The new reference data reflected changes resulting from the replacement of the 1948 temperature scale, changes in the properties of the thermocouple materials, and improvements in the methods used to fit the data.

Gaithersburg Heat Division scientists Burns, Scroger, and Wilbur S. Hurst used specially built high-temperature, high-vacuum furnaces for testing thermocouple thermometers capable of measurements at temperatures above 2000 °C. The thermocouples, made of refractory metals such as tungsten and rhenium, required special insulating and protective materials, and special care in assembly to avoid rapid degradation in use.[124]

Assigning Values to Mass

Changes in the methods used to assign values to mass standards resulted in a given weight being credited with several different values of mass over a period of time. In order to provide guidance to metrologists on mass assignment, Paul E. Pontius, chief of the Mass, Length, and Volume Section of the Optical Physics Division, prepared a historical summary of weighing methods and periodic changes in the mass system. Pontius also provided instructions for converting a value assigned on one basis to the corresponding value assigned on another.[125]

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[122] L. L. Sparks and J. G. Hust, "Thermoelectric voltage of silver-28 at % gold thermocouple wire SRM 733, versus common thermocouple materials (between liquid helium and ice fixed points)," *NBS Special Publication 260-34* (1972); L. L. Sparks and R. L. Powell, "Low temperature thermocouples; KP, 'normal' silver, and copper versus Au-0.02 at % Fe and Au-0.07 at % Fe," *J. Res. NBS* **76A**, No. 3, pp. 263-284 (1972).

[123] R. L. Powell, W. J. Hall, C. H. Hyink, Jr., L. L. Sparks, G. W. Burns, M. G. Scroger, and H. H. Plumb, "Thermocouple reference tables based on the IPTS-68," *NBS Monograph* **125**, 410 pp., March 1974.

[124] G. W. Burns, W. S. Hurst, and M. G. Scroger, "High reliability, sheathed, beryllia insulated, tungsten-rhenium alloy thermocouple assemblies—their fabrication and EMF stability," *NASA CR-134549,* pp. 1-36, June 1974.

[125] P. E. Pontius, "Mass and mass values," *NBS Monograph* **133**, 39 pp., January 1974.

Margaret G. Scroger connected an absorption roughing-pump system to a high-vacuum oven used in refractory-metal thermocouple research.

New Density Scale

Horace A. Bowman, Randall M. Schoonover, and C. Leon Carroll, members of the Mass, Length, and Volume Section, created a new scale of density for use in calibration.[126] The new scale originated with four samples of single-crystal silicon, for which the scientists determined the density in terms of international standrds of mass and length.

The group had spent several years in planning the experiment on which the new scale would be based. They chose single crystals of silicon as their "working standards" because of the chemical and physical stability of silicon and the relative ease with which it could be handled in density comparisons. An interferometer,

[126] H. A. Bowman, R. M. Schoonover, and C. L. Carroll, "A density scale based on solid objects," *J. Res. NBS* **78A**, No. 1, 13-40 (1974).

developed at the Bureau by James B. Saunders, was used to measure the diameters of a set of steel balls, commercially manufactured as nearly perfect (within 1 ppm) spheres. From the measured diameters, the volumes of the spheres were readily calculated. Measurement of the masses of the balls immediately allowed the group to calculate their densities.

In a newly designed hydrostatic weighing apparatus, the volumes of the silicon crystals were evaluated in terms of the volumes of the steel balls. Once the masses of the crystals were measured, their densities could readily be calculated.

The authors estimated the uncertainty of their density determinations to be about 1 ppm. This figure represented a significant decrease (about a factor ten) below the variation found in recent international density intercomparisons. Equally valuable was the new volumetric-comparison apparatus and the measurement techniques developed by the three metrologists.

Electromagnetic Units

Chester H. Page, chief of the Electricity Division and soon to complete a distinguished scientific career (35 years at NBS when he retired in 1977), took notice of the general lack of understanding of the quantities defining electromagnetic fields in 1974. Observing the paucity of a logically consistent set of definitions of electromagnetic field quantities in textbooks and other educational materials, Page wrote a short but useful treatise on the subject for the *American Journal of Physics.* His contribution included a brief philosophical discussion of the topic and a consistent system of definitions.[127]

Primary Time and Frequency Standards

James A. Barnes, chief of the Time and Frequency Division, and Gerhard M. R. Winkler of the U.S. Naval Observatory collaborated to produce a publication describing the U.S. system of time and frequency standards. Their two organizations had chief responsibility for keeping and disseminating the standards. Barnes and Winkler discussed the methods used to assure consistent values and to provide useful information to all who needed it.[128]

Helmut Hellwig, chief of the Time and Frequency Standards Section, prepared a status report on operating frequency standards, as well as those that were currently under study. He described the levels of accuracy associated with various standards.[129]

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[127] C. H. Page, "Definitions of electromagnetic field equations," *Amer. J. Phys.* **42**, 490-496 (1974).

[128] J. A. Barnes and G. M. R. Winkler, "The standards of time and frequency," *NBS Technical Note 649,* 91 pp., February 1974.

[129] H. Hellwig, "Status report on primary frequency standards," *NBS Technical Note 646*, 15 pp., September 1973.

Using the Superconducting Voltage Standard

Procedures and measurements used to establish a new definition of the U.S. legal volt via the ac Josephson effect were described by Bruce F. Field, Thomas F. Finnegan, and Jan Toots for the metrological community in the journal *Metrologia.*[130] Thin-film tunnel junctions capable of producing a 10 mV output, augmented by high-accuracy voltage comparators, were the primary tools for the new definition.

As noted elsewhere in this volume, the Josephson junction functioned as a frequency-to-voltage converter with the conversion factor equal to $2e/h$, a constant whose value was determined as 483 593.420 GHz/V_{NBS}.

Evaluating X-Ray Wavelengths

Richard D. Deslattes and Albert Henins evaluated the wavelengths of x-ray reference lines (the $K_{\alpha 1}$ lines of copper and molybdenum) through the use of a nearly perfect single crystal of silicon.

A two-step experiment was used by the two physicists to achieve their goal. In the first step they determined the lattice repeat distance of the silicon crystal in terms of the visible wavelength of a stabilized He-Ne laser. In the second, they used the same crystal to diffract the reference x-ray lines, thus calibrating those wavelengths in terms of the laser wavelength.[131]

In 1974, Deslattes was presented the Samuel Wesley Stratton award for his work on length standards.

Progress in Chemistry Research

Chemistry research at NBS included many specialized topics. The following examples touch only a few of these; more are discussed in other sections throughout this chapter.

A New Calorimeter

Late in 1972, Edward Prosen and Marthada Kilday published the details of a solution calorimeter that had been a decade in development.[132] The instrument had been in use for most of that period, including measurements that led to the certification of two Standard Reference Materials for solution calorimetry. However, no archival discussion of its design, construction, and use had been presented. In their 1972 paper, Prosen and Kilday included measurements on the enthalpies of reaction of sulfuric acid with two different hydrates of sodium hydroxide, along with sufficient detail to allow the reader to appreciate the precision of the device.

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[130] B. F. Field, T. F. Finnegan, and J. Toots, "Volt maintenance at NBS via 2e/h; A new definition of the NBS volt," *Metrologia* **9**, No. 4, 155-166 (1973).

[131] R. D. Deslattes and A. Henins, "X-Ray to visible wavelength ratios," *Phys. Rev. Lett.* **31**, No. 16, 972-975 (1973).

[132] Edward J. Prosen and Marthada V. Kilday, "An adiabatic solution calorimeter and measurements of a standard reaction for solution calorimetry," *J. Res. NBS* **77A**, No. 2, pp. 179-204, (1973).

The calorimeter was designed to operate in the temperature range 293 K to 363 K (room temperature to near the normal boiling temperature of water) and to accommodate about 300 mL of solution in a platinum-lined, silver reaction chamber, along with some 3 mL of solid reactant in a platinum sample holder. Variable-speed stirring (200-850 rpm) of the reactants was accomplished by a platinum stirrer. All other parts in contact with the reactants or their vapor were made of platinum as well. A calibrated platinum resistance thermometer, measured using a sensitive Mueller-type resistance bridge, was used to monitor the temperature of the reaction.

An important feature of the calorimeter was an adiabatic shield surrounding the reaction vessel; it was equipped with a heater energized by signals from a six-junction thermocouple thermometer connected so as to respond to slight temperature differences (typically less than 0.1 mK) between the shield and the reaction chamber.

Phase Diagrams For Ceramists

On October 30, 1974, Ernest M. Levin was awarded the Department of Commerce Gold Medal posthumously for his exceptional contributions to the science of ceramics. A Bureau employee for 30 years, Levin had made the study of ceramics his life work. The citation for his award noted Levin's efforts in the field of phase equilibria and immiscibility in glasses, but most especially his contribution to "Phase Diagrams For Ceramists, a standard reference and text book in many university courses."[133]

Recognizing the enormous value of dependable information on phase equilibria in ceramic materials, the American Ceramic Society had published a half-dozen compilations of phase diagrams beginning in 1933 with a contribution from NBS prepared by F. P. Hall and Herbert Insley.[134] Levin and Howard F. McMurdie, both staff members in the NBS Mineral Products Division, had participated in the publication of some of these compilations.

In 1964, the Society published a 600-page book that regularized the presentation of the phase-diagram information. The diagrams themselves—2066 in number—were preceded by a note on temperature scales, a discussion on interpretation of phase diagrams, information on experimental methods, and a bibliography. The book was written by Ernest Levin, Carl R. Robbins, and Howard McMurdie with the editorial assistance of Margie Reser of the Society. A standard format was adopted for presentation of the phase diagrams.

The same authors produced a supplement to "Phase Diagrams For Ceramists" in 1969, with an additional 2000 entries.

[133] "26th Annual Honor Awards Program, U.S. Department of Commerce, 1974. "NIST Historical Collection.

[134] F. P. Hall and Herbert Insley, "A compilation of phase-rule diagrams of interest to the ceramist and silicate technologist," *J. Amer. Ceram. Soc.*, **16**, pp. 455-567 (1933).

Ernest M. Levin, a physical chemist in the Inorganic Materials Division, joined NBS in 1937. His primary scientific interest was high-temperature phase equilibria in refractory oxides. He received both the Silver Medal (1960) and the Gold Medal (1974) from the Department of Commerce in recognition of the high quality of his work.

Another supplement to the text, containing yet another 850 phase diagrams, was in progress in 1974 under the authorship of Levin and McMurdie when both Levin and Ms. Reser, the editor from the American Ceramic Society, became unable to continue the work. Levin died in August of 1974 and Reser in January of 1975. With the assistance of a group of colleagues, including several from NBS, the volume was completed and dedicated to Levin and Reser. Levin had personally been involved in preparing 42 of the diagrams contained in the three volumes.[135]

Prior to publication of the fourth and fifth volumes in the phase diagram series in 1981 and 1983 respectively, a Phase Diagrams for Ceramists Data Center was established at the Bureau under the auspices of the Office of Standard Reference Data. Robert S. Roth and Lawrence P. Cook of the Ceramics, Glass, and Solid State Science Division teamed with Taki Negas of the Chemical Stability and Corrosion Division to write the new volumes, which contained 838 and 663 phase diagrams, respectively.[136] Commentaries on the diagrams were provided by a group of 32 experts.

[135] Robert S. Roth, Mary A. Clevinger, and Deirdre McKenna, *Phase Diagrams for Ceramists: Cumulative Index for Volumes I-V*, (Columbus, Ohio: The American Ceramic Society, 1984).

[136] Robert S. Roth, Taki Negas, and Lawrence P. Cook, *Phase Diagrams for Ceramists Volume IV*, Geraldine Smith, Editor, (Columbus, Ohio: The American Ceramic Society, 1981). See also Robert S. Roth, Taki Negas, and Lawrence P. Cook, *Phase Diagrams for Ceramists Volume IV*, Geraldine Smith, Editor/ACerS, Mary A. Clevinger, Editorial Assistant/NBS, (Columbus, Ohio: The American Ceramic Society, 1983).

Howard F. McMurdie, trained as a chemist, joined NBS in 1928. He officially retired in 1966 after a robust career in x-ray diffraction, but continued work at the Bureau for more than a decade under the auspices of the International Center for Diffraction Data. As this history was written, McMurdie—more than 90 years old—still contributed to NIST projects.

Further volumes in the series were written in 1987, 1989, 1990, 1992, and 1994. Together, they constitute a remarkable contribution from NBS/NIST to the study of ceramics.

Critical Behavior in Gases

Work in the area of statistical physics began in the Heat Division with the formation in 1960 of a section devoted to that topic. Melville S. Green, winner of both a Guggenheim Fellowship and a Fulbright Award for the excellence of his work in the field, was the first chief of the section. Green quickly built a group of considerable stature in the field, including Marjorie Boyd, Martin J. Cooper, Julius L. Jackson, Sigurd Y. Larsen, Raymond D. Mountain, Robert A. Piccirelli, Harold J. Raveche, Baldwin Robertson, and Jan V. Sengers. In 1968, Green left NBS to join the faculty at Temple University; he was succeeded by Raymond Mountain, himself a Department of Commerce Gold Medal winner in 1983.

In one of his last publications at the Bureau, Green collaborated with Maria Vicentini-Missoni, a guest researcher from the University of Rome, Italy, and Johanna M. Levelt Sengers in a detailed study of thermodynamic properties of fluids near their critical points. The three scientists found that they could apply a scaled equation of state to carbon dioxide, xenon, and ^4He in the critical region, and that the results were consistent with several types of thermodynamic data.[137] In a placement that was perhaps not coincidental, the following paper in the same issue of the *Journal of Research,* written by Raymond Mountain, discussed a related topic—a dynamical model for the Brillouin-scattering spectrum of critical opalescence in carbon dioxide.

Several systems were investigated in the critical-point region by Sandra C. Greer in collaboration with Johanna Sengers, George T. Furukawa, and Robert Hocken during the early 1970s. These included thermodynamic anomalies in steam, heat capacity of argon-methane mixtures, and concentration gradients and thermal expansion in nitromethane-methylpentane mixtures.

In 1975, efforts to understand the behavior of gases near their critical points received a further boost from the work of Jan V. and Johanna M. H. L. Sengers. These scientists analyzed six fluids, using statistical methods: ^3He, ^4He, Xe, O_2, CO_2, and H_2O. They employed two scaled equations of state and confined their analysis to the critical region. They found that, within the limits of experimental accuracy, the two equations agreed with the data, lending credence to the idea that there existed a universality in critical behavior of gases.

Based upon their success, they offered parameters for 14 fluids in terms of a universal equation of state for the critical region.[138]

In a related study, Johanna Sengers provided historical insight on the development of the Van der Waals equation into a tool useful for modern scaling laws. Sengers described the features of Van der Waals' work that concerned critical phenomena, then traced the progress to the modern concepts of scaling and the universality of critical behavior in fluids.[139]

Johanna Sengers received the NBS Condon Award in 1975 and the Department of Commerce Gold Medal Award in 1978 for the quality of her work in thermodynamics.

Reaction Rate Constants

A study of the rates of reaction of methylene with carbon monoxide, oxygen, nitric oxide, and acetylene was completed by A. H. Laufer and Arnold M. Bass.[140] The experiments were accomplished by the use of flash photolysis of ketene in helium gas, with analysis of the reaction products performed in a gas chromatograph.

Both singlet and triplet methylene reactions were identified in the experiments. The rate constants ranged in magnitude from 10^{-11} cm^3 molecule^{-1} sec^{-1} to 10^{-15} cm^3 molecule^{-1} sec^{-1}.

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[137] M. Vicentini-Missoni, J. M. H. Levelt Sengers, and M. S. Green, "Analysis of thermodynamic properties in the critical region of fluids," *J. Res. NBS* **73A**, No. 6, pp. 563-591 (1969).

[138] J. M. H. L. Sengers and J. V. Sengers, "Universality of critical behavior in gases," *Phys. Rev.* **A12**, No. 6, 2622-2627 (1975).

[139] J. M. H. L. Sengers, "From Van der Waals' equation to the scaling laws," *Physica* **73**, 73-106 (1974).

[140] A. H. Laufer and A. M. Bass, "Rate constants for reactions of methylene with carbon monoxide, oxygen, nitric oxide, and acetylene," *J. Phys. Chem.* **78**, No. 14, 1344-1348 (1974).

Johanna M. H. L. Sengers adjusted the load on a piston gage which was used for accurate measurement of the pressure of gases used in her studies of critical phenomena.

Clinical Chemistry Standards

The development of a cholesterol Standard Reference Material (SRM 911) in 1967 marked the Bureau's entry into the field of clinical chemistry standards. The cholesterol SRM was followed quickly by others for urea (SRM 912), uric acid (SRM 913), creatinine (SRM 914), and calcium carbonate (SRM 915). These first contributions were made under the technical direction of Robert Schaffer, then chief of the Organic Chemistry Section of the Analytical Chemistry Division (ACD).

Sandra C. Greer mixed nitroethane and 3-methylpentane in a dry box as part of her research on critical phenomena in binary liquid mixtures.

In 1969, the Bureau signed an interagency agreement with the National Institutes of Health, Institute for General Medical Science. Under terms of the agreement, NIH would support ACD personnel in the development of additional clinical standards. More than two dozen standard chemicals, thermometers, and other apparatus were developed over a period of years under that program. Besides Schaffer, NBS scientists contributing to the project included William R. Shields, Bruce Coxon, Richard A. Durst, I. Lynus Barnes, Oscar Menis, John A. Simpson, Billy W. Mangum, Robert W. Burke, Radu Mavrodineanu, Rance A. Velapoldi, and Klaus D. Mielenz.

In 1971, International Federation of Clinical Chemistry officials asked NBS to assist in the development of clinical reference methods (RM). J. Paul Cali led the way to realization of this goal with an RM for measuring calcium levels in serum.

In 1974, Food and Drug Administration Bureau of Medical Devices managers initiated an interagency agreement for development of more RMs and for refinement of the isotope dilution mass spectrometry technique (IDMS) as a clinical tool to verify the accuracy of organic RMs. The IDMS method was used subsequently for cholesterol, glucose, urea, uric acid, creatinine, and triglycerides.

Robert Schaffer received the NBS Rosa Award in 1985 along with citations from the American Association for Clinical Chemistry for his contributions to the Bureau's clinical chemistry standards program.

The program remained as a fixture of NBS/NIST assistance to U.S. medical needs through the mid-1990s.[141]

Mathematics in Analytical Chemistry

An extensive bibliography containing nearly 600 references was compiled by Lloyd A. Currie, James J. Filliben, and James R. DeVoe on the use of mathematical and statistical methods used in analytical chemistry during the period 1967 to 1972.[142] Currie had a deep interest in the topic—he had written a definitive paper on the extraction of information from analytical chemistry experiments, proposing exact defining equations and formulas both for the general case and with specific application to radiochemistry investigations.[143]

The bibliography was the result of a collaboration between the Analytical Chemistry Division and the Statistical Engineering Section of the Applied Mathematics Division. It covered several categories of publication:

- Reviews, conferences, journals, and books.
- Method characterization.
- Planning and optimization of experiments.
- Curve fitting.
- On-line computers.
- Specialized methods.

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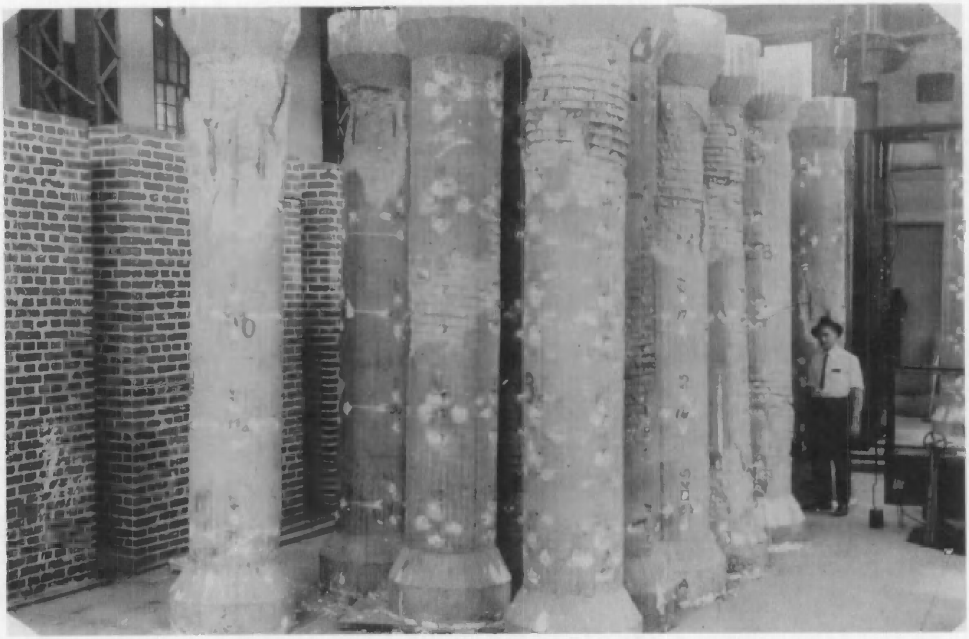
[141] Robert Schaffer, George N. Bowers, Jr. (Clinical Chemistry Laboratory, Hartford, Connecticut Hospital), and Robert S. Melville, (National Institutes of Health), "History of NIST's contributions to the development of Standard Reference Materials and Reference and Definitive Methods for clinical chemistry," *Clin. Chem.* **41**, No. 9, pp. 1306-1312 (1995).

[142] L. A. Currie, J. J. Filliben, and J. R. DeVoe, "Statistical and mathematical methods in analytical chemistry," *Anal. Chem. Ann. Rev.* **44**, 497R-512R (1972).

[143] Lloyd A. Currie, "Limits for qualitative detection and quantitative determination," *Analytical Chemistry* **40**, No. 3, March 1968, pp. 586-593.



Investigations for the building and construction industry began at the Bureau of Standards in the 1920s. In this 1920 photograph, brick piers and concrete columns were stress tested at the Bureau's Pittsburgh facility.

Building Science

It is fair to say that the Bureau of Standards has been studying problems connected with buildings and other structures since its founding in 1901. The acquisition of a 100,000 pound dead-weight tester in 1904 might be judged an official beginning, as might the formation of a Structural Materials Division around 1914, the creation of a Division of Building and Housing in 1921, or the first publication of Building Materials and Structures Reports in 1937.[144] No matter. Both the Congress and the Department of Commerce long understood that independent scientists and engineers could evaluate structures from informed and objective points of view, providing insights that could greatly improve America's construction industry.

Herbert Hoover, Secretary of Commerce from 1921-1928, established a Building Code Committee and a Division of Building and Housing within his department with the aim of stimulating the building industry. At the same time, a Research Associate program was initiated at NBS to encourage cooperation between the construction industry and Bureau scientists; the industry-sponsored associates took back to their companies a first-hand appreciation for the importance of laboratory-tested ideas for building, exerting a positive influence on the quality of building construction.[145]

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[144] Cochrane, *Measures for Progress*, pp. 79, 131, 334.

[145] Paul R. Achenbach, "Building research at the National Bureau of Standards," *NBS Building Science Series 0*, October 1970, p. 6.

Initially fragmentary, contributions of NBS to the building industry became more cohesive in 1947 with the formation of the Building Technology Division under Douglas E. Parsons; sections included Structural Engineering, Fire Protection, Heating and Air Conditioning, Exterior and Interior Coverings, and Codes and Specifications. A. Allan Bates, James R. Wright, and Richard N. Wright (no relation to James) followed Parsons in leading the building science group as the organizational title changed over the years, but the group continued to focus on its central mission: to provide a sound base of data and analysis to undergird the U.S. construction industry.

A Center for Building Technology

With the beginning of Fiscal Year 1973 on July 1, 1972, Secretary of Commerce Peter G. Peterson directed that NBS should establish a Center for Building Technology (CBT). James R. Wright was chosen as the first Director of CBT. An advisory committee was formed to monitor its work. Three divisions were incorporated into the new center: Building Environment, Paul R. Achenbach, chief; Structures, Materials, and Life Safety, under William C. Cullen; and Technical Evaluation and Applications, headed by Harry E. Thompson. In addition, there were three offices: Building Standards and Codes Services, headed by Gene A. Rowland; Housing Technology, under Edward O. Pfrang; and Federal Building Technology, Sam Kramer, chief.

From 1966 to 1972, the full-time building research staff grew from 100 to 250. The growth was in part a response to the 1967 formation of the National Conference of States on Building Codes and Standards, and in part to the 1968 creation of an Office of Research and Technology in the Department of Housing and Urban Development, which in turn initiated *Project Breakthrough.*

In 1974, James Wright was chosen by director Richard Roberts as deputy director of the Institute for Applied Technology. Richard N. Wright was selected to succeed his namesake James as the second director of CBT. Richard Wright came to NBS from the University of Illinois in 1971. He served as chief of the Structures Section until he became center director. In that position, he led an NBS team to investigate earthquake damage to Managua, Nicaragua in 1972.

The Building Science Series

As noted in Chapter 1, a new series of NBS publications was begun in 1965 to take the place of the earlier *Building Materials and Structures Reports* as a convenient outlet for archival publications on the technology of building and as a means of centralizing the dissemination of information from the center. The new communication, with no fixed publishing schedule, was entitled the *Building Science Series.* The basic document in the series, written by Paul R. Achenbach and issued late in 1970, described the history of building research at NBS, the Bureau's contemporary program, and forecasts for the future.

Work of the New CBT

In part, changes in the scope of the Bureau's building-research program were brought about by the acquisition of new facilities on the Gaithersburg site. For example, the new structures laboratory allowed the group to supplement the usual testing machines with a reinforced, two-meter-thick tie-down floor and hydraulic actuators as a loading system that extended over an area 17 m on each side. Both fixed and cyclic loading could be applied, with forces varying in amplitude and frequency. Thirteen special-purpose environmental chambers—one large enough to accommodate an entire house—permitted tests ranging from air conditioning to thermal conductivity.

The range of activities undertaken by the building science group at NBS over the years was a broad one, as we shall demonstrate in the following paragraphs. Activities in fire research, long a part of the building research program, are discussed in a separate section.

- Computer models for the dynamic thermal performance of buildings were developed by Tamami Kusuda.[146] With the use of the large environmental chamber, predictions of the models could be compared with tests on full-scale houses under winter and summer weather cycles. As the models matured and confidence grew in their use, they became the basis for both commercial and Department of Energy designs for energy-efficient buildings.[147]

- Investigations at NBS into the inadequate performance and excessive failure of electric heat pumps, introduced in the early 1960s for family housing in the United States, revealed specific areas of failure and pointed the way to improved designs. As a result of the earlier work, reliable heat pumps were quickly made available when the energy crisis of 1973 prompted American builders to seek alternatives to electrical resistance heaters.

- An apparatus developed by Mahn H. Hahn, an *Industrial Research Associate,* was built to measure the dew point in sealed glass envelopes and thus to evaluate the moisture content in double-pane glass. The apparatus and its use became valuable assets to the construction industry.

- Thermal resistance of building insulation of various thickness could be measured with improved accuracy as a result of the development of a new line-source guarded hot-plate device. Henry E. Robinson, Mahn Hee Hahn, and Daniel R. Flynn designed the new instrument.[148]

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[146] T. Kusuda, "Thermal response factors for multi-layer structures of various heat conduction systems," *ASHRAE Transactions* **75**, Part 1, pp. 246-271 (1969).

[147] T. Kusuda, "NBSLD, the computer program for heating and cooling loads in buildings," *NBS BSS 69,* 398 pp. July 1976.

[148] M. H. Hahn, H. E. Robinson, and D. R. Flynn, "Robinson line-heat-source guarded hot plate apparatus," *Amer. Soc. for Test. and Mat. Special Technical Publication* **STP 544** 1974, pp. 167-192.

Mahn Hee Hahn, Research Associate from the American Society for Testing and Materials, with the dew/frost point apparatus he developed to measure the moisture content of the air space in sealed insulating glass. The device received the IR-100 award from Industrial Research magazine as one of the most significant new technical products of 1975.

- In 1974 mobile homes accounted for 20 % of all new U.S. housing. To obtain uniform construction standards for safety, durability, and economy, the Department of Housing and Urban Development engaged NBS to define the problems to be addressed on these factors. William G. Street, William E. Greene, Jr., James H. Pielert, and Leopold F. Skoda undertook the study and prepared an *NBS Interagency Report*, number 75-690, in 1975.

- Collapse of the Skyline Plaza apartment complex on Mar 2, 1973, at Bailey's Crossroads in Fairfax, Virginia, caused the Occupational Safety and Health Administration to ask NBS to ascertain the nature of the failure and to address the general question of the adequacy of construction codes in multi-story buildings. The Bureau investigation, headed by Edgar V. Leyendecker and S. George Fattal, led to significant changes in construction codes pertaining to that incident. In addition, the work led to a long-term NBS program in non-destructive testing methods for ongoing construction.

- A flood in Fairbanks, Alaska in 1967 caused extensive damage to hundreds of homes. A visiting team of NBS engineers was able to recommend recovery procedures that minimized loss of property. The event triggered ideas for disaster mitigation at NBS and elsewhere. A 1972 workshop on building practices for disaster mitigation, held at NBS with the cooperation of the National Science Foundation, touched on problems caused by earthquake, wind, flood, and other dynamic hazards. Studies initiated as a result of the workshop[149] created the policy basis for the Earthquake Hazards Reduction Act of 1977 and a national program for earthquake hazard reduction in 1978. The Federal Emergency Management Agency, the U.S. Geological Survey, and the National Science Foundation joined NBS as lead agencies in the program.
- A new industry was established as a result of a 1975 NBS study of the premature failure of decking on highway bridges. Failure of the decks appeared to result from corrosion from deicing salts, which limited the useful life of the reinforcing bars to 5-10 years. A Bureau project conducted by James R. Clifton, Hugh F. Beeghly, and Robert G. Mathey identified several spray-applied powdered epoxy resins that gave promise of extending the service life of bridge decks to about 40 years.
- Lawrence W. Masters and his colleagues developed a systematic method in 1974 for predicting the service lives of building materials and other construction items that was used by the American Society for Testing and Materials as the basis for a new standard practice for accelerated testing.
- In 1973, NBS was asked to develop a technical basis for energy conservation in building construction. *NBSIR 74-452,* issued in 1974, contained an approach to the problem that was both technically and economically sound. Edited by James L. Heldenbrand, the document became the basis for a national consensus standard. Arthur D. Little Corporation estimated that use of the new approach would save nearly 50 % of the annual energy consumption for the average building.

Energy From Sunlight

One of the methods for energy conservation most often cited by environmentalists during the 1970s was solar power. The sun, they reasoned, offered free and reliable energy to Planet Earth every day; why not use it? Research projects to use sunlight for power blossomed immediately, their managers seeking methods and locations where solar power could provide a realistic source of energy to conserve increasingly expensive and polluting supplies of oil and coal.

NBS embarked on a program of developing standard test methods for solar energy collectors and thermal storage systems in the early 1970s under the leadership of James E. Hill. The work was initiated following a request from the National Science

[149] One of these was R. N. Wright, S. Kramer, and C. G. Culver, "Building practices for disaster mitigation," *NBS Building Science Series* **46**, 1973.

Foundation. Center for Building Technology staff purchased a factory-built four-bedroom house in 1972 and installed it in the center's large environmental chamber. There it was subjected to simulated summer and winter weather conditions while data were obtained on the interior response of the house to the heating and cooling loads. Then the house was moved to an outdoor site on the Gaithersburg grounds and tested under actual weather conditions.

During the latter part of 1974, a solar heating and cooling system was added to the house under the sponsorship of the Federal Energy Administration. Criteria for the new installation included the use of the forced-air distribution system that was already part of the house and installing only commercially available solar units that would satisfy at least 75 % of its energy needs. Installation and testing were supervised by James Hill and Thomas E. Richtmyer. Their report, published as *NBS Technical Note 892,* provided a complete discussion of the project, its successful results, and lessons learned.

The Federal Housing Administration of the Department of Housing and Urban Development led the way in many solar power projects. NBS was asked to participate in these projects as a result of the *Solar Heating and Cooling Demonstration Act of 1974.* The Bureau role was to develop guidelines for the evaluation of the economic performance of solar-energy heating and cooling systems, based on measurement data created or verified by NBS. In response to its new mandate, the Bureau asked its Center for Building Technology to formulate a plan to guide the development and implementation of standards for solar heating and cooling applications. The CBT plan was adopted by a committee of the American National Standards Institute, helping to coordinate industry and government efforts to utilize solar power. In the meantime, CBT engineers began to accumulate data to undergird the formulation of solar-power standards. With colleagues George E. Kelly and Tamami Kusuda, James Hill created protocols that led to national standards for solar-system evaluation.[150]

Rosalie T. Ruegg, an economist in the Center for Building Technology, led the way to the application of life-cycle cost analysis for solar systems.

By 1978, there were some 7 documents describing standards, codes, and performance criteria for solar energy systems.

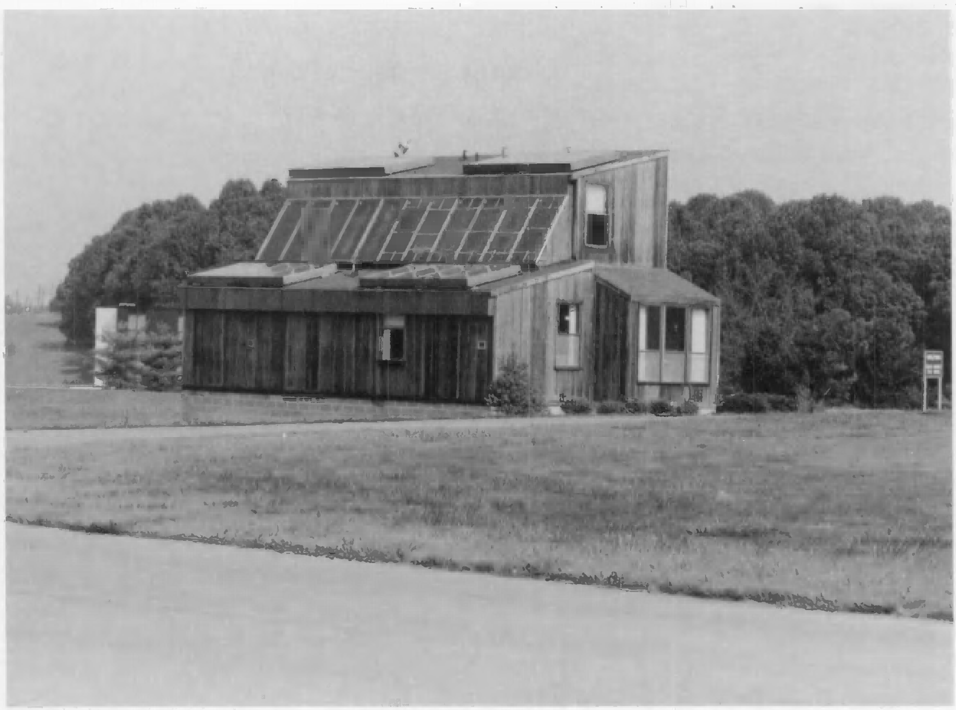
Building Systems—A Performance Concept

The keynote for a new approach to building was struck during a 1968 Gaithersburg conference on *Performance of Buildings—Concept and Measurement.*[151] James R. Wright, then chief of the Building Research Division, stated:

> We have developed a definition for the performance concept and a set of five terms leading to a performance-type building code.

[150] See G. E. Kelly and J. E. Hill, "Method of testing for rating thermal storage devices based on thermal performance," *NBSIR 74-634* May, 1975, 45 pp. See also J. E. Hill and T. Kusuda, "Method of testing for rating solar collectors based on thermal performance," *NBSIR 74-635* December 1974, 63 pp.

[151] "Performance of Buildings—Concept and Measurement," *NBS Building Science Series 1,* W. W. Walton and B. C. Cadoff, editors, January 1970, 132 pp.



Solar collectors were installed in the National Bureau of Standards solar townhouse, a laboratory for a number of energy-conservation studies.

Wright drew upon the writing of John P. Eberhard to define the concept. The performance concept, wrote Eberhard, should begin with a statement of desired attributes of a material, component, or system in order to fulfill the requirements of the intended user. No instruction should be given as to the specific means to be employed in achieving the results.[152] Leading to the performance-based building code, he suggested, are performance requirements, performance criteria, evaluation techniques, performance specifications, and performance standards. Each of those terms could help to judge the adequacy of a given building technique to meet the actual needs of its occupants. This idea stood in sharp contrast to traditional building standards that prescribed materials and construction techniques.

In May 1972, the International Union of Testing and Research Laboratories for Materials and Structures teamed with the American Society for Testing and Materials and the International Council for Building Research Studies and Documentation to stage a symposium in Philadelphia devoted wholly to criteria for performance of

[152] J. P. Eberhard, "The performance concept: a study of its application to housing," *NBS Report No. 9849*, **1**, 47 (1968).

At left, NBS Institute for Applied Technology Director F. Karl Willenbrock and NBS Director Richard W. Roberts listened as Jim Hill of the Center for Building Technology (front right) described research at the NBS solar townhouse to Representatives George Brown of California and Don Fuqua of Florida. Behind them from the right were NBS Congressional Liaison Esther C. Cassidy, NBS Deputy Director Ernest Ambler, and Bill Wells of the House Science and Technology Committee staff.

buildings and their sub-systems. The editor of the proceedings, Bruce E. Foster, was on the staff of the Building Research Division. Many contributions to the symposium were offered by division staff members.[153] We note some of these here:

- Richard N. Wright, at that time still chief of the Structures Section, pointed out in a discussion presented jointly with A. H.-S. Ang from the University of Illinois the necessity of deciding how to prescribe performance criteria that were essential to human use of a building—for example, safety—without ignoring such problems as cost minimization.

- A general discussion of *Project Breakthrough,* initiated by the Department of Housing and Urban Development to solve the problem of creating 26 million new homes during the decade of the 1970s, was presented by Edgar V. Leyendecker. The project consisted of eight operational objectives:

[153] "Performance concept in buildings," Proceedings of a symposium, May 2-5, 1972, Philadelphia, Pennsylvania, *NBS Special Publication 361,* B. E. Foster, editor, 819 pp., February 1972.

1) Develop the means to increase housing production.
2) Modernize land-zoning regulations.
3) Develop performance criteria for building codes.
4) Upgrade the quality of professionals involved in the building industry.
5) Attract more skilled labor to the housing industry.
6) Encourage the development of new techniques and materials.
7) Encourage participation in housing modernization among state governments.
8) Encourage innovation in home financing.

- Norman F. Somes and Felix Y. Yokel discussed how testing procedures could be adapted to the performance concept in order to obtain realistic simulation of an actual structure without specifying the actual materials used in its construction. They suggested several useful criteria, including the selection of critical assemblies, critical loading conditions, critical environmental factors, and variability in performance.

- One problem associated with the new testing procedures was the paucity of performance data on conventionally constructed buildings. This topic was discussed by Somes and Yokel in collaboration with George C. Hsi and Hai S. Lew.

- An NBS computer program designed to augment standard industry procedures for calculating heating and cooling loads for buildings was described by Tamami Kusuda and Frank J. Powell. The program allowed the prediction of indoor temperatures from given values of air-conditioning and thermal insulation.

- Evaluation of the performance of structural building elements and interior-finish materials under fire conditions could be obtained from responses to low-intensity fires, according to Dan Gross and Jin Bao Fang. They recommended the use of burning wastebaskets or upholstered chairs to provide reproducible fire conditions.

- Another construction feature that needed attention in terms of performance evaluation was the response of structural adhesives to the effects of aging and environmental stresses. Thomas W. Reichard, Lawrence W. Masters, and J. H. Pielert classified the thousands of adhesives available to the industry into only three classes—those intended for use only during transport to the job site; those intended for long-term use, but not intended to carry structural loads; and those whose long-term strength was critical to the integrity of the building. The scientists prepared small test specimens of particular types of adhesives and subjected them, for example, to flexure tests after water submersion for one week. Such testing helped substantially in industry efforts to improve the performance of construction adhesives.

- Winthrop C. Wolfe made a similar contribution with regard to flooring finish, where the performance criteria included sanitation capability, solvent resistance, and wear characteristics.

Space Science

Bureau activities in space science during this period included astronomical studies, rocket technology, and scientific experiments in space. As is the case in many areas, NBS contributions in space science are mentioned in other sections as well.

Interstellar Species

Encouragement from David R. Lide, Jr., chief of the NBS Office of Standard Reference Data, helped to launch the Bureau into the identification of certain interesting interstellar species.

Lide assumed the leadership of the Office of Standard Reference Data early in 1969. He urged two staff members of his old section in the Optical Physics Division, Donald R. Johnson, a National Research Council-National Academy of Sciences postdoctoral research associate in 1967, and William H. Kirchhoff, a postdoctoral research associate in 1964, to evaluate the molecular spectroscopy literature for the benefit of scientists in the new field of radio astronomy. Since both scientists already had experience in that field, they happily pursued dual careers—critically examining data for the division's Molecular Spectroscopy Data Center part of the time, studying short-lived species in the laboratory and in outer space part of the time. Both activities were successful, soon involving, among others, Francis X. Powell and Frank J. Lovas, also of the Optical Physics Division.[154]

The group made many spectroscopic observations of short-lived reaction intermediates and other species of importance to radio astronomy and astrophysics, including the free radical OH, deuterated formyl ions, ethanol, sulfur dioxide, and dimethyl ether.[155]

Lovas and Johnson also were credited with helping Lewis Snyder of the Joint Institute for Laboratory Astrophysics and David Buhl of the Goddard Space Flight Center of NASA to identify maser emissions from red giant stars. Snyder and Buhl detected the signals late in 1973 in the Orion Nebula, using the 12 m radio telescope of the National Radio Astronomy Observatory. The nature of the radiation indicated the presence of maser action, but its complexity defied identification. Lovas and Johnson, however, were able to identify the signals as originating from vibrational excitation in SiO. Their identification was later confirmed by other astronomers.[156]

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[154] F. X. Powell and D. R. Johnson, "Microwave detection of $H_2{}^{18}O$," *Phys. Rev. Lett.* **24**, No. 12, 637 (1970). See also D. R. Johnson, F. J. Lovas, and W. H. Kirchhoff, "Microwave spectra of molecules of astrophysical interest. I. Formaldehyde, formamide, and thioformaldehyde," *J. Phys. Chem. Ref. Data* **1**, No. 4, 1011-1046 (1972).

[155] D. R. Johnson and F. J. Lovas, "A new look at the laboratory microwave spectrum of cyanoacetylene," *Astrophys. J.* **169**, 617-619 (1971). See also D. R. Johnson and F. J. Lovas, "Microwave detection of the molecular transient methyleneamine ($CH_2 = NH$)," *Chem. Phys. Lett.* **15**, No. 1., 65-68 (1972). See also L. E. Snyder, J. M. Hollis, B. L. Ulich, F. J. Lovas, and D. R. Johnson, "Radio detection of interstellar sulfur dioxide," *Astrophys. J.* **198**, No. 2, L81-L84 (1975).

[156] Barbara G. Levi, "Silicon-monoxide masers show up in infrared stars," *Physics Today* pp. 17, 20, November 1974.

Their work was significant for scientists in fields as disparate as astrophysics and air pollution. Johnson and Lovas were jointly awarded the Department of Commerce Gold Medal in 1977.

Stellar Modeling

T. R. Ayres and Jesse L. Linsky constructed models for the star Arcturus, based upon spectral observations of ionized calcium and magnesium. The models separately considered the upper photosphere and chromosphere. They also studied the formation of a particular member of the Balmer series, Hϵ, in the sun and in Arcturus as part of their continuing work on stellar chromospheres.[157]

In collaboration with G. H. Mount, Linsky also suggested that the sun may contain a significantly lower carbon abundance than previously thought. The two physicists reached this conclusion on the basis of a detailed study of the spectra of solar CN, in which they assumed an absence of local thermodynamic equilibrium. The new estimate affected other astrophysical calculations.[158]

David G. Hummer and P. B. Kunasz offered two contributions to the study of radiative transfer in stellar matter during this period. In papers published in the *Monthly Notices of the Royal Astronomical Society,* they considered the fundamentals of line formation in extended spherical atmospheres whose constitutive properties depended on radius in an arbitrary way. Their study prompted them to propose a numerical solution to the line-transfer problem in spherically symmetric atmospheres.[159]

Hummer and D. Mihalas analyzed the spectrum of nitrogen III in celestial bodies known as O stars on the basis of a detailed solution to the coupled statistical-equilibrium and transfer equations for a multi-line, multilevel, multi-ion ensemble. Their results, indicating that N III lines could be produced in static, non-extended atmospheres in radiative equilibrium, provided evidence that the presence of emission lines in a spectrum was not in itself proof for the existence of a stellar chromosphere.[160]

Along with G. B. Rybicki, Hummer provided an extended discussion of the formation of spectral lines in optically thick systems for the journal *Annual Reviews of Astronomy and Astrophysics.*[161]

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[157] T. R. Ayres and J. L. Linsky, "Stellar model chromospheres. III. Arcturus (K2 III)," *Astrophys. J.* **200**, No. 3, pp. 660-674 (1975); same authors, "Stellar model chromospheres. IV. The formation of the Hϵ feature in the sun (G2 V) and Arcturus (K2 III)," *Astrophys. J.* **201**, No. 1, pp. 212-221 (1975).

[158] G. H. Mount and J. L. Linsky, "A new solar carbon abundance based on non-LTE CN molecular spectra," *Astrophys. J.* **202**, No. 1, L51-L54 (1975).

[159] P. B. Kunasz and D. G. Hummer, "Radiative transfer in spherically symmetric systems. III. Fundamentals of line formation," *Mon. Notic. Roy. Astron. Soc.* **166**, No. 1, 19-55 (1974). Also, same authors, "Radiative transfer in spherically symmetric systems. IV. Solution of the line transfer problem with radial velocity fields," *Mon. Notic. Roy. Astron. Soc.* **166**, No. 1, 57-78 (1974).

[160] D. Mihalas and D. G. Hummer, "Analysis of light-ion spectra in stellar atmospheres. III. Nitrogen III in the O stars," *Astrophys. J.* **179**, No. 3, 827-845 (1973).

[161] D. G. Hummer and G. B. Rybicki, "The formation of spectral lines," Chapter in *Annual Reviews of Astronomy and Astrophysics,* **9**, 237-270, 1971.

In recognition of the quality of his scientific leadership in stellar radiative transfer, Hummer became the 13th NBS staff member to win the Arthur S. Flemming award.

Rocket Technology

Certain thermodynamic properties of molybdenum, graphite, MoF_5, and niobium were measured, others were calculated from models by Thomas B. Douglas and Charles W. Beckett to complete data sets on materials important to rocket technology. For Mo, accurate enthalpy measurements in the temperature range 273 K to 1170 K were coupled with data obtained earlier at NBS to complete a set of thermodynamic functions for that element from 273 K to 2100 K. Fast-pulse heat-capacity data, believed accurate within 3 %, were obtained on graphite over the range 1500 K to 3000 K. Change in the normal spectral emittance and sample radiance near the melting temperature of niobium were observed using the pulsed technique as well.[162]

The sub-second pulse method, employed with great effectiveness by Cezairliyan in work described in Ch. 2, was used also to obtain information on the specific heat, electrical resistivity, and hemispherical total emittance for iron and a niobium-tantalum-tungsten alloy in the range 1500 K to 2800 K. A solid-solid transformation (gamma iron to delta iron) was detected in each of the different types of measurement, demonstrating the feasibility of fast phase-transition observations.[163]

Consumer Protection

In a sense, all NBS work protected the consumer—his person, his pocketbook, or the quality of his technical information and products. In this section, however, we highlight studies applicable directly to medicine, environmental protection, and equity in trade.

Materials for Prosthetic Devices

The successful use of metals for prosthetic devices depended upon three properties—"biocompatibility," adequate mechanical properties, and high corrosion resistance.[164] Anna Fraker, newly arrived at NBS in 1967 as a young postdoctoral research associate, joined J. R. Parsons, a Presidential Intern, and NBS scientists M. P. Yeager, J. A. S. Green, Cletus J. Bechtold, and Arthur W. Ruff, former chief of the Metallurgy Division, in a long-term study of prosthetic metals. In their investigations, they collaborated with many groups outside NBS to evaluate candidate metals.

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[162] T. B. Douglas and C. W. Beckett, "Thermodynamics of chemical species important to rocket technology," *NBSIR 73-280*, 109 pp., January 1973.

[163] T. B. Douglas and C. W. Beckett, "Thermodynamics of chemical species important to rocket technology," *NBSIR 73-281*, 122 pp., July 1973.

[164] See, for example, Anna C. Fraker and A. W. Ruff, "Metallic surgical implants: state of the art," *J. Metals* **29**, No. 5, pp. 22-28 (1977).

Among the most promising metals tested were stainless steel, cobalt alloys, and titanium.[165] Utilized by the aerospace industry for its strength and moderate density, titanium won a high place among prosthetic metals for its resistance to corrosion by bodily tissues and fluids. The Bureau metallurgists expanded the store of knowledge on the suitability of titanium and other prospective implant materials through studies of microstructures, surface properties, and reactions with physiological solutions such as salines, uric acids, and amino acids.

They found that titanium typically formed a tough oxide surface film that resisted attack by biological materials. They also investigated a variety of titanium alloys involving aluminum, vanadium, and palladium. An interesting feature of the study was the indication that certain crystalline orientations showed reduced susceptibility to chemical attack.[166]

Tumor Detection—the Birth of a New Medical Technique

Non-invasive detection of malignancies in patients was a long-time goal of the medical community. NBS scientists, no less eager than physicians to ease human suffering, glimpsed a possibility that led to the medical specialty that came to be known as *Magnetic Resonance Imaging.*

Irwin D. Weisman and Lawrence H. Bennett of NBS, Louis R. Maxwell, Sr., a retired government scientist, and Mark W. Woods and Dean Burk of the National Cancer Institute knew that differences between normal tissue and tumorous tissue had been detected in laboratory samples by measuring their proton nuclear spin-lattice relaxation times. Why not, they thought, use their specialty, pulsed nuclear magnetic resonance, on living subjects? That technique would give a measure of tissue relaxation times. If the experiment worked, it would open the possibility of quick, non-invasive cancer detection.

To test their idea, the group enlisted several mice whose tails became test samples. The scientists transplanted malignant melanoma tumors onto the mouse tails, splinted them to reduce movement, and placed them within a resonance probe coil anchored between the poles of a powerful electromagnet. Success! The mice appeared to be unharmed by the test procedure, and the researchers found an easily detectable difference in spin-lattice relaxation time (0.7 s vs 0.3 s for normal tissue).

Plenty of details remained to be worked out before the new technique would become a routine—though expensive—medical diagnostic procedure for the detection of many types of abnormal tissue in patients throughout the world. But the authors saw the future clearly in their first report on the experiments:

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[165] J. R. Parsons and A. W. Ruff, "Survey on metallic implant materials," *NBSIR 73-420,* December 1973, 55 pp.

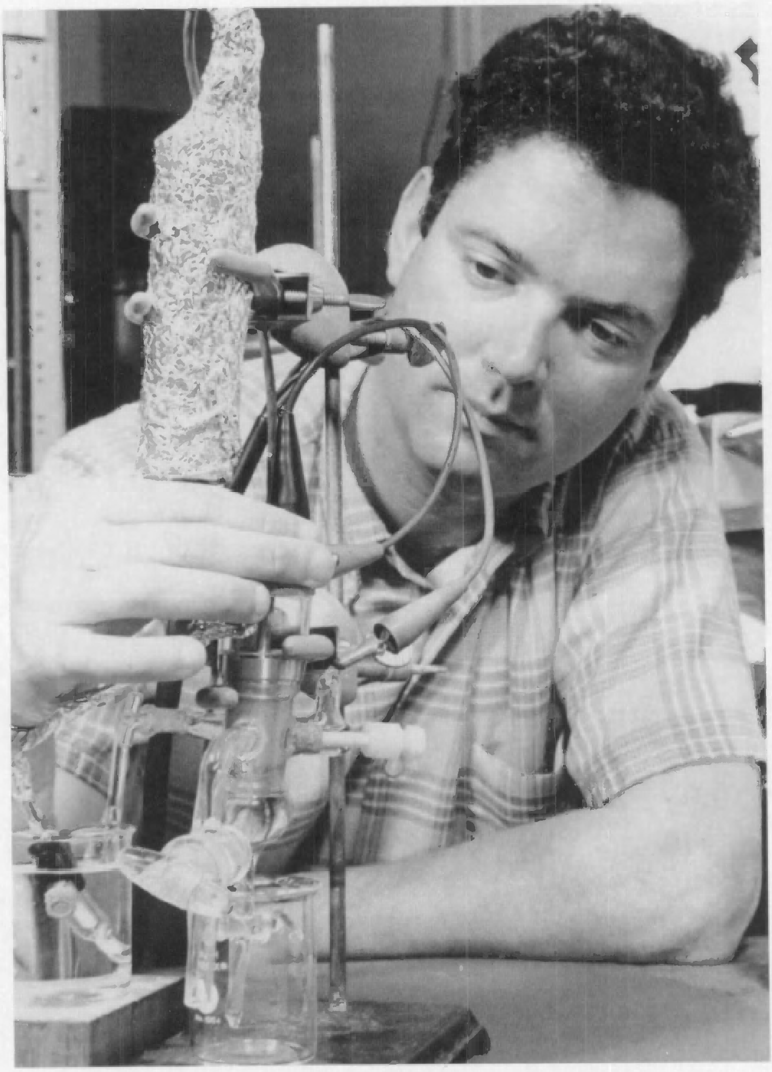
[166] A. W. Ruff and A. C. Fraker, "Investigation of the anisotropic anodic polarization behavior of titanium," *Corrosion* **30**, No. 7, pp. 259-264 (1974).

NBS metallurgist Anna C. Fraker showed school children an x ray of a surgically implanted artificial hip joint.

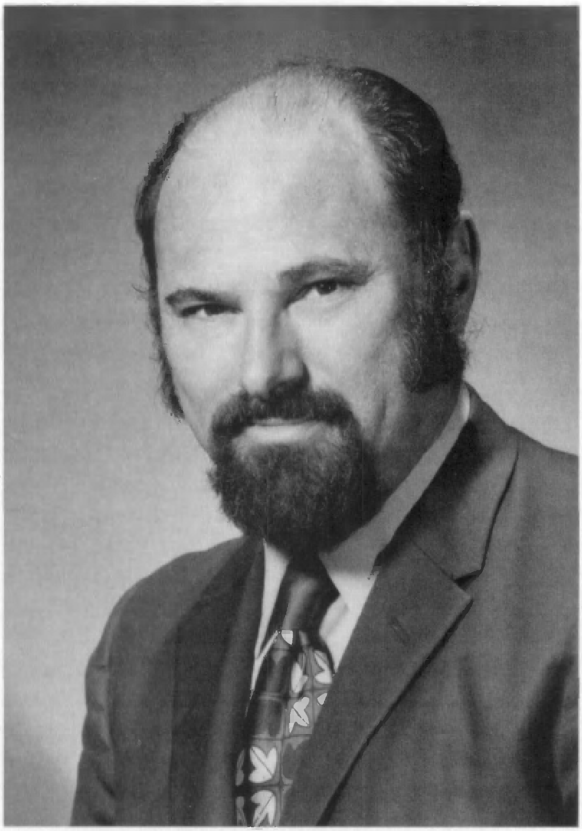
> We have been able to detect and monitor the growth of a cancer (a transplanted S91 melanoma) in a live animal, using pulsed NMR. Our results suggest that it would be worthwhile to attempt to develop this technique for the detection and monitoring of tumors in humans. Perhaps NMR could take its place beside thermography or radiography as a nonsurgical technique for cancer detection and analysis of cancer growth rate.[167]

The concept embodied in the discovery by the five-man group generated considerable excitement. About 600 requests were received for reprints of their report. The idea was quickly seized for use in non-invasive medical diagnostics. Renamed *Magnetic Resonance Imaging* (MRI) to avoid the frightening word "nuclear," the technique blossomed into a medical specialty. A technical display created by the American Museum of American History bears a caption that reads, in part, "The clarity of the images produced by magnetic resonance imaging far surpasses that of conventional x rays and rivals those of CAT scans. In addition, this technology allows investigators to monitor and study chemical changes in live tissue on a molecular level without intruding into the body." The display gave credit to the Bureau scientists for their seminal role in MRI development.

[167] Irwin D. Weisman, Lawrence H. Bennett, Louis R. Maxwell, Sr., Mark W. Woods, and Dean Burk, "Recognition of cancer in vivo by nuclear magnetic resonance," *Science* **178**, pp. 1288-90 (Dec 22, 1972).



NBS chemist John R. Ambrose developed tests to predict how surgically implanted materials would react to bodily tissues and fluids. In this photograph, Ambrose worked on a laboratory method that simulated crevice-corrosion in the body.



Lawrence H. Bennett joined NBS after receiving the Ph. D. degree in physics from Rutgers, the State University of New Jersey, in 1958. Among his research interests was the electronic properties of metals and alloys, for which he received the Department of Commerce Gold Medal Award in 1971.

Sniffing Out Pollutants

A small group of scientists in the Optical Physics Division—Arthur G. Maki, W. Bruce Olson, and A. Kaldor—and their colleagues A. J. Dorney and I. M. Mills from the university at Reading, England made a study of the detection of pollutants by optical means. They developed a technique for the detection of nitric oxide emanations from sources such as internal combustion engines and smokestacks, based upon the use of a relatively inexpensive system involving lasers and magnets.

Using the Zeeman effect, which enabled the resonant frequency of an optical transition to be magnetically shifted to a different value, they could detect airborne NO at the level of 3 parts per million.[168] A major air pollutant, NO produced smog and human discomfort, including eye irritation.

The group also resolved an uncertainty affecting the detectability of sulfur trioxide, a pollutant found in acid rain. Performing two different optical experiments and a band calculation, they were able to remove an ambiguity in the assignment of the frequencies of two of the Raman-active infrared lines of the SO_3 molecule.[169]

[168] A. Kaldor, W. B. Olson, and A. G. Maki, "Pollution monitor for nitric oxide: a laser device based on the Zeeman modulation of absorption," *Science* **176**, No. 4034, p. 508 (May 5, 1972).

[169] A. Kaldor, A. G. Maki, A. J. Dorney, and I. M. Mills, "The assignment of ν_2 and ν_4 of SO_3," *J. Mol. Spectrosc.* **45**, No. 2, 247-252 (1973).

Sizing Aerosols With Lasers

Cary Gravatt, a Polymers Division physicist, developed a method for the determination of the size distribution of particulate matter in air.

In the technique, air carrying the particles was blown through a continuous-wave laser beam. Light scattered from the particles was collected by separate annular fiber-optic rings set at slight angles to the laser axis. The fiber optics carried the scattering signals to photomultiplier tube detectors. Analysis of the signals from two rings yielded estimates of the diameter of each particle, irrespective of the index of refraction of the particle. By varying the angles of the observing rings, Gravatt could preferentially search for particles of various sizes.

Besides the particle sizes, the apparatus also yielded information on the chemical natures of the particles and on their concentrations.

The new instrument found application in monitoring all types of aerosols, from dust in homes, factories, and coal mines to clouds, fuels, paint sprays, and smokestack emissions.[170]

Honest Measure for Natural Gas

Increased use of liquefaction to facilitate trade in natural gas involved the Cryogenics Division in an investigation of the density of that valuable energy source.

Shipping large quantities of natural gas from the remote sites where it was often found was prohibitively expensive until techniques were developed to transport the product—mostly methane, but with variable fractions of nitrogen, ethane, propane, and butane—in liquid form. Monster tanker ships were built to carry the product to user markets, keeping the liquefied gas below its boiling temperature near 120 K (about −250 °F).

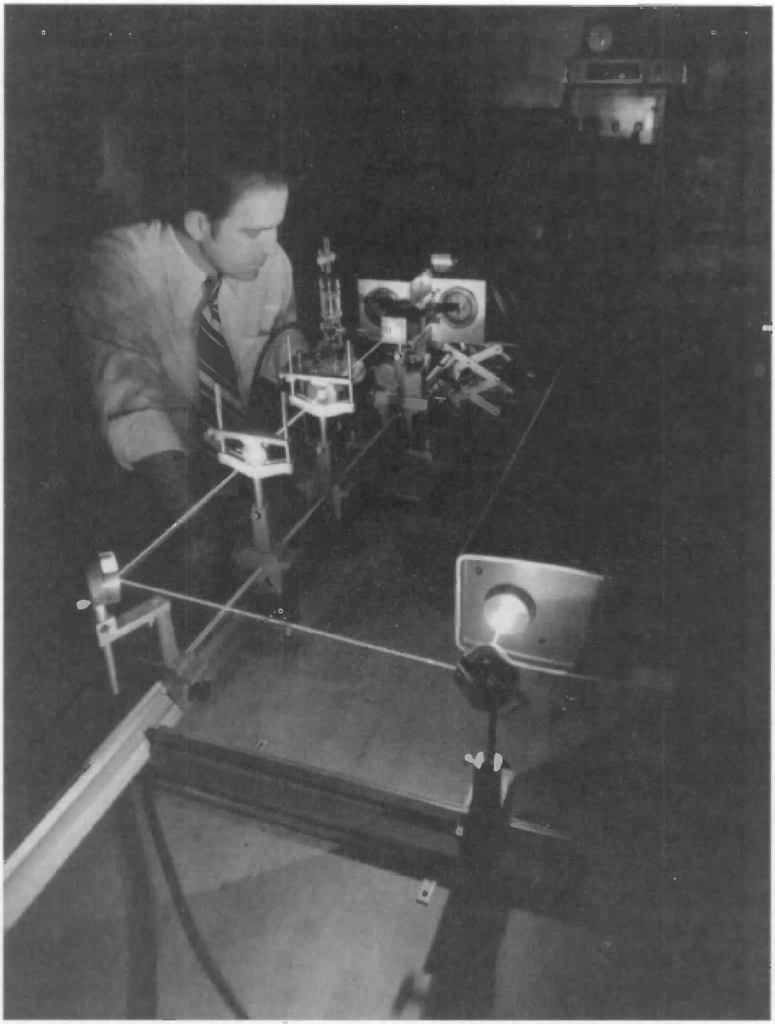
Trouble came when the buyers and sellers realized that during the long trek to the user, part of the liquefied gas evaporated, so that the assay performed prior to loading was no longer valid.

A consortium of 10 energy companies came to NBS, asking the Bureau to measure the densities of various mixtures of the components of natural gas to help buyer and seller agree on a reasonable value for a given shipment.[171]

By mid-1974, B. A. Younglove, physicist in the Cryogenics Division, was able to report the results of a whole series of measurements on methane. He measured the specific heat of saturated liquid methane at 66 temperatures over the range 95 K to 187 K and calculated the specific heat at constant volume at 20 densities ranging from 0.8 of the critical density to 2.8 times the critical density, for the temperature range

[170] C. C. Gravatt, Jr., "Real time measurement of the size distribution of particulate matter by a light scattering method," *J. Air Poll. Control Assn.* **23**, No. 12, 1035-1038 (1973). See also *NBS Technical News Bulletin,* December 1972 pp. 276-277.

[171] "Research grant for LNG study," *Tech. News Bull.*, November 1972, p. 259.



Cary Gravatt of the NBS Polymers Division positioned a device that blew a jet of dust-laden air across a laser beam. The particle size distribution was determined in real time by measuring the ratio of the amount of light scattered at two angles. Gravatt developed the apparatus as part of the NBS Measures for Air Quality Program which provided technical support for the U. S. Environmental Protection Agency.

from 91 K to 300 K.[172] These were the most comprehensive measurements made until that time on compressed liquid methane. The uncertainty level, below 0.5 %, was sufficiently small to permit use of the data for thermodynamic calculations needed by producers and shippers of liquefied natural gas.

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[172] B. A. Younglove, "The specific heats, C_σ, and C_v, of compressed and liquefied methane," *J. Res. NBS* **78A**, No. 3, 401-410 (1974).

R. D. Goodwin assisted in the work by calculating a comprehensive set of thermophysical properties for methane over the temperature range from 90 K to 500 K and for pressures up to 700 times atmospheric pressure. In computing his results, Goodwin used a new equation of state. He based his calculations mostly on ideal-gas specific heats and on experimental pressure-density-temperature relations.

Emphasizing the importance of accurate information on the properties of methane for the design engineer, Goodwin made use of a great deal of existing experimental data, including that provided by Younglove, to evaluate his results. He found substantial variation in existing heat-of-vaporization data, but found agreement with one set of data within about 2 %. His heat capacity calculations agreed with the measured values of Younglove within about 2 % over the region of overlap, as well.[173]

What a Noise!

Everyone knew that big trucks could be extremely loud. The interesting question was: how loud? In cooperation with the U.S. Department of Transportation and the American Trucking Association, NBS scientists measured the noise levels of trucks. They used a research runway operated by the National Aeronautics and Space Administration at Wallops Island, Virginia. Thirteen diesel tractor-trailer combinations and a gasoline-powered delivery van were tested by William A. Leasure, Jr., Thomas L. Quindry, Denzil E. Mathews, and James M. Heinen.[174]

Measurements were taken using microphones located 15 cm from each ear of the truck driver. At the same time, exterior measurements were made by a series of microphones that heard pretty much what other drivers or residents along the road would have heard. Both stationary and moving measurements were performed. The results indicated that, indeed, trucks can be loud (75 dB to 95 dB). The Occupational Safety and Health Administration recommended an eight-hour-per-day noise limit of 90 dB to avoid permanent hearing loss.

Other loud sounds were evaluated as well, including the firing of pistols and rifles.

It was only a small paradox that the anechoic chamber in the Sound Building— without doubt the quietest place at the Bureau— was a focal point for laboratory experiments on other types of noise. One of several experimental rooms in the building, the anechoic chamber achieved its quiet because it was lined with large fiberglass wedges paired in a pattern that absorbed more than 99 % of the sound originating within it.

One of the studies conducted in the anechoic room during Roberts' tenure was a series of hearing aid investigations, conducted for such sponsors as the Veterans Administration. The quality of microphones, loudspeakers, and other audio equipment was evaluated as well.

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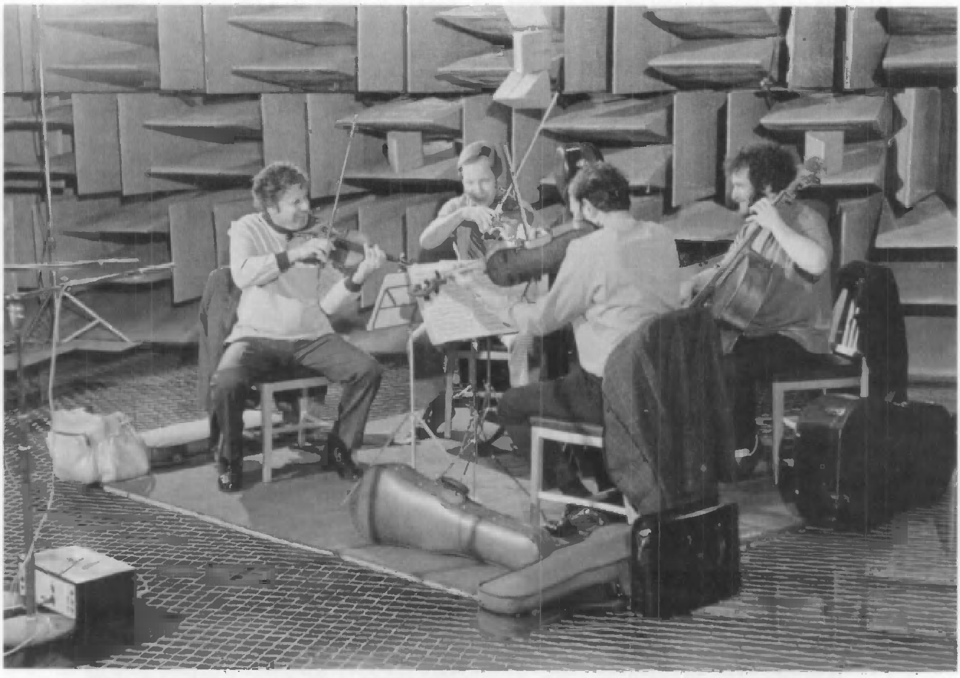
[173] R. D. Goodwin, "The thermophysical properties of methane, from 90 to 500 K at pressures to 700 bar," *NBS Technical Note 653,* 274 pp., April 1974.

[174] W. A. Leasure, Jr., T. L. Quindry, D. E. Mathews, and J. M. Heinen, "Interior/exterior noise levels of over-the-road trucks," *NBS Tech. Note 737,* 314 pp., September 1972. See also *NBS Tech. News Bull.,* February 1973, pp. 32-33.

Physicist Michael T. Kobal of the NBS Sound Section developed a test to evaluate the effectiveness of hearing protectors used on firing ranges.

An anthropomorphic mannequin used for acoustic research at NBS "listened" through an over-the-ear hearing aid in an anechoic chamber as part of a testing program conducted for the Veterans Administration. Martin Bassin positioned the sound source.



In March 1976, the Juilliard String Quartet tested the acoustical properties of their rare 17th and 18th century instruments in the NBS anechoic chamber against those of a matched set of new instruments made by Massachusetts instrument maker Marten Cornelissen. During the same visit, the quartet treated the Gaithersburg staff to an open rehearsal in the Green Auditorium.

In striking contrast to the anechoic chamber, the walls of a reverberation chamber, made of concrete, reflected about 95 % of sound striking them. The acoustic absorption of architectural materials was evaluated there, as was the intensity of sound emitted by machinery.

A third Sound-Building facility, containing small, insulated listening booths, was used for noise-annoyance studies by—among others—John A. Molino. In one such study, student-age subjects could reduce the intensity of sound they heard through earphones by tapping more frequently on a telegraph key. The attention of the subjects was focused on a reading task, the announced goal of their participation in the experiments. Molino sought in the experiments to develop an "aversion" method for evaluating human distaste for a variety of sounds, from pure tones to "white noise."[175]

[175] J. A. Molino, "Measuring human aversion to sound without verbal descriptors," *Percept. Psychophys.* **16**, No. 2, 303-308 (1974).

The NBS Sound Section conducted experiments to rate sounds according to their "loudness," "annoyance," and "unpleasantness" in an effort to find an objective basis for product standards and rational urban planning. In this photograph, a subject heard varying types and intensities of sound. She could diminish uncomfortable sound levels by pressing the response key.

Building Better Incinerators

How could NBS help municipalities to better dispose of their combustible waste? That was the question asked by the American Society of Mechanical Engineers (ASME).[176] It was not a trivial question, since the "typical" municipal waste stream was anything but uniform. The incinerator engineer needed to know what materials might be found in the waste stream, and what might be the consequences of burning

[176] "NBS helps with problems of waste incineration," *NBS Tech. News Bull.*, February 1973, p. 42.

the stuff. He did not want to produce poisonous effluent. He needed to monitor and, if possible, to regulate the combustion temperature to obtain optimal results.

The Bureau, it seemed, could help in two ways. One way was to actually burn statistically selected samples of trash to evaluate the range of combustion temperatures and products, and this type of combustion experiment was performed at NBS by a group that included Martin L. Reilly and Kenneth Churney. Another method was to provide data on heats of formation for the most common waste materials in a form that combustion engineers would find usable. This task was accomplished by NBS chemists George T. Armstrong and Eugene S. Domalski in collaboration with colleagues from the ASME.

Armstrong, Domalski, and their co-workers compiled thermodynamic data needed by waste-incinerator engineers for more than 1300 substances. Included in the compilation were the following:

- Heats of combustion and formation for 719 organic compounds containing the elements C, H, N, O, P, or S.
- Thermodynamic property values for organic halogen compounds, organometallics, and metal salts of organic acids, tabulated in the *NBS Technical Note 270* series by Donald D. Wagman, William H. Evans, and Vivian B. Parker.
- Data on certain hydrocarbons, treated by Frederick D. Rossini. The needed information was published in book form by the ASME.[177]

Meeting the Energy Crisis

As observed earlier in this chapter (see A Crisis in Energy), energy based on the consumption of oil reached premium prices during this period as most of the world's major oil-producing countries discovered the political and economic leverage inherent in restricting oil sales. Efforts at NBS to mitigate the energy crisis took several forms—turning down the office thermostats in winter, measuring thermal conductivity of insulation materials, studying alternative energy sources, and evaluating the rate of energy consumption of popular appliances, to name a few. Some of these types of projects are noted in this section.

Meeting the Energy Crisis in Housing, Travel, and Business

The Building Research Division staff was busy with energy-conservation projects during the Nixon administration, although the division continued to work on a great variety of other problems as well. The rapidly rising cost of oil—source of much of America's power—gave new impetus to efforts to maximize the efficiency with which energy was used.

[177] *Combustion Fundamentals for Waste Incineration,* S. R. Beitler, G. T. Armstrong, E. S. Domalski, and T. R. Keane, editors (New York, NY: The American Society of Mechanical Engineers, 1974) 217 pp.

In 1975, NBS invited a group of consumers from Montgomery County, Maryland to provide their reactions to three proposed energy guide labels for home laundry equipment.

As early as 1970, Jersey City, New Jersey, had been selected as a demonstration site for improved housing construction as part of *Project Breakthrough,* an initiative of the Department of Housing and Urban Development. One of the first Bureau contributions to the program, involving Jack E. Snell and Paul R. Achenbach, was the identification of operating and performance data on the total consumption and distribution of energy on the site as a precursor to utilizing energy in an effective manner.[178] Such features as the design and use of appliances, heating and ventilating equipment, and power distribution equipment were considered in the study. Later, in 1974, Snell was selected to head the newly created Office of Energy Conservation, located in the Center for Building Technology.

A detailed examination of one portion of the energy-conservation program—maximizing dollar savings over the life of residential heating and cooling equipment—was treated by Stephen R. Petersen. He discussed the economics of modifying insulation and installing storm windows and doors in terms of the climate, fuel costs, and materials costs at the location of the residence under study.[179]

[178] J. E. Snell and P. R. Achenbach, "Total energy systems: A review of recent NBS activities," *Proc. Effective Energy Utilization Symp., Drexel University, Philadelphia, Pa.,* June 8-9, 1972, pp. 201-233.

[179] S. R. Petersen, "Retrofitting existing housing for energy conservation," *NBS Building Science Series* 64, December 1974, 76 pp.

Making the Most of Your Energy Dollars was published in 1975 by the National Bureau of Standards and the Federal Energy Administration. It provided guidelines to homeowners in determining the most cost-effective energy improvements for their homes.

In another energy-conservation study, David M. Levinsohn and James T. McQueen estimated the fuel consumption of automobiles in terms of the types of vehicles and the characteristics of the roadways involved. They considered the use of expressways, arterial roads, and local streets, with the fuel consumption varying according to operating conditions. The authors expressed the belief that such basic data could be used by urban planners to design transportation grids for maximum energy conservation.[180]

Yet another contribution from the Bureau took the form of a handbook, *Energy Conservation Program Guide for Industry and Commerce (EPIC).* It was written by Robert R. Gatts, Robert G. Massey, and John C. Robertson to suggest specific techniques by which businesses could economize on their use of energy while still meeting their organizational goals.[181]

The result of a collaboration between NBS and the Federal Energy Administration, EPIC was a guide to energy conservation that became a university text. It offered details of methods that could be used to inaugurate programs in energy conservation, as well as more than 200 suggestions for saving energy. Each of the one-sentence

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[180] D. M. Levinsohn and J. T. McQueen, "A procedure for estimating automobile fuel consumption on congested urban roads," *NBSIR 74-595,* August 1974, 20 pp.

[181] R. R. Gatts, R. G. Massey, and J. C. Robertson, "Energy Conservation Program Guide for Industry and Commerce," *NBS Handbook 115,* September 1974, 212 pp.

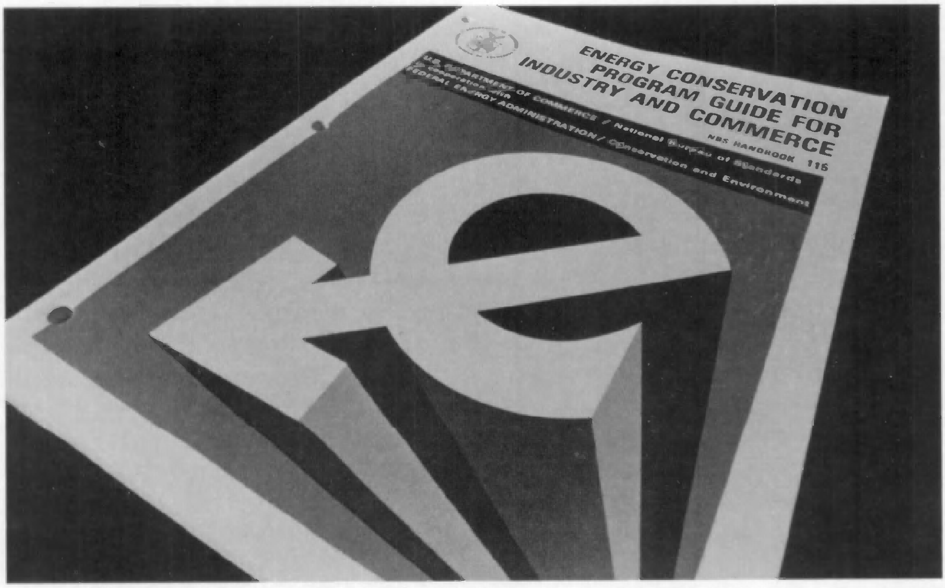
suggestions was labeled an *Energy Conservation Opportunity.* Actual case histories illustrated the ideas, which encompassed—among others—minimizing the expenditure of electrical power, processing energy, and energy use in the handling of materials.

The guide also provided useful methods for calculating the energy savings realized in particular cases. Organizations were listed from which information could be obtained on conservation projects, too. The original cost of the guide was less than $3.

One of the first college courses to make use of the new guide was offered by the School of Continuing Education of the University of Pittsburgh. It was known as the *Energy Management for Industry and Commerce course.* Instructors in the course often obtained advice on presenting the material from the NBS Office of Energy Conservation.[182]

Supplements to update the EPIC guide were issued over a period of several years.

An Office of Housing Technology (OHT) was established at NBS in 1972 under the leadership of Edward O. Pfrang, James G. Gross, and Joseph Greenberg. By August of that year, the office was involved in several projects. These included



In 1975 NBS published the *Energy Conservation Program Guide for Industry and Commerce.* The guide gave specific practical hints and case studies on energy-saving for small and medium-sized companies as well as for corporate giants.

[182] "An EPIC undertaking: out of the classroom, into the plant," *NBS Dimensions,* January 1976, pp. 6-9.

Project Feedback, an attempt to evaluate consumer reaction to housing innovations developed in *Operation Breakthrough;* an energy-conservation program associated with the Jersey City, New Jersey, Breakthrough site; and a project assessing the dangers to children from lead-based paint.[183]

In *Project Feedback,* consumer reactions were obtained directly by interviews with citizen residents of the modernized housing. The energy-conservation project produced data on the efficiency of utilization of waste heat—generated as a by-product of electric power production—for residential heating, cooling, and hot-water production. The lead-paint project involved detection methods for the offending paint and the development of methods for the removal of the paint or otherwise eliminating the danger to children from the paint.

Preventing Electrical Blackouts

The transmission of large quantities of electrical power could be adversely affected by transient currents on the lines, in worst cases causing power blackouts. Shunt reactors, large devices similar to transformers, could "tune out" such transients, thus stabilizing power transmission. Accurate measurement of power losses arising from the use of shunt reactors, however, was a problem for electric utilities. It was solved by Oskars Peterson, chief of the High Voltage Measurements Section of the Electricity Division, along with his colleagues Walter J. Mangan, Ronald Stanley, and William E. Anderson—a Presidential Intern from the University of Missouri. These scientists developed a self-balancing high voltage capacitance bridge which was a key component of the solution.[184]

Used with appropriate auxiliary equipment, the new bridge provided accurate measurements of the power losses accompanying the installation of high-voltage shunt reactors, even though the losses engendered by the highly efficient reactors were so small that they were difficult or impossible to measure by conventional means.

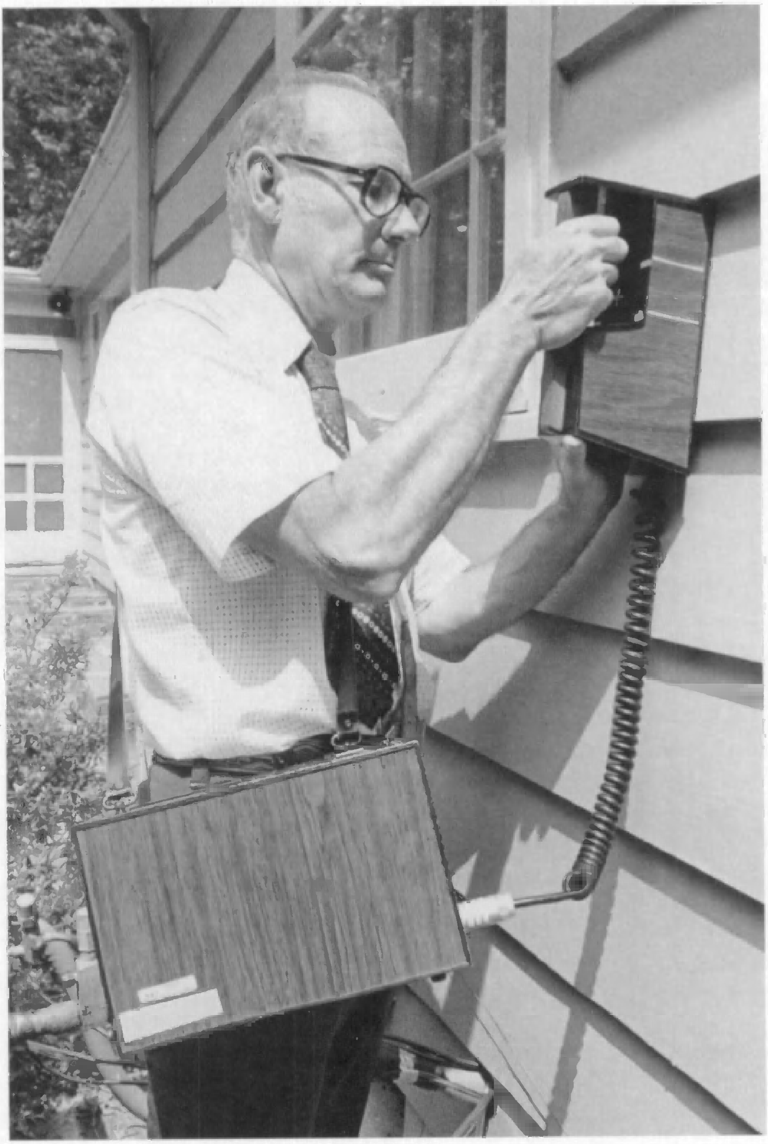
The new bridge also permitted the initiation of a new NBS calibration service for large capacitors and shunt reactors.

Looking for Cleaner Power from Coal

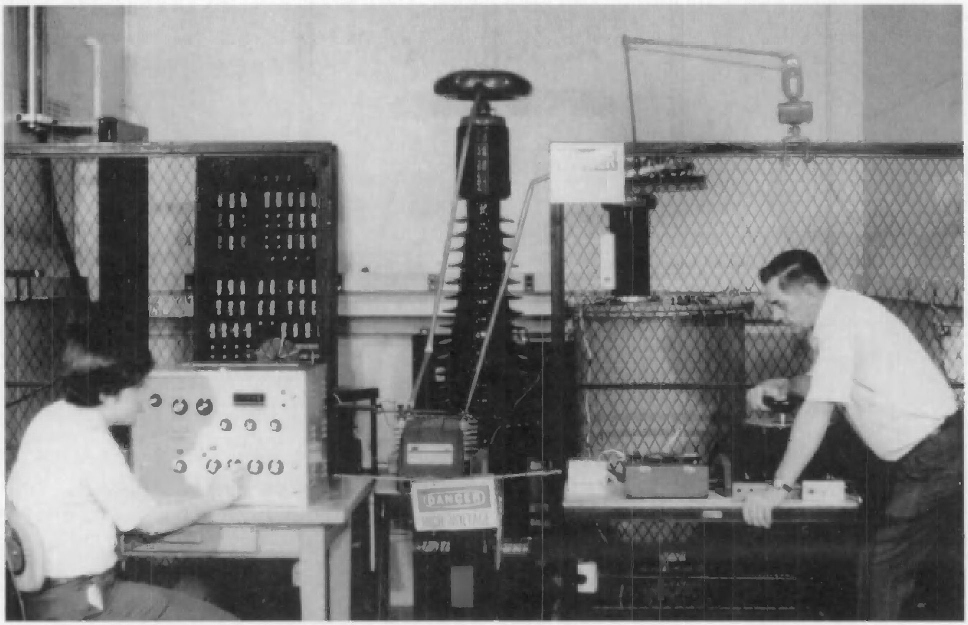
During the tenures of President Nixon and Director Roberts, the Nation searched earnestly for new sources of energy. Especially desired were new, cleaner uses for America's large domestic supply of coal.

[183] Other studies in the OHT included the spread of smoke and flame in fires; building foundations; piping materials; the thermal performance of entire buildings; design criteria for air conditioning; accelerated aging of building components; and the economics of housing. See *NBS Technical News Bulletin,* August 1972, p. 193.

[184] O. Petersons and W. E. Anderson, "A wide-range high-voltage capacitance bridge with one PPM accuracy," *IEEE Trans. Instrum. Meas.* **IM-24,** No. 4, pp. 336-344 (1975). See also "Shunt reactor power loss," *NBS Tech. News Bull.,* April 1973, p. 91.



Philip A. Cramp, a chemist with the NBS Center for Building Technology, operated a portable X-ray-fluorescence instrument to measure lead levels on the exterior wall of a house.



Chief of the NBS High Voltage Measurements Section Walter J. Mangan (standing) and Presidential Intern William E. Anderson used the self-balancing high voltage capacitance bridge to perform a power loss measurement.

John B. Wachtman and Samuel J. Schneider wrote a brief summary of U.S. needs for more efficient and cleaner power generation from coal, followed by a description of the hostile environments existing in high-temperature gas turbines, magnetohydrodynamic power generators, and coal gasifiers. The need for data and test methods was reviewed, and known material properties were summarized.[185]

Some progress was made during the period in the arcane study of magnetohydrodynamics (MHD), wherein a conducting stream of hot, ionized gas was passed through a transverse magnetic field, producing electric current in electrodes placed in the gas stream. Since it was expected that the power extracted by the MHD apparatus would be nearly free of the polluting products commonly found with coal or oil combustion, the option seemed well worth pursuing. However, the technique had its own drawbacks; high temperatures (typically above 2000 °C), a corrosive atmosphere produced by alkali-salt seed materials, and large temperature gradients.

With support from the Department of the Interior Office of Coal Research, Bureau scientists studied the resistance of known MHD materials to the corrosive MHD environment. They also investigated the properties of materials that might be used in MHD systems.

[185] J. B. Wachtman and S. J. Schneider, "Measurements and standards for high temperature materials in energy conversion and clean fuel production," *Stand. News* **1**, No. 8, 16-23 August 1973.

One form of MHD used as a fuel a type of coal, either natural or synthetic. Bureau scientists studied the composition, electrical conductivity, and viscosity of natural coal slags and the resulting fly ash, using chemical techniques, x-ray analysis, and thermal analysis. The natural variability of coal from different sources lent extra interest to the study. The composition and chemical reactions to be found in the gasified slag also were examined, along with the chemical and physical properties of known and potential seed materials that would be introduced into the system to increase gas-phase conductivity.

Technical results obtained during the period July 1972 to July 1974 were reviewed for a program initiated to generate properties data on materials for MHD. The program, sponsored jointly by NBS and the Office of Coal Research, involved a sizable group from the Bureau: Samuel J. Schneider, Webster Capps, Hans P. R. Frederikse, William R. Hosler, Dale A. Kauffman, Ernest M. Levin, Clyde L. McDaniel, Taki Negas, and Ernest R. Plante. Data were obtained in the reporting period for phase equilibria, electrical characteristics, and vaporization. Information was also obtained on the viscosity of several MHD components: coal slag materials, alkali seed materials, electrodes, and insulators.[186]

One of the projects involved measurements by Frederikse and Hosler of the electrical conductivity of coal slag—some natural and some synthetic—in the range 1200 K to 1700 K, at very low (10^{-6} of atmospheric) O_2 pressure. The authors expressed surprise that the measured conductivity was as high as 10^{-2} ohm^{-1} cm^{-1} at 1700 K, and they speculated on the cause, which they thought might be a ferrous-ferric electron transfer.[187]

Modeling the Fusion Plasma

The tantalizing concept of controlled nuclear fusion as an inexhaustible energy source coaxed large sums of money from supporting agencies and enormous amounts of effort from scientists in those days. The Bureau participated in the search in several of its laboratories.

One such effort, in its initial stage at that time, sought to provide a model of the fusion plasma to be used in developing instruments and analytical techniques for the evaluation of temperatures and electron densities. The project involved the use of a wall-stabilized electric arc burning in a hydrogen atmosphere, operated by a cosmopolitan team that included William R. Ott and Wolfgang L. Wiese of the Bureau's Optical Physics Division; Kurt Behringer, a guest worker from the Technical University in Munich, Germany; G. Gieres of the University of Dusseldorf in Germany, and Patrick Fieffe-Prevost, a visiting scientist from the National Bureau of Metrology in Paris.

[186] S. J. Schneider, W. Capps, H. P. R. Frederikse, W. R. Hosler, D. A. Kauffman, E. M. Levin, C. L. McDaniel, T. Negas, and E. R. Plante, "High temperature MHD materials," *NBSIR 74-543* 129 pp., August 1974.

[187] H. P. R. Frederikse and W. R. Hosler, "Electrical conductivity of coal slag," *Proc 13th Symp on engineering aspects of magnetohydrodynamics, Stanford U, March 26-28, 1973 paper* IV. 4. 1-IV. 4. 3.

The team built the electric arc to produce temperatures as high as 24000 K, hotter than the surface of the sun. Eight electrodes created the arc discharge, and 24 water-cooled copper discs restricted it to a volume 2 mm in diameter. Along its center, the arc temperature reached its maximum values; therefore, its properties were viewed "end-on."

The arc produced enormous amounts of radiation in the vacuum ultraviolet (vuv) region, just as a fusion plasma would. The continuum emission from the arc was employed as a radiometric standard. Its range, 165 nm to 360 nm in 1973, was expected to reach deeper into the vuv region upon further refinement.[188]

By 1975, the behavior of the arc was better understood, and its wavelength range extended down to 124 nm.[189]

Saving Energy at NBS

John D. Hoffman, Director of the Institute for Materials Research, summarized the activities of an NBS Energy Task Force that was created to develop contingency plans to keep the laboratories functioning in the event that energy conservation became mandatory.

Hoffman noted that NBS used about 115 million kWh of electrical energy and some 780 billion btu of heating fuel annually. About 85 % of the energy was used for climate control. Viable conservation measures were identified and implemented as parts of the program, including reduction in lighting, zone shut-downs of air handling, and thermostat adjustments. These steps saved about 12 % in electrical power usage and abut 18 % in heating fuel annually. Further conservation measures were considered feasible if conditions warranted.[190]

Alternative Fuels for Vehicles

Another contribution from the Bureau on behalf of energy technology was initiated by David A. Didion and James E. Hill of the Thermal Engineering Systems Section, Center for Building Technology. They adapted two NBS vehicles—a half-ton and a one-ton truck—to operate on gaseous fuels. The goal of the project was to compare engine performance with those fuels—compressed natural gas and liquefied petroleum gas (propane)—to that achieved with gasoline.

The testing group monitored emissions of hydrocarbons, carbon monoxide, and nitrogen oxides. They found that the gaseous fuels burned much cleaner (factors of three to ten) than gasoline in each category.

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[188] W. R. Ott, P. Fieffe-Prevost, and W. L. Wiese, "VUV radiometry with hydrogen arcs, I: Principle of the method and comparisons with blackbody calibrations from 1650 Å to 3600 Å," *Applied Optics* **12**, No. 7, 1618-1629 (1973).

[189] W. R. Ott, K. Behringer, and G. Gieres, "Vacuum ultraviolet radiometry with hydrogen arcs, 2: The high power arc as an absolute standard of spectral radiance from 124 nm to 360 nm," *Appl. Opt.* **14**, No. 9, 2121-2128 (1975).

[190] "Energy conservation at the NBS laboratories," *NBSIR 74-539*, 81 pp., July 1974.

NBS scientists compared the performance and exhaust emission characteristics of motor vehicles run on gasoline, compressed natural gas, and liquefied petroleum gas for the U. S. Postal Service. In this photograph, David K. Ward made engine adjustments during a test on a half-ton truck.

Whether the U.S. government, with its 300,000 to 400,000 vehicles, would switch a significant number of them to the cleaner-burning fuels was problematic. The change would involve refitting the carburetion system of each vehicle for use with the new fuel, as well as enaction of a scheme for supplying the gases in the quantities and at the locations needed for convenient use. But at least government vehicle managers now had factual information on which to base decisions.[191]

New Ideas in Physics

In this section we highlight Bureau advances in instrumentation that markedly improved the ability of scientists to make physical measurements.

[191] "Comparative performance of motor vehicles operated on gasoline, compressed natural gas, and propane," *NBS Tech. News Bull.*, August 1973, pp. 188-190.

High-Precision Spectrophotometer

A new spectrophotometer built by Klaus D. Mielenz and Kenneth L. Eckerle was expected to noticeably improve the quality of measurements in its field. The reliability of the basic unit of luminous intensity—or brightness—depended on the quality of the instruments used in its realization, so that improvements such as the one made by the two optical physicists was important progress in defining the standard.

Mielenz and Eckerle achieved new spectrophotometric accuracy by incorporating off-axis mirror optics rather than traditional lenses, and by placement of the sample in a collimated and linearly polarized beam. They also were able to compensate more effectively for detector non-linearity in the new instrument.

The new spectrophotometer employed a grating-type monochromator with circular entrance and exit apertures; it also incorporated a stabilized tungsten-ribbon lamp. A low-power laser was built into the system for alignment of the device. The detector was a photomultiplier tube with a stabilized power supply.

Early tests with the spectrophotometer indicated an instrumental uncertainty of approximately 10^{-4} transmittance units and an imprecision about half that large.[192]

A "Topografiner" Looks At Metal Surfaces

A closer look at metal surfaces became possible through the development of a new type of instrument by Bureau physicists Russell D. Young, John F. Ward, and Frederic E. Scire. Given the name "Topografiner," the prototype device permitted the topographic mapping of metal surfaces with a vertical resolution of 3 nm.[193] Clearly this was an instrument with a bright future.

Young, the team leader, came to NBS from Pennsylvania State University, where he mastered the science of field-emission microscopy under Erwin W. Müller. In a detailed 1971 article in the journal *Physics Today,* Young pointed out the value to surface science of an instrument that would allow surface measurements at the atomic level.[194] He mentioned several instruments, including one of his own, that could possibly reach atomic resolution.

The elements of the topografiner were few: a metal field-emission point, sharpened to a radius of about 10 nm; two orthogonal piezoelectric drive units arranged so as to move the point assembly in a plane parallel to a test surface; a third, finer piezoelectric drive operated by a servo system so as to maintain a fixed distance between the point and the test surface; and a mechanical stabilizing technique to restrict vibration to the lowest level then possible in their laboratory.

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[192] K. D. Mielenz and K. L. Eckerle, "Design, construction, and testing of a new high accuracy spectrophotometer," *NBS Tech Note 729,* 60 pp., June 1972. See also K. D. Mielenz, "Physical parameters in high accuracy spectrophotometry," *J. Res. NBS* **76A**, No. 5, 455-467 (1972).

[193] R. Young, J. Ward, and F. Scire, "The topografiner; an instrument for measuring surface microtopography," *Rev. Sci. Instrum.* **43**, No. 7, 999-1011 (1972).

[194] R. D. Young, "Surface microtopography," *Physics Today* **24**, No. 11, 42-49 (1971).

In using the topografiner, Young, Ward, and Scire prepared three-dimensional plots of the test surface from the voltages driving the three piezoelectric crystals. The plots rendered accurately the surface of an infrared diffraction grating, thus demonstrating the capability of the instrument to record the profile of a well-characterized surface.

The unusual mechanical stability of the topografiner, which was essential to its success, was demonstrated by the three physicists in a study of electron tunneling. Disconnecting the in-plane piezoelectric drives and putting aside the servomechanism for the point, the team could use the vertical drive to move the point closer and closer to a metal surface. Recording the current-voltage characteristic of the point-surface system, they were able to demonstrate for the first time metal-vacuum-metal tunneling at separations estimated to be less than 2 nm. At larger separations, they observed a gradual transition to the region governed by the Fowler-Nordheim equation.[195]

One might have expected scientific studies with the topografiner to produce elegant experiments in surface physics at NBS for years to come but, surprisingly, that was not to be. In 1972 work on the instrument was stopped by Young's supervisors so that his ideas could advance the study of industrial surface finish in another part of the Bureau. The topografiner was perhaps the first major victim of the Bureau trend towards "relevance."

Young's work with the topografiner was continued by Gerd Binnig and Heinrich Rohrer, employees of the IBM laboratories in Zurich, Switzerland. In 1986, they shared half of the Nobel Prize in physics for their design of the scanning tunneling microscope. The other half of the prize went to Ernst Ruska, who invented the electron microscope in 1931. The seminal work by Young, Ward, and Scire was noted in the Nobel documentation.

Young received the 1974 Edward Uhler Condon award for his 1971 article in *Physics Today*. He received the Department of Commerce Silver Medal Award in 1979. In 1986, he received a Presidential Citation from Ronald Reagan. In 1992, he received the Gaede Langmuir Award from the American Vacuum Society.

Young's impact on the Bureau reached even further than his personal efforts. During Young's development of the topografiner, J. William Gadzuk, E. Ward Plummer, and E. Clayton Teague, each of whose work is noted elsewhere in this volume, joined NBS specifically to collaborate with him. Each made substantial contributions to science while working at the Bureau.

Making Free Radicals Inside Lasers

Free radicals play important roles in air-pollution studies, in research on flames, in high-temperature chemistry, and in aerospace phenomena.

George H. Atkinson, Allan H. Laufer, and Michael J. Kurylo, III, found a way to overcome problems generated by the short lifetimes of many free radicals—they simply moved the radical-producing equipment into the cavity of a dye laser.[196]

[195] Russell Young, John Ward, and Fred Scire, "Observation of metal-vacuum-metal tunneling, field emission, and the transition region," *Phys. Rev. Lett.* **27**, No. 14, 922-924 (1971).

[196] G. H. Atkinson, A. H. Laufer, and M. J. Kurylo, "Detection of free radicals by an intracavity dye laser technique," *J. Chem. Phys.* **59**, No. 1, 350-354 (1973).

Russell D. Young received the Ph. D. degree in physics from Pennsylvania State University in 1959. He worked at NBS from 1961 to 1981. His principal research interest was the characterization of surfaces. While a group leader in the Atomic Physics Division, he led the development of the Topografiner, forerunner of the scanning tunneling microscope.

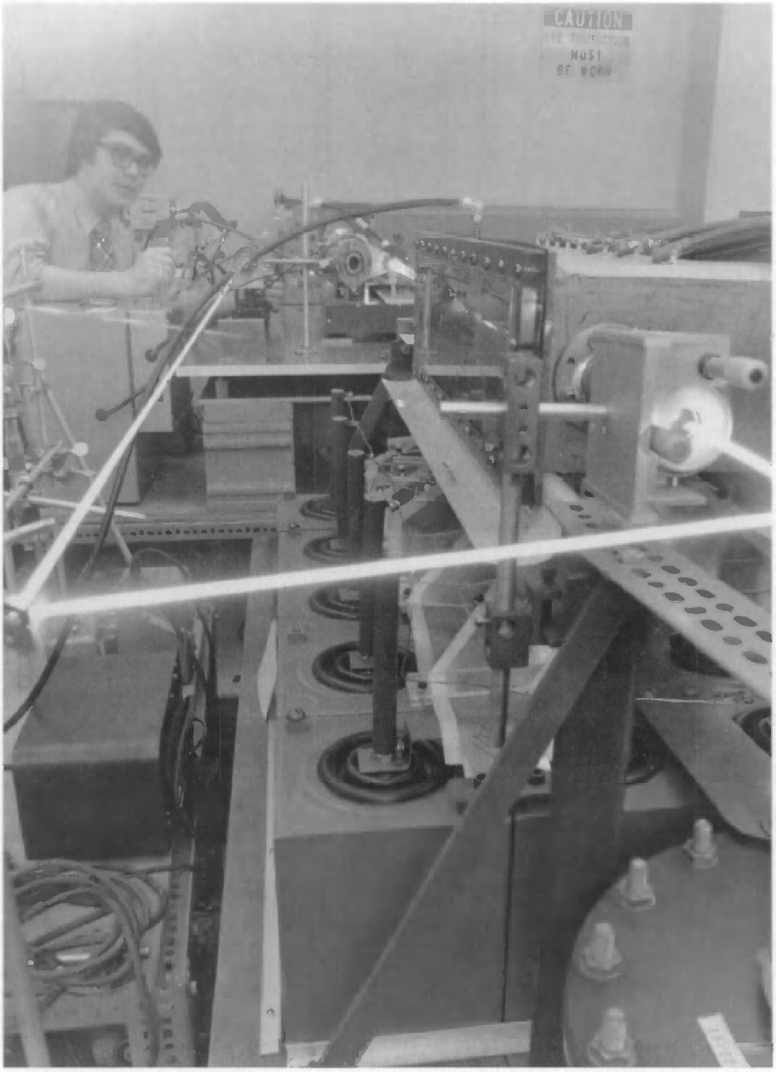
Much of the information about free radicals was obtained by observing the way in which they absorbed radiation. The NBS optical physicists found a way to incorporate the free-radical-production apparatus, a vacuum flash photolysis unit, into the cavity of a dye laser. The flash unit, consisting of a 75 cm long, fused-silica, evacuable reaction cell, utilized a 1000 J discharge to create free radicals in nitrogen gas. The dye laser, employing rhodamine 6G in ethanol, could produce about 300 mJ of output energy for analysis by a 2 meter grating spectrograph.

Early results were obtained on the species NH_2 and HCO; their spectra were more easily detected and analyzed by the new apparatus than had been the case with other techniques.

Progress in Optical Radiation Measurements

Jon C. Geist, physicist in the Optical Radiation Section of the Heat Division, initiated a new series of publications on optical radiation measurements with a 60-page treatise on the Bureau's intention to create a scale of total irradiance, using electrically calibrated, absolute detectors. His discussion included a theoretical analysis of known error sources in that type of realization, based upon detector development that occurred during the period 1968-71.[197]

[197] J. Geist, "Optical radiation measurements: Fundamental principles of absolute radiometry and the philosophy of this NBS program," *NBS Technical Note 594-1*, 59 pp, June 1972.



George H. Atkinson used a dye laser to detect free radicals, a technique that he developed at the National Bureau of Standards with Allan H. Laufer and Michael J. Kurylo.

The series was published over a several-year period as supplements to *NBS Technical Note 594*.

The second note in the series was written by Edward F. Zalewski, A. Robert Schaefer, Kshiti Mohan, and Donald A. McSparron. It described some of the basic instrumentation developed for use in photometry, including photodetector amplifiers, lamp-power circuitry, and mechanical components. Also presented were results of experiments on stability and directional-intensity tests of two types of lamps.[198]

McSparron and Velma I. Burns reviewed then-current procedures, equipment, and techniques used in photometry calibrations, including luminous intensity, luminous flux, and color temperature. Details of the uncertainty calculations associated with the program were discussed, as well.[199]

The next contribution to the series was written by Bruce Steiner, who described the National Measurement System for Radiometry and Photometry, emphasizing the role played by NBS in improving the system. Steiner noted the impact of optical-radiation measurements on the electro-optics industry—an industry that itself affected U.S. public health and safety, energy, meteorology, agriculture, and environmental activities. He also pointed out the many areas where improved capabilities for measurement were needed.[200] Steiner continued his discussion in a second note that emphasized the roles played in the measurement system by the Council for Optical Radiation Measurements and other professional groups.[201]

Details of the stability and temperature characteristics of certain photodetectors were described in a 1973 contribution to the optical-radiation-measurements series. Mohan, Schaefer, and Zalewski compared selenium-barrier-layer photocells and silicon PIN and PN type photodiodes operated in the photovoltaic or non-biased mode. The physicists studied detector-output stability over one-day periods and they investigated fatigue and hysteresis effects, as well as the temperature dependence of the detector output, all with an eye to using the devices for goniometric flux measurements or in other radiometric or photometric applications.[202]

William B. Fussell used the series to describe a new theory of the photometric integrating sphere.[203] The theory involved certain approximations to the geometry of the sphere, its baffle and lamp, and the absorptive and reflective characteristics of the sphere interior. Fussell then offered a method for evaluation of the measurement errors associated with use of the sphere. He also tabulated the diffraction losses for a range

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[198] E. F. Zalewski, A. R. Schaefer, K. Mohan, and D. A. McSparron, "Optical radiation measurements: Photometric instrumentation and research (1970 to 1971)," *NBS Technical Note 594-2,* 44 pp., September 1972.

[199] V. I. Burns and D. A. McSparron, "Optical radiation measurements: Photometric calibration procedures," *NBS Technical Note 594-3,* 35 pp., November 1972.

[200] B. Steiner, "Optical radiation measurements: The impact of radiometry and photometry and the role of NBS," *NBS Technical Note 594-4,* 56 pp., March 1973.

[201] B. Steiner, "Optical radiation measurements: The present state of radiometry and photometry," *NBS Technical Note 594-6,* 56 pp., March 1974.

[202] K. Mohan, A. R. Schaefer, and E. F. Zalewski, "Optical radiation measurements: Stability and temperature characteristics of some silicon and selenium photodetectors," *NBS Technical Note 594-5,* 16 pp., June 1973.

[203] W. B. Fussell, "Optical radiation measurements: Approximate theory of the photometric integrating sphere," *NBS Technical Note 594-7,* 39 pp., March 1974.

of experimental geometries, for wavelengths from 0.2 μm to 100 μm. He included in his discussion general formulas for the losses—derived from the Kirchhoff scalar paraxial diffraction theory—as well as estimates of the uncertainties of the tabular values.[204]

Ninth in the optical radiation measurements series was a contribution prepared by William H. Venable, Jr. and Jack J. Hsia. In it, the authors developed a mathematical description of spectrophotometric measurements.[205]

Crystalline Response to Shock Waves

Donald H. Tsai, trained at the Massachusetts Institute of Technology in aeronautical engineering, had a natural interest in shock waves. He indulged the interest by initiating a long-term study of the response of crystal lattices to shock waves. By 1974, Rosemary MacDonald—a theoretical physicist and colleague of Tsai's in the Heat Division's Equation of State Section—was collaborating with him on the problem.

The two scientists developed a molecular dynamics mathematical model to account for the propagation of shock waves in three-dimensional crystals. Their 1974 theoretical "experiments" were performed with a computer on perfect base-centered-cubic crystals equipped with an interatomic potential originally created for α-iron.

They made the crystals as large as could be accommodated by the available computers—125 unit cells. To study thermal relaxation with their model, they followed the propagation of high-temperature heat pulses into the crystals, observing the phenomenon of second sound, which they concluded was a quite general property of excitation in the solid state.[206]

Tsai and MacDonald refined their model and their computations, using ever larger crystals and more detailed analysis as computational capability—obtained from large computers outside NBS—increased. In 1976, they were able to comment on first sound, which they found to be a high-velocity sound wave that left behind it changes in both kinetic and potential energy in the crystal. These changes did not quickly come into equilibrium. They also found that second sound was a slower thermal wave, which did reach equilibrium. In their work, they had extended the concept of second sound to high temperatures and high pressures.[207] In a summary written later for the journal *Reviews of Modern Physics,* D. D. Joseph and Luigi Preziosi commented:

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[204] W. B. Fussell, "Optical radiation measurements: Tables of diffraction losses," *NBS Technical Note 594-8,* 39 pp., June 1974.

[205] W. H. Venable, Jr., and J. J. Hsia, "Optical radiation measurements: Describing spectrophotometric measurements," *NBS Technical Note 594-9,* 49 pp., November 1974.

[206] Donald H. Tsai and Rosemary A. MacDonald, "Heat pulse propagation in a crystal: a molecular dynamical calculation," *Solid State Communic.* **14**, 1269-1273 (1974).

[207] D. H. Tsai and R. A. MacDonald, "Molecular-dynamical study of second sound in a solid excited by a strong heat pulse," *Phys. Rev.* **B14**, No. 10, 4714-4723 (1976).

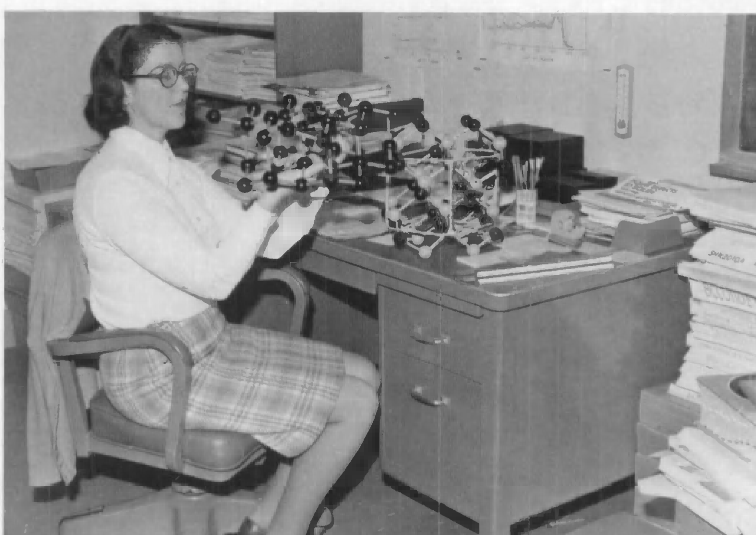
> The correspondence between the theory and calculations of this paper for high temperatures and short times and, to some degree, the experiments on second sound in helium II and dielectric crystals at very low temperatures and longer times, is astonishing.[208]

Tsai continued to work on shock dynamics even after retirement from NBS, gradually considering the effects of crystal imperfections such as vacancies, dislocations, and impurities. These, he found, led to structural relaxation under shock loading and to the generation of "hot spots" in the crystal.

Advice for Inventors

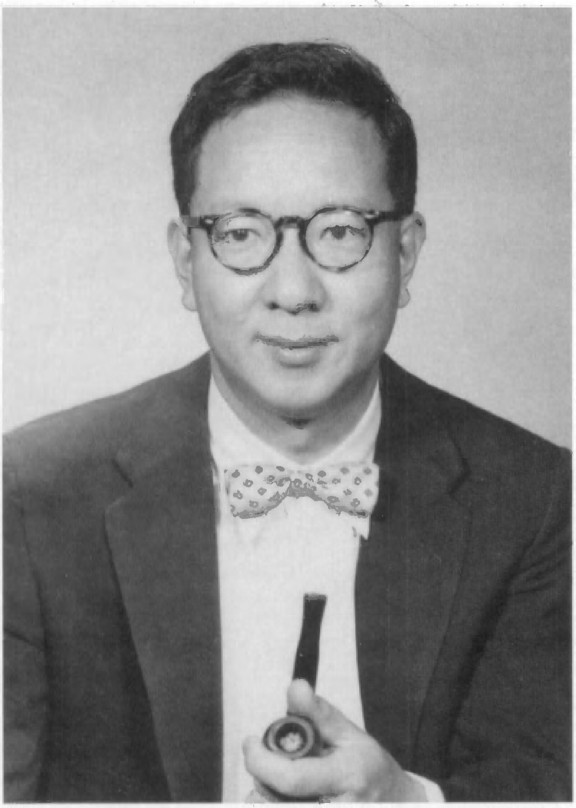
During a conference on *The Public Need and the Role of the Inventor,* held during June 11-14, 1973, at Monterey, California, Jacob Rabinow, the Bureau's dean of inventors, had sobering words for the day's image of the "wealthy" inventor:

> If that's your notion of the typical modern-day Edison, forget it. Nowadays, when an inventor is on the way to the bank, he's probably crying all the way because he has to borrow money to finance his latest quixotic gamble.



NBS physical theorist Rosemary A. MacDonald held a model intended to show the distortions in a crystal that resulted from an incoming shock wave.

[208] D. D. Joseph and Luigi Preziosi, "Heat waves," *Revs. Mod. Phys.* **61**, No. 1, 41-73 (1989).



Donald H. Tsai joined the Engines and Lubrication Section of the NBS Heat and Power Division in 1952. He was one of the first members of the Equation of State Section of the Heat Division when it was formed in 1961; his principal research interest there was the dynamical response of crystals to shock waves.

Rabinow was a reliable source.[209] He had a lifetime of invention behind him, including such important devices as a magnetic automobile clutch, an automatic letter-sorting system for the U.S. Post Office, and an optical character reader.

The conference mentioned above was co-sponsored by NBS, the Department of Commerce, and the National Inventors Council (NIC). Rabinow and F. Essers edited the proceedings, which were published as an *NBS Special Publication.*[210] There were 18 featured speakers, including Betsy Ancker-Johnson, Assistant Secretary of Commerce for Science and Technology; Richard W. Roberts, the new Director of NBS; Charles Stark Draper, Chairman of the NIC; Robert D. Tollison, senior economist on the President's Council of Economic Advisors; and Daniel V. De Simone, executive director of the Federal Council for Science and Technology, formerly head of the Bureau's Metric Study program.

[209] The outspoken Rabinow offered advice to inventors in several ways—often by individual counseling, as sometime director of the NBS Office of Innovation and Invention, and through his writing. Author of many articles on invention and the problems encountered by inventors, Rabinow late in his career wrote a book, *Inventing For Fun and Profit,* (San Francisco, California: San Francisco Press, 1989).

[210] "The public need and the role of the inventor," *NBS Special Publication 388*, F. Essers and J. Rabinow, editors, 215 pp., May 1974.

The "invention conference" was held to make more clear the climate in which America's inventors labored and to seek changes that might encourage invention for the benefit of the Nation. Topics included the patent system, technology trends, possible incentives for inventors, and the relationships among inventors, corporations, and academia.

A few months earlier, Director Roberts attended a National Inventor's Day celebration staged by the American Patent Law Association.[211] Rabinow, chief research engineer in the Institute for Applied Technology, received recognition:

> For his many significant contributions as an inventor, for his unique ability to stimulate others to create and innovate, and for his continuing dedication to the highest principles of the patent system.

By that time, Rabinow already held 200 American patents and about 70 foreign ones. Equipped with an M. S. degree in electrical engineering from the City College of New York in 1938, he tackled the invention process fearlessly. As a result of his efforts, he received numerous awards, including the Naval Ordnance Department Award (1945), a National Defense Research Committee certificate of commendation (1945), the Presidential Certificate of Merit (1948), the Department of Commerce Gold Medal (1949), a War Department certificate of appreciation (1949), Fellow of the IEEE (1956), the Franklin Institute Edward Longstreth Medal (1959), the 50th Anniversary medal of the City College of New York School of Engineering (1969), the Jefferson Medal of the New Jersey Patent Law Association (1973), the Harry Diamond Memorial Award (1977), Scientist of the Year award, Industrial Research and Development magazine (1980), Doctor of Humane Letters, Towson State University (1983), and the Lemelson Award of the Massachusetts Institute of Technology (1998).

During the year of his death, 1999, Rabinow was honored by the Cosmos Club of Washington, DC, as Man of the Year.

Progress in Computer Science

Networking With Minicomputers and Microcomputers

As the trend began of supplementing the use of mainframe computers with smaller computers, each dedicated to specific jobs, the question of networking—interconnecting—the so-called "mini" or "micro" computers became an area of interest for the Bureau's computer experts.

Thomas N. Pyke, Jr., provided a discussion of the applications in which the smaller computers might be suitable, and the configurations which the interconnections could take. Pyke pointed out that, if the trend continued, as seemed likely, new standards written especially for those systems would become necessary.[212]

[211] "Rabinow Honored by Patent Law Association," *NBS Standard,* March 1973, p. 1.

[212] T. N. Pyke, Jr., "Networked minis and micros—configurations, applications, and standards," *Proc. Symp. on Mini Micro Computers, U.S. Naval Academy, Annapolis Maryland, April 15, 1975* pp. 44-46.

Jacob Rabinow, an electrical engineer, was a successful inventor. He worked at NBS from 1934 to 1953 and from 1972 until his retirement in 1989. He provided technical leadership to the Bureau in ordnance development and in the evaluation of inventions. He received many honors for the quality of his work.

First model of a letter-coding station for an automatic mail sorting machine built by Rabinow Engineering Company under contract to NBS. Letters, one at a time, were presented to the operator who read the addresses, abbreviated their important parts, and typed the abbreviations onto the backs of the envelopes by means of a special printer. The printing code was in a binary form, and appeared in the form of "dot" or "no dot" on the envelope. The operator was John McDonald.

More About Networking

Dennis W. Fife, chief of the Software Analysis Section of the Institute for Computer Science and Technology, addressed the issue of "networking" computers for typical user organizations. He noted that networking allowed sharing of resources and rapid communication among the network users. He identified five stages of networking, ranging from the simplest—merely interconnecting the machines—to more advanced techniques involving several participating institutions.

Fife also provided guidance for management in the form of an evolutionary framework against which institutional goals could be measured.[213]

Ira W. Cotton addressed the same topic, but from the point of view of a study summarizing the practices of managers employing different types of computer networks. Several examples of successful networks were reviewed: the Advanced Research Projects Agency network; the MERIT network; the Triangle Universities Computation Center network; the Oregon State Regional network; and TYMNET, a commercial version.[214]

Data Encryption

Sending proprietary information via telephone lines or electromagnetic broadcast signals became a risky business as methods matured for intercepting such communications. One alternative to abandoning the techniques altogether involved data encryption. Dennis K. Branstad, commenting on the problem, noted that various levels of encryption were available. By employing user identification, access authorization, and access control machinery, the user could reduce considerably the likelihood of compromised data.[215]

FORTRAN Test Programs

One of the first computer programming languages was called FORTRAN. A draft American National Standard document, X.3.9-1966, described the language in standard form. In order to provide a mechanism by which a FORTRAN user could determine whether a particular compiler would accept the forms and interpretations specified in the standard, Frances E. Holberton and Elizabeth G. Parker prepared a test program which they described in a series of informative publications.

The series was named the *NBS FORTRAN Test Programs.* They were made available in *NBS Special Publication 399.* Three volumes were published in October 1974. Volume 1, Documentation for versions 1 and 3; Volume 2, Listings for version 1; and Volume 3, Listings for version 3.

Nuclear Physics

An indication of the range of the Bureau's program in nuclear physics, including theory, instrument development, measurements, and standards, is given in this section.

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[213] D. W. Fife, "Network management for expanded resource sharing," Chapter 7 in *Facts and Figures* pp. 55-61 (Princeton, NJ: The Interuniversity Communications Council, 1974).

[214] I. W. Cotton, "Network management survey," *Proc. Hawaii Int. Conf. on Systems Sciences, Univ. of Hawaii, Honolulu, Hawaii Jan. 8-10, 1974.*

[215] D. K. Branstad, "Encryption protection in computer data communications," *Proc Fourth Data Communications Symp., Quebec City, Canada, October 7-9, 1975* pp. 8-1 to 8-7.

Defining Ionizing Radiation

As a first step in portraying the use of radiation for the sterilization of medical and biological materials for the International Atomic Energy Agency, William L. McLaughlin and N. W. Holm composed a brief discussion of the physical characteristics of ionizing radiation.[216]

In a few pages they reviewed the physics and chemistry involved in the interactions of ionizing radiation with matter. They noted the quantities used in monitoring energy deposition by radiation as well. The objective of the project was to show how radiation could be used to inactivate fungi, bacteria, and viruses without significant damage to the host material.

Half-Lives of Radioactive Species

A determination of the half-life for decay of ^{252}Cf was recounted by Valentine Spiegel, Jr. He obtained the value (2.638 $\pm$ 0.007) years as the half-life for the rare isotope. The accuracy of the value derived from careful measurements over nearly five years, coupled with corrections for the contribution of activity from radium in the sample and for competing neutron-production from ^{250}Cf atoms.[217]

Radiation Exposure Standards

New exposure-rate standards were set for ^{60}Co and ^{137}Cs by the Bureau as a result of measurements made using a new spherical type of ionization chamber. The measurement corrections involved with the new chambers were evaluated more accurately than had been the case with the cylindrical chambers used previously, according to Thomas P. Loftus and James T. Weaver, Jr.[218]

Measurements were obtained using six replicas of the spherical chamber; agreement among the results was described as "excellent." The experiments led to reductions in the standards for safe exposure to radiation from the two nuclides. As of July 1974, the exposure standard for ^{60}Co was reduced by 0.7 % and that for ^{137}Cs was reduced by 0.8 %.

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[216] W. L. McLaughlin and N. W. Holm, "Physical characteristics of ionizing radiation," chapter 1 in *Manual on Radiation Sterilization of Medical and Biological Materials* Technical Report No. 149, International Atomic Energy Agency, Vienna, Austria, 1973.

[217] V. Spiegel, "The effective half-life of californium-252," *Nucl. Sci. Eng. Tech. Note* **53**, No. 3, 326 (1974).

[218] T. P. Loftus and J. T. Weaver, "Standardization of ^{60}Co and ^{137}Cs gamma-ray beams in terms of exposure," *J. Res. NBS* **78A**, No. 4, pp. 465-476 (1974).

Sum Rules for Photon-Proton Scattering

A new sum rule relating to elastic photon scattering was derived by Leonard C. Maximon and James S. O'Connell. The rule described forward Compton scattering between photons and protons. The two scientists obtained the new rule by deriving the relations between integrals over forward elastic-photon scattering amplitudes, forward elastic cross-sections, and total cross-sections, using the applicable dispersion relations.[219]

Radionuclide Metrology

A new international summer school on radionuclide metrology provided several Bureau scientists with opportunities to lecture on their specialties in 1972. The school was held in Yugoslavia during late August 1972. Among the talks were the following:[220]

The work of J. M. Robin Hutchinson, Wilfrid B. Mann, and Patricia A. Mullen on sum coincidence counting at NBS was described. The use of two thallium-activated sodium iodide crystal detectors resulted in order-of-magnitude improvement in the accuracy of the sum-peak technique of coincidence counting. The method became comparable in accuracy to the conventional beta-gamma and gamma-gamma coincidence counting methods. The new technique was applied to ^{94}Nb, ^{88}Y, ^{26}Al, and ^{207}Bi.

A review of low-level radioactivity measurements was offered by Hutchinson, Mann, and R. W. Perkins. They described the sensitivities of a variety of detectors used for alpha, beta, and gamma rays. They also presented examples of low-level measurements—a standard reference material incorporating bovine liver, and radioactive contaminants in industrial samples of aluminum, copper and steel.

The development by Samuel B. Garfinkel, Mann, and John L. Pararas of automatic sample changers for the NBS 4π beta-gamma coincidence counter and the gamma-ray intercomparator was discussed. The new devices permitted the automatic measurement of as many as 30 sources for up to ten counting periods each. Good control of source-detector distances was an additional advantage of the instruments.

Wilfrid Mann presented a review of NBS work on radioactive calorimetry, with particular emphasis on the standardization of ^{63}Ni. Mann discussed the results of intercomparisons involving two Canadian laboratories, the National Research Council and Atomic Energy of Canada Limited.

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[219] L. C. Maximon and J. S. O'Connell, "Sum rules for forward elastic photon scattering," *Phys. Lett.* **48B**, No. 5, 399-402 (1974).

[220] *Proc. First Intl. Summer School on Radionuclide Metrology, Herceg Novi, Yugoslavia, August 21-September 1, 1972,* printed in *Nucl. Instrum. Methods* **112**, Nos. 1 and 2 (1973).

A survey was presented by Lucy M. Cavallo, Bert M. Coursey, Garfinkel, Hutchinson, and Mann on the growing need for higher skills and improved facilities in radioactive-assay work. They noted that the value of commercial use of radio-isotopes had already reached $80 million annually. In the face of such a demand, the Bureau had to develop new strategies to satisfy it; these were discussed, with special emphasis on the use of radiopharmaceuticals and environmental measurements.

Welcome to CAMAC

CAMAC, a modular instrumentation system used to transmit digital data between instruments, between instruments and computers and between instruments and computer peripherals, was described in a series of publications by Louis Costrell. The CAMAC system was developed by a committee of European laboratories. Its use was endorsed by the Nuclear Instrument Module Committee of the U.S. Atomic Energy Commission.[221]

Costrell, at that time chief of the Radiation Physics Instrumentation Section, was a much-decorated veteran of nearly 30 years of service to NBS. In 1967, he was awarded a Department of Commerce Gold Medal for his work in nuclear instrumentation. In recognition of his contributions to many developments, including the CAMAC project, he was presented with the Harry Diamond Award in March, 1975. The citation recognized a career "that exemplified the highest type of scientific effort in Government service."

Electronic Technology

Semiconductor Measurement Technology

NBS Special Publication 400 provided an extensive reference literature in electronic technology of that time. Fourteen publications were offered in 1974 and 1975 in the series.

- Volumes 1, 4, 8, 12, and 17 were edited by W. Murray Bullis. They described NBS methods of measurement for semiconductor materials, process control, and device development during the third quarter of 1973 (Volume 1, issued March 1974, 68 pp.), the first quarter of 1974 (Volume 2, issued November 1974, 101 pp.), the second quarter of 1974 (Volume 8, issued February 1975, 70 pp.), the third quarter of 1974 (Volume 12, issued May 1975, 59 pp.), and the fourth quarter of 1974 (Volume 17, issued November 1975, 79 pp.). Accomplishments included measurement of current and capacitance on metal-oxide-semiconductor (MOS) capacitors, evaluation of transistor die attachments, analysis of interlaboratory comparisons of electron scattering in transistors, and a variety of other activities.

[221] L. Costrell, "CAMAC instrumentation system—introduction and general description," *IEEE Trans. Nucl. Sci.* **NS-20**, No. 2, 3-8 (1973).

- Volume 2, edited by George G. Harman, was 109 pages long. It was issued in January 1974. Entitled *Microelectronic ultrasonic bonding,* it contained excerpts of work in that area over the previous 4 years, arranged so as to provide a useful and coherent reference to NBS efforts in ultrasonic bonding. Specific topics included measurement equipment; setup and reliability of bonding machinery; bonding examples; and bond properties.
- Volumes 3 and 9, edited by Harry A. Schafft, summarized presentations at two workshops co-sponsored by NBS and the Advanced Research Projects Agency. The first workshop was entitled *Measurement problems in integrated circuit processing and assembly;* the second, *Hermicity testing for integrated circuits.*
- Volume 5, edited by George J. Rogers, David E. Sawyer, and R. L. Jesch, was entitled *Measurement of transistor scattering parameters.* It contained 53 pages and was issued in January 1975. In it, the authors discussed the results of an interlaboratory comparison of electron-scattering parameters for three types of transistors. The results indicated a need for more careful control of measurement methods if the participating laboratory personnel wished to obtain data with minimum variation from measurement to measurement.
- Volume 6, edited by Martin G. Buehler, contained an overview of microelectronic test patterns. It contained 24 pages and was issued in August 1974. The test patterns considered were designed to evaluate fabrication processes, allowing the operator to determine, for example, whether a given process was under control and produced reliable microcircuits.
- Volume 10 contained a report of a symposium on spreading-resistance measurements, held at NBS Gaithersburg during June 1974. The editor was James R. Ehrstein. The text of 293 pages included both contributed papers and the transcripts of discussions.
- Volume 11, edited by Richard L. Mattis and Martin G. Buehler, described a computer program for calculating dopant density profiles from capacitance-voltage data. The program was written in the BASIC language.
- Volume 13, edited by Alvin H. Sher, was entitled *Improved infrared response technique for detecting defects and impurities in germanium and silicon p-i-n diodes.* Sher enumerated the many advantages of the method and warned of its few limitations.
- Volume 20, edited by John M. Jerke, was titled *Optical and dimensional-measurement problems with photomasking in microelectronics.* Jerke described the purpose of photomasks and the processes by which they were utilized in integrated circuit production, as well as the problems in their use.

The series furnished a comprehensive, up-to-date set of references on semiconductor measurement methods.

Electronic Devices in the U.S.S.R.

Charles P. Marsden collected data on active devices, ranging from receivers to microwave devices, semiconductors, phototubes, and thermistors, in the Soviet Union. The information was obtained from a variety of published sources.[222]

Resistivity Of Silicon

Round-robin measurements suggested by the Resistivity Task Force of the American Society for Testing and Materials Committee F-1 indicated that an improved standard procedure for measurement of circular silicon slices with four in-line probes could be accomplished with a resulting imprecision near 2 %.

The experimental procedures followed in the study were detailed by W. Murray Bullis. Non-uniformity of wafer resistivity appeared to limit the precision of most measurements, but corrections for temperature, wafer thickness and diameter, and improper probe position also were noted as important variables.[223]

In another study, Bullis and W. Robert Thurber reviewed the status of resistivity and carrier-lifetime studies in gold-doped silicon, particularly dwelling on remaining inconsistencies in experimental results on three topics: an apparent discrepancy between total and electrically active gold; a discrepancy—observed in specimens with large gold concentrations—between calculated and measured resistivity in both n-type and p-type materials; and the unexpected diversity in data on capture cross sections.[224]

Thermal Impedance of Power Transistors

Discrepancies appearing in measurements of the thermal impedance of power transistors using two different methods were discussed by David L. Blackburn and Frank F. Oettinger. It seemed that the pulsed-heating-curve method gave values different from those obtained with the cooling-curve technique. The two scientists discovered that the discrepancies arose because the power density distributions changed as the devices were heated, leading to different results depending upon the direction of heat flow. They provided an analytical method for obtaining reproducible values.[225]

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[222] C. P. Marsden, "Tabulation of published data on electron devices of the U.S.S.R. through December 1973," *NBS Technical Note 835,* 130 pp., November 1974.

[223] W. M. Bullis, "Standard measurements of the resistivity of silicon by the four-probe method," *NBSIR 74-496,* 75 pp., August 1974.

[224] W. R. Thurber and W. M. Bullis, "Resistivity and carrier lifetime in gold-doped silicon," *Air Force Cambridge Research Laboratories Report AFCRL-72-0076,* 37 pp., January 1972.

[225] D. L. Blackburn and F. F. Oettinger, "Transient thermal response measurements of power transistors," *Proc. IEEE Power electronics Specialists Conf, Bell Telephone Laboratories, Murray Hill, NJ, June 10-12, 1974,* pp. 140-148.