CHAPTER TWO

BRIGHT PROSPECTS FOR NBS (August 1969–May 1972)

It was a terrible year for America, 1968, but one of great expectations for the National Bureau of Standards. The paradoxical existence of an optimistic attitude among the staff of NBS—arising in the midst of a mordant pessimism for the future of their country among the American public—had its resolution in the anticipation of vigorous new leadership for the Bureau. True, the NBS budget was confining; it was necessary for many a manager to seek funding from sources outside of Congress in order to reach for new programs or, sometimes, to support existing ones. Also true, the state of the scientific equipment was precarious in many a Bureau laboratory. But the staff was strong, the laboratories themselves were modern, and the reputation of NBS for integrity and scientific capability was secure. Allen Astin had left a fine legacy.

The Bureau staff could not anticipate all the changes that were in store for their agency, although the signs were there to be seen. Public support of the scientific establishment was declining; the decrease was felt most keenly among those involved in fundamental studies. In response to that decline, there was a rising insistence on "relevance," the ability to justify projects in terms of immediate public benefits. Continually growing was the number of large programs created to address the troubles of a beleaguered American industry. The one change that was obvious was that Allen Astin was stepping down from his post of 17 years. The prospect that a vigorous new leader could magnify the gains achieved under Astin was exciting.

A NATION IN DISTRESS

The Nation saw, in 1968, an avalanche of misery of the sort that it had felt in 1963 when the vigorous life of John Kennedy was stopped in an instant by an assassin's bullet. Historian James Patterson called 1968 "the most turbulent year" in the period 1945-1974.[1]

The year began with the Tet offensive in Vietnam. President Lyndon Johnson had seen the number of U.S. military personnel in Vietnam mushroom from the 17,000 "advisors" of Kennedy's truncated term to 500,000 troops.[2] The stepped-up American presence was certain, said General Westmoreland, to give America a "light at the end of the tunnel." Surely, such a large military force would make short work of an unpopular conflict. Just in time, too, for war protesters already were tramping the streets of the Nation's capital.[3]

[1] Of many chronicles of the post-WWII/Vietnam era, one by James T. Patterson, *Grand Expectations: The United States, 1945-1974* (New York: Oxford University Press, 1996) is among the most thorough. The quote is from the title of Chapter 22.

[2] Ibid., p. 595.

[3] Ibid., see photos following p. 558.

The North Vietnamese chose the time of Tet, the holiday of the lunar new year in January, to show their determination to withstand the American escalation. In one of many simultaneous, bloody attacks, soldiers stormed the U.S. embassy in Saigon, breaching the heavy walls of the compound and leaving their dead and dead American defenders on the lawn. With that concerted, multi-pronged assault, the North Vietnamese quenched the light at the end of the tunnel—the Vietnam war was obviously far from over.

On March 31, 1968, a downhearted Lyndon Johnson announced to the American people that he was halting the bombardment of North Vietnam. He also told a stunned radio audience, "I shall not seek, and I will not accept, the nomination of my party for another term as your President."[4]

The national disasters continued in April of 1968. Martin Luther King, who nearly single-handedly had kept heated racial tensions from exploding, was cut down in Memphis by an assassin. Before that day was out, fires were burning in a dozen American cities. Riots, arson, and mayhem killed or injured more than 20,000 people within a few days. The Nation's capital itself saw hundreds of fires and ten killings.[5]

Robert Kennedy was a victim in 1968 as well. Mounting a vigorous campaign for President even before Johnson's withdrawal, Kennedy rallied the Nation to resist the forces of anarchy, racial discrimination and despair. In June, after he completed a speech at a Los Angeles hotel and was leaving the scene, Kennedy, too, was shot and killed.[6]

There were still 6 months of 1968 for the Nation to endure. They were not happy months.

The Democratic national convention of 1968, which took place in Chicago during August, was marred by Mayor Richard Daley's heavy-handed response to ever-present anti-war demonstrators. Along with bystanders, reporters, photographers—even medical personnel—the demonstrators were pursued, clubbed, tear-gassed, and arrested. The scene turned many in the watching American public away from the Democratic presidential ticket of Hubert Humphrey and Edmund Muskie and towards the Republican candidates, former Vice-President Richard Nixon and Maryland Governor Spiro Agnew. The stage was set for more nasty years still to come.

RICHARD MILHOUS NIXON

Richard Nixon, as a young lawyer in California, had no political plans. Certainly, he had no program that would carry him to the White House. An outstanding student at Whittier College, a small Quaker school, Nixon received a scholarship to the law school at Duke University, graduating third in his class of 25 with an LLB degree in 1937. By 1940, he was settled in a law practice. In June of that year he married Thelma Patricia Ryan, whom he met during his membership in a little theater group.

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[4] Ibid., p. 685.

[5] James MacGregor Burns, *Crosswinds of Freedom*, (New York: Vintage Books, 1990) p. 413.

[6] Ibid., p. 414.

Nixon's low-key life changed with America's entry into World War II. He served in the U.S. Navy from 1942-46, returning to California just in time for the Republican party to recruit him as an opponent to Congressman Jerry Voorhis. Quickly finding a campaign technique that would serve him well in future races, he attacked Voorhis as a tool of the Communist Party. The accusation, loosely based but effective, combined with Nixon's youth, his wartime service, and his excellence at debate to elect him to the U.S. Congress, Class of 1946, where he joined a Republican majority.

Nixon served vigorously in the House. He helped craft the Taft-Hartley labor bill as a member of the Committee on Education and Labor, and, as a member of the Committee on Un-American Activities, he helped convict suspected spy Alger Hiss of perjury. He found Congressional service much to his liking and eagerly took the opportunity to campaign against Helen Gahagan Douglas for the Senate in 1950.

A scarcely modified "She's-A-Communist-Tool" campaign, coupled with an increasingly effective speaking ability, elected Nixon to the U.S. Senate, where he carried the party message nation-wide with perhaps 200 speeches to the faithful during 1951 and 1952. The party, grateful and impressed, looked kindly upon the choice of Nixon as the vice-presidential candidate to accompany the 1952 presidential bid of Dwight David "Ike" Eisenhower, the intensely popular leader of America's military forces in Europe during World War II.

Nixon's first brush with political disaster, a revelation of secret political funds donated by wealthy supporters, occurred during the 1952 campaign. Nixon overcame the potentially lethal problem by dint of a masterful speech; he remembered with rancor, however, certain "enemies"—particularly some aggressive members of the press who questioned his ethics.

Eisenhower and Nixon defeated Illinois ex-Governor Adlai E. Stevenson and Alabama Senator John Sparkman by nearly 6 million votes of the 60 million cast. Ike, a political neophyte, proved to be a forceful president, though his health began to fail before his first term was complete. He was instrumental in bringing the Korean War to a cease-fire in July 1953, and he offered quiet support to those who eventually brought low his fellow Republican, Senator Joseph McCarthy. Ike willingly fought the Cold War, endorsing the development of thermonuclear weapons and an aggressive intelligence effort. Despite suffering a heart attack in 1955, he easily won re-election to the presidency in 1956. It was said that Eisenhower was not especially fond of Nixon. On two occasions the President offered Nixon a Cabinet post, but Nixon opted to remain as Vice President.[7] The 1956 Eisenhower-Nixon margin of victory over Stevenson and Tennessee Senator Estes Kefauver was larger than that enjoyed in 1952.

During his two terms as Vice President, Nixon was increasingly called upon to assist Ike with his ceremonial functions. Besides his heart attack in 1955, the war hero suffered an ileitis attack in 1956 and a stroke in 1957. Nixon visited some 56 countries as Vice President, including notable visits to Venezuela and the U.S.S.R. In Venezuela, Nixon's cavalcade was disrupted by local insurgents, including members of the local

[7] Stephen Ambrose, *Eisenhower: Soldier and President* (New York: Simon & Schuster, 1990), pp. 400-405.

Communist Party; Nixon displayed courage in the face of the attackers, and the world noticed. In Moscow, Nixon confronted Nikita Krushchev during a visit to a kitchen-appliance booth at a trade fair, "jawing" with the old Communist fearlessly. Again, the world noticed.

Nixon's string of electoral victories was interrupted, however, when he ran for President of the United States and, later, for Governor of California. The Nixon-Henry Cabot Lodge presidential ticket lost to John F. Kennedy and Lyndon B. Johnson in the 1960 presidential campaign; then Nixon lost again, to Edmund G. "Pat" Brown, in the 1962 California gubernatorial race. Disappointed and "through with public office" Nixon moved to New York, then called one last press conference to chastise some of his enemies in the press, announcing, "You won't have Nixon to kick around anymore, because this is my last press conference."

However, as noted above, 1968 was an unusual year. Perhaps longing for the bright light of politics, Nixon secured so many primary presidential votes in 1968 that his early opponent, George Romney, Governor of Michigan, withdrew from the race for the Republican nomination. Then Nixon outlasted Nelson Rockefeller and Ronald Reagan to win his party's nomination. He and Maryland Governor Spiro Agnew won the election over former Vice-President Hubert Humphrey and his running-mate, Senator Edmund Muskie, and over the surprisingly popular third-party candidates, Alabama Governor George Wallace and Air Force General Curtis LeMay. Nixon didn't realize at the time that his real trouble was just beginning.

Facing Adversity

President Nixon was beset by a host of problems as soon as he took office. The list could have served as a medical report for an ailing nation, beginning with the deep political turmoil described in the previous sections and including social inequities, growing inflation, increasing unemployment, a shaky stock market, and worsening international trade balances.

Vietnam, the Soviet Union, and China

International affairs interested Richard Nixon. He had seen the world as Vice President under Eisenhower, and he felt that—by relying on a mixture of toughness, understanding, and diplomacy—he could bring a new level of quiet to world disorder. His primary preoccupation, no doubt, was Vietnam, although he was confident that he could get results with the U.S.S.R. and China as well.

Nixon chose Henry Kissinger as his security advisor. Kissinger, a former professor of government at Harvard, was anxious to practice his craft in the international arena; Nixon gave him his chance.

Nixon and Kissinger—both secretive men, much given to manipulation and craving of public acclaim—made an odd couple, occasionally working at cross-purposes. Yet they gradually brought about a marked reduction of the American presence in Vietnam and improved relations with both the Soviet Union and China.

Nixon had a "secret plan" to end the war in Vietnam, he told audiences while campaigning for president in 1968. This, like other claims by other men, was not a statement that should be taken literally. However, Nixon confided to aides that he felt confident in his ability to bring the North Vietnamese to the bargaining table. He called his method the "madman theory"; known to be a rabid anti-communist, he would frighten the enemy with the specter of nuclear disaster. And in truth, he and Kissinger were always ready with bombs when persuasion was needed in Vietnam—and occasionally in Cambodia and Laos, too.

As they stepped up the bombing war in Vietnam, Nixon and Kissinger reduced the number of American soldiers on the ground. In June 1969 Nixon announced the withdrawal of 25,000 troops. The South Vietnamese correctly surmised that support for their cause was diminishing within the U.S. government. Antipathy for the war within the American public became still more pronounced.

In February 1972, Nixon traveled to China, seeking improved relations with the Communist giant. The trip was largely for show, as he gained no concessions from his hosts; in fact, he volunteered that America would reduce the size of its military force in Taiwan, thus weakening the position of the island country in the United Nations.

In May 1972, as Lewis Branscomb was departing from the National Bureau of Standards, President Nixon paid a visit to Moscow to sign—with his counterpart, Leonid Brezhnev—a *Strategic Arms Limitation Treaty* and another document restricting the use of anti-ballistic missiles. The treaties offered an improvement in communications between the two Cold-War enemies, if little in terms of actual arms reduction. Again, an ancillary deal actually went against the interest of the United States: large quantities of American grain were offered at bargain prices to the Soviets, thus reducing U.S. supplies and mildly aggravating inflation in America.

Domestic Issues

Nixon was not interested in social programs, or especially taken with domestic politics. He had derided Johnson's Great Society during his presidential campaign. Nevertheless, social troubles—indeed, troubles of many varieties, both domestic and international—abounded, and their cure would require vigorous action. Prodded by a largely progressive Democratic Congress, Nixon collaborated in the enactment of a considerable amount of social legislation during his first term in office. Included in the list were: an extension of the Voting Rights Act of 1965; funding for the war on cancer, for enhanced medical training, and for the arts; a ban on gender bias in higher education; greater support for those in poverty; creation of the Environmental Protection Agency and the Occupational Safety and Health Administration; and the Clean Air Act, the Federal Water Pollution Control Act, and the Consumer Product Safety Act.[8] This legislation affected the National Bureau of Standards both directly and indirectly, as we shall see.

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[8] James T. Patterson, *Grand Expectations*: Ch. 23.

Despite his participation in a program of social progress, the American public displayed decidedly mixed feelings towards President Nixon. The 1970 elections left the Congress securely in Democratic hands, and the public, finding it difficult to make ends meet and encouraged by a national press that was increasingly critical of the President, gave him little credit for his part in the new social legislation.

In August 1971, unable to ignore the Nation's economic ills, Nixon announced a *New Economic Policy.* He instituted a 90-day freeze on wages and prices, he ended the link between dollars and gold, and he placed a temporary 10 % surcharge on imports. These steps represented a radical departure from the Republican economic credo; they showed President Nixon to be, in fact, flexible in his economic thinking. The new policy included a promise to reduce Federal spending—a recurring Republican theme—and a proposal to eliminate 5 % of all Federal employment. The effects of these promises were quickly felt at NBS.

For purposes of Nixon's re-election in 1972, his New Economic Policy worked well. The national economy made a notable, though transient, recovery that fitted nicely with the President's statesmanlike performances in China and the Soviet Union. However, the underlying problems remained, to surface again during Nixon's second term.

The availability of energy for use in the United States became a visible problem during Nixon's presidency, too. The Arab oil-producing states, forced by a common war against Israel to cooperate, discovered that oil export prices and quotas could be powerful weapons in international affairs. Although the Arab countries occasionally returned to the self-defeating practice of unilateral action, by 1971 oil prices began a rise to levels never before seen. In the United States, oil consumption continued to increase despite presidential efforts to encourage conservation.

By virtue of tape recordings of White House conversations made public later, we know that President Nixon was preoccupied right from the time of his election in 1968 with plans for re-election to a second term in 1972. Nearly every move was scripted as much to improve the image of the Nixon administration as for its value to the Nation's welfare. During his second term, Nixon's determination to seek revenge for real and imagined political damage by those on his "enemies list" carried him well beyond the limits of ordinary political maneuvering.

A New Director for the National Bureau of Standards

In Gaithersburg, Maryland, and in Boulder, Colorado, the men and women of the National Bureau of Standards were well aware of the Nation's anguish. They were, after all, citizens, parents, husbands, and wives. Each was touched in various ways by the war, by the Nation's economic ills, and by racial conflict.

The U.S. Civil Rights Commission, studying the results of moving several government agencies from city locations to the suburbs, noticed that the National Bureau of Standards had lost an aggregate 73 black employees—while the overall employment rose by 125—when the Bureau headquarters was moved to "the sticks." The Commission suspected racial discrimination in housing, hiring, or both.[9] And discrimination there was.

The feeling in the air at NBS, however, was that good things were about to happen in 1968.

Allen Astin had made known in 1967 his plans to retire during 1969, when he would be 65 years old. He had served the Bureau and the Nation well for over 35 years—17 of them as NBS Director—at the time of his retirement. All of his years had been challenging and some of them were hard labor as well.[10]

Astin had seen—in many cases, had precipitated—the shift in Bureau work away from the military projects that had dominated NBS during World War II, leaving the agency more tranquil in spirit and more nearly supported by direct congressional appropriations than it had been for many years. About 80 % of Bureau funding came directly from Congress in 1968, twice the wartime percentages of 40 % or less.

Burned into Astin's memory was the AD-X2 travail. He had not only survived that ordeal but—because of his own exemplary behavior and that of the NBS staff throughout the incident—it had served to elevate beyond question the Bureau's reputation for accuracy and integrity.

Astin regarded as the capstone of his service to NBS his efforts to develop a mission statement for the Bureau and to advance a general recognition of its unique, triune role in American technological life:

1. To provide a complete and consistent system of physical measurements in harmony with the international system.
2. To provide essential services leading to accurate and uniform physical measurements throughout the United States.
3. To provide needed data on the properties of matter and materials of technological importance.

Astin communicated the ideas underlying the NBS mission repeatedly, often inserting them into his testimony before the House Appropriations Subcommittee that monitored the Bureau.[11]

As he entered his last year as director, Astin was happy that he could recommend a successor who showed such great promise.

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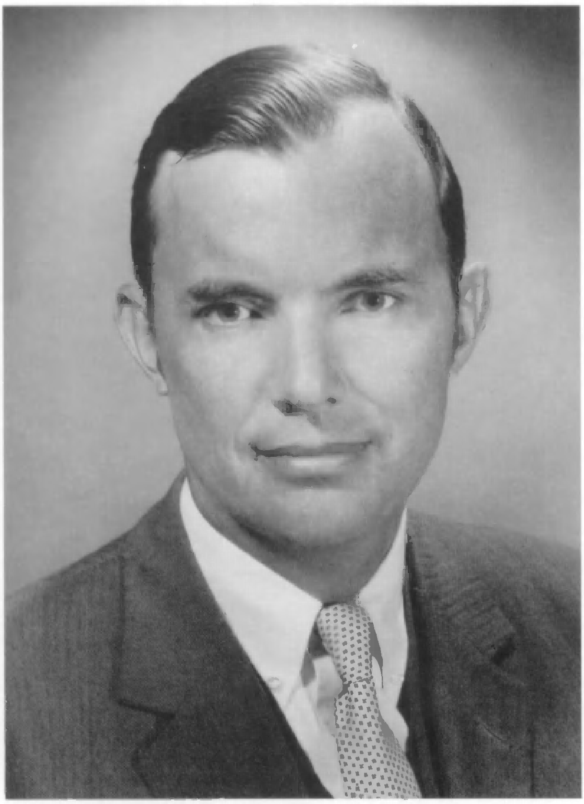
[9] Leonard S. Rubinowitz, *Low Income Housing: Suburban Strategies*, (Cambridge, MA: Ballinger Publishing Co, 1974) p. 179.

[10] Besides the brief references in this volume, there are more detailed discussions elsewhere of Astin's difficult years. See, for example, Elio Passaglia, *A Unique Institution*, and *Science: Evidence, Truth and Integrity*, NBS Special Publication 690, January 1985.

[11] See, for example, House Appropriations Subcommittee hearings, March 28, 1968, pp. 1191-1200.

Lewis McAdory Branscomb

Astin's choice to be the sixth Director of the National Bureau of Standards was Lewis Branscomb. The potential in the man was grand, in Astin's view. Branscomb was barely 42 years old, a product of Asheville, North Carolina; Duke University (A. B. summa cum laude, 1945); the U.S. Naval Reserve; and Harvard University (M. A. 1947 and Ph. D. in physics, 1949). He had been invited to join the staff of the Bureau by Director Edward Condon in 1951, and it had soon become clear that this man would make a mark.



Lewis M. Branscomb, sixth director of the National Bureau of Standards.

Branscomb's Negative Ion Photodetachment Experiments

Branscomb badly wanted in 1951 to perform a particular experiment involving negative hydrogen ions. He felt that the experiment was important for several reasons, one of which related to astrophysics. The sun's light, it had been known for years, really did not satisfy Planck's theory of thermal radiation from a hot body in the way that radiation from a laboratory blackbody did. The spectral distribution of the sun's radiation was "wrong"—that is, the radiant flux per unit wavelength measured over all the radiating wavelengths yielded a curve that differed from Planck's classic spectral distribution law. This deviation had been ascribed to absorption of visible and near-infrared radiation in the sun's photosphere by negative hydrogen ions, but laboratory evidence for this absorption was lacking. Branscomb wanted to look for photodetachment of electrons in negative hydrogen; he wanted to evaluate the cross-section for the process and study its wavelength dependence.

Unable to gather the resources for this work at Harvard, Branscomb took a train ride from Boston to Washington to see about the prospects at NBS. He met with several scientists at the Bureau, including Director Edward Condon. When Condon met Branscomb and heard of his plans, he encouraged the young physicist to try to assemble his experiment at the Bureau. Atomic physics was Condon's favorite field of science, and Branscomb seemed to Condon to be just the sort of scientific go-getter, trained in the new quantum physics, who could help rejuvenate the NBS scientific staff.

Branscomb was happy to contemplate work at NBS where long-term experiments, sometimes involving large collections of equipment and manpower, were known to be the norm rather than the exception. Robert D. Huntoon, Chief of the Bureau's Atomic and Radiation Physics Division, offered Branscomb a job, along with the opportunity to undertake his experiment. Branscomb also found at the Bureau the leeway needed to bring on board Stephen J. Smith—like himself a new Ph. D. from Harvard—and a succession of other bright, young scientists to help with the project.

The experiment that Branscomb designed was successful. He and two colleagues, Wade L. Fite and Stephen Smith, published in the journal *Physical Review* details of the apparatus and the first results.[12] The experiment confirmed the theoretical view that the photodetachment reaction could be significant in the solar spectrum. As Branscomb and Smith put it:

> The departure of the continuous solar spectrum, between 0.6 μm and 1. 6 μm, from the Planck blackbody curve were first ascribed by R. Wildt to the continuous absorption of the H^- ions in the solar photosphere. The electron affinity of H^- is about 0.75 eV and the ion has only one bound state. Hence the absorption of visible and near-infrared radiation leads to photodetachment according to the equation
>
> $$H^- + h\nu = H + e^-.$$
>
> The calculation of the cross-section for this process has been carefully performed by S. Chandrasekhar. Until the work of Branscomb, Fite, and Smith, negative-ion photodetachment had not been observed in the laboratory.

[12] L. M. Branscomb and Wade L. Fite, "Photodetachment of the hydrogen negative ion," *Physical Review* **93**, No. 3, p. 651 (1954); L. M. Branscomb and Stephen J. Smith, "Experimental Cross Section for Photodetachment of Electrons from H^- and D^-," *Physical Review* **98**, No. 4, p. 1028 (1955); Oral History, L. M. Branscomb, July 11, 1988.

The apparatus put together by Branscomb, Fite and Smith had yielded results in good agreement with the theoretical prediction for the sun's atmosphere. As a result of their work, a wholly new experimental area in ion photodetachment suddenly became available, allowing Branscomb and his colleagues at NBS to study ions that were significant in the earth's upper atmosphere as well as in the atmospheres of stars. They expanded on the hydrogen work to include the study of negative atomic and molecular oxygen ions, O^- and O_2^-, the evaluation of electron affinities, and the relation of these reactions to the earth's ionosphere.[13]

For nearly two decades this area of physics was the domain of Branscomb and a growing atomic-physics research group at NBS. Eventually the series of projects would lead to the founding of the Joint Institute for Laboratory Astrophysics in conjunction with colleagues at the University of Colorado.

Branscomb surely had a flair for physics. And he found the Bureau to be a very congenial place to practice science. He said:

> I very quickly appreciated that, first of all, the Bureau is the unique place in all the world to do very hard, very accurate, as well as very precise measurements . . . Therefore, if you wanted to push the fundamental standards by the most innovative means and make radical progress in basic standards of measurement, the way to do it was to hire outstanding scientists who wanted to do a piece of pure science that was so hard to do that they had to invent a new basic standard of measurement in order to do it.[14]

In 1954 Branscomb was named Acting Chief of the Bureau's Atomic Physics Section. Peter Bender joined the group in 1956, and Earl Beaty and theorist Sydney Geltman (hired from the Applied Physics Laboratory of Johns Hopkins University in Silver Spring, Maryland) came in 1957.

The Joint Institute for Laboratory Astrophysics

Besides his intense interest in physics, Branscomb had another flair, too—one which eventually would take him right out of the laboratory. This gift was ability in scientific administration. Branscomb was deeply perceptive about projects and programs in technical fields, and he had strong ideas about how to accomplish them. These qualities were combined in his nature with a very persuasive personality to make him the center of a whirlwind of activity.

Branscomb's interest in scientific administration surfaced during 1957-58, while he fulfilled a Rockefeller Public Service Fellowship at the University College in London. He said:

> The Rockefeller Public Service Award was the most wonderful thing that ever happened to me, except for the (Harvard) Society of Fellows. It was a full-year sabbatical. It paid for you and your family to go wherever you were going

[13] Lewis M. Branscomb, "A Review of Photodetachment and Related Negative Ion Processes Relevant to Aeronomy," *Annales de Geophysique* **20**, pp. 88-105 (1964).

[14] L. M. Branscomb, Oral History, July 11, 1988.

> overseas. It had provision for incidental expenses. I went off to University College in London, where Sir Harry Massey was, who had written the only book on negative ions that existed. I went for the purpose of greatly expanding and co-authoring the book with him. That never happened. The reason was that I divided all the problems of negative ions up into chapters and each chapter grew and grew as I discovered how little people knew. What was to be a book ended up as 10 research careers in all these areas. I met another Bureau employee whom I had known very briefly at Harvard as a graduate student and that was Dick (Richard N.) Thomas. Thomas was at the Boulder Lab, one of two astrophysicists hired by the NBS Boulder Labs, who had a connection with the High Altitude Observatory . . . We began to hatch out the idea that there really ought to be a proper group of atomic physicists interested in astrophysical applications, and astrophysicists who really wanted to do the astrophysics not in the classical way but in the quantum mechanical way . . . We cooked up the idea, the two of us, that if somehow we could take the atomic physics group in (NBS) Washington and these two astrophysicists—John Jeffries was the other one—in Boulder and marry them up, we would leave the Bureau and we would go somewhere, and we would do this great thing.[15]

This "great thing" became a project which was to occupy the attention of Branscomb for a decade.

Director Astin, approached by Branscomb with the idea that one of the Bureau's most productive research groups wanted to leave in order to further its research goals, suggested that the work could be done as a part of NBS. Together, they explored the possibilities.

Meanwhile, late in 1959, the NBS Atomic and Radiation Physics Division was separated into two divisions—the Radiation Physics Division, under the leadership of Lauriston S. Taylor, and the Atomic Physics Division, with Lewis Branscomb as its chief.

The discussions involving Branscomb and Astin about a new research organization —the "great thing" of Branscomb's Rockefeller sabbatical—began to focus on the nature and purpose of such an entity. In its Annual Reports for the period 1960-1962 the Bureau described plans for a new project to complement national programs in space science, plasma physics, and atmospheric research.[16] In 1960 the Space Sciences Board of the National Academy of Sciences heard the Bureau plans and recommended to the Department of Commerce that a coordinated program be undertaken for the study of the basic physics of atoms and molecules in terrestrial, planetary, and stellar atmospheres.

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[15] Ibid.

[16] *Miscellaneous Publication 237,* December 1960, p. 10; *Miscellaneous Publication 242,* December 1961, p. 6; *Miscellaneous Publication 246,* December 1962, p. 7. In the last-named reference, NBS announced the establishment of the Joint Institute for Laboratory Astrophysics in collaboration with the University of Colorado.

The proposal for a program that would connect NBS with a university in the study of laboratory astrophysics attracted considerable attention in the scientific community, where the lack of trained astrophysicists was known to be a serious one; the reception accorded the concept was entirely favorable in that sector. In the Department of Commerce, however, many questions were raised—about the propriety of participation by NBS staff members in the everyday teaching activities of a university, for one thing, not to mention the difficulty of giving the government employees appropriate compensation for teaching. The department also was concerned about the suitability of sharing rented space between staff members of a university and Bureau employees. Nor did the department feel comfortable about the creation of a DoC entity expressly devoted to basic scientific research, ordinarily the province of the National Science Foundation.

These administrative questions involved NBS Director Astin in detailed discussions with several officials in the Department of Commerce. Memoranda traveled the circuit, carrying ideas and concerns back and forth. Astin and his legal minds pointed out to the DoC and *their* legal minds the similarity of the proposed venture to the Smithsonian Astrophysical Observatory, where Civil Service employees held joint academic appointments at Harvard University, and to the NASA Institute for Space Sciences, where Robert Jastrow, chief of the NASA theoretical division, simultaneously held the position of Professor Adjoint in the Department of Geology at Columbia University. Also discussed was the idea that teaching would help mightily to provide a stimulating research atmosphere and to disseminate the latest information in a rapidly changing field that held intense interest for important portions of the U.S. government.

Eventually the natural nervousness of the Commerce Department in contemplating a new approach to the way NBS wanted to do its work was overcome. A major part in calming the department's fears was played by the many proponents of the program in the upper circles of the federal science establishment—Branscomb and Astin had prepared their case carefully and could easily establish a need for the new undertaking.

Desirous of placing the NBS astrophysical project in the fertile environment of a university with a strong graduate program in astronomy, the Bureau group held preliminary discussions with Harvard, the University of California at San Diego, the University of Arizona and the University of Colorado. The last-named school had several advantages—a High-Altitude Observatory and a Laboratory for Atmospheric and Space Physics within the University framework, plus the nearby National Center for Atmospheric Research.[17]

Many details of the new program had to be attended to, since the prospective entity was a most uncommon species for NBS.

At last, a Joint Institute for Laboratory Astrophysics (JILA) was created through a Memorandum of Understanding between the NBS and the University of Colorado. The Memorandum was announced on April 13, 1962, by the two organizations.

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[17] Lewis Branscomb, Oral History, July 12, 1988.

The general features of JILA as planned included the following components:

1. Staff (intended eventually to number about 25).

- NBS employees (initially, eight staff members from the NBS Atomic Physics Division and two—both theoretical astrophysicists—from the NBS/Boulder laboratories) who would be assigned to JILA to work and who would hold adjunct professorships at UC.
- Faculty members in astrophysics and space physics from UC.
- Faculty members in the aerodynamics department of UC.
- Up to ten visiting members—usually on one-year appointments—working on problems of their choice while on leave from their own institutions.

2. Scientific objectives.

- Research in basic atomic physics.
- Research on the cooperative behavior of gaseous species important to astrophysics.
- Applications of stellar astrophysics.

3. Academic objectives.

- Teaching in the UC undergraduate and graduate programs.
- Providing seminars and personal instruction for students.
- Increasing the number of scientists trained in the astrophysics area.

As of April 1962 Lewis Branscomb became the first JILA Chairman. He and a small band of carefully selected colleagues soon left Washington for a bright new future near the Rocky Mountains. The group included John L. Hall (Ph.D., Carnegie Institute of Technology, 1961, interested in laser research); Stephen J. Smith (Ph.D., Harvard University, 1954, specialist on photodetachment of negative ions); Gordon H. Dunn (Ph.D., University of Washington, 1961, whose interest focused on atomic collisions); George Chamberlain (Ph.D., Yale University, 1961, working on atomic beams); Earl C. Beaty (Ph.D., Washington University, 1956, whose fields were ionic mobilities and atomic clocks); Lee J. Kieffer (Ph.D., St. Louis University, 1958, studying spins and moments in radioactive nuclei and electron-atom scattering); Sydney Geltman (Ph.D., Yale University, 1952, expert on the theory of ionic mobilities, atomic scattering, ionization and photodetachment); and Peter Bender (Ph.D., Princeton University, 1956, interested in atomic clocks and atomic resonance phenomena).[18, 19]

[18] See p. 8 in *The Bureau Drawer*, Vol. 3, No. 9, May-June 1962.

[19] Gordon Dunn, Lee Kieffer, and Stephen Smith shared the Department of Commerce Gold Medal Award in 1970 for their studies of atomic collisions.

The first participants in the Joint Institute for Laboratory Astrophysics from NBS were, from left to right, Earl C. Beaty, Steven J. Smith, Gordon H. Dunn, Lewis Branscomb, Lee J. Kieffer, Peter Bender, John L. Hall, Sydney Geltman, George Chamberlain, and Carl Pelander.

From the perspective of NBS the group became Division 95, Laboratory Astrophysics, with residence in the Boulder, Colorado Armory Building. The Atomic Physics Division, by this time comprising seven sections, was left in the capable hands of Karl Kessler, a career atomic spectroscopist.

In the fall of 1966, the JILA building—a 10-story office tower, laboratory wing and auditorium shown in the accompanying photo—was completed and occupied, bringing to full fruition the plans laid a decade earlier by Branscomb and Thomas for this new "great thing."

As this narrative continues, we shall frequently recognize important contributions from the staff of JILA.

The Joint Institute for Laboratory Astrophysics Building on the campus of the University of Colorado in Boulder.

Branscomb's Outside Activities

By 1960, Branscomb had begun to play an increasingly active role in the scientific establishment beyond the confines of NBS. From 1960-65 he served on the Reaction Rate working group of the Defense Atomic Support Agency. In 1961, he also took on the chairmanship of the Division of Electron Physics of the American Physical Society and service on the Advisory Committee on Ballistic Missile Defense for the Advanced Research Projects Administration. Participation in such groups intensified as Branscomb's administrative talents became more widely known.

While Branscomb was chief of the Atomic Physics Division in 1961, he was awarded the Department of Commerce Gold Medal for Exceptional Service. The award was based upon "contributions to basic knowledge of atomic processes of stellar atmospheres, terrestrial ionosphere and interplanetary space." The medal was given principally to recognize the importance of his work on photodetachment of electrons from hydrogen ions.

In 1962, Branscomb was presented the Arthur S. Flemming Award, given to honor Federal employees under the age of 40 for unusually meritorious work.

From 1965-69, Branscomb served on the President's Science Advisory Committee (PSAC) as Chair of the Panel on Space and Technology. At that time, he was the only member of PSAC who was a working scientist at a Federal laboratory.

In 1966 Branscomb was appointed to the Board of Editors of the American Physical Society. In 1968 he began service as Editor of the Review of Modern Physics, supporting with his own efforts his belief in the value of the review literature both for scientific data and for science generally.

That same year he was given the Bureau's Samuel Wesley Stratton Award, which honors unusually significant research contributions to science or engineering in support of NBS objectives.

BRANSCOMB BECOMES NBS DIRECTOR

Allen Astin had made very clear his desire to be succeeded as NBS Director by Lewis Branscomb. A methodical man, Astin had planned ahead for his retirement in 1969, when he would turn 65 years of age. John Kincaid, Assistant Secretary of Commerce for Science and Technology, wondered in a memorandum to his boss, Secretary Alexander Trowbridge, whether the best way to achieve an orderly transition at the Bureau might be for Astin to step aside prior to the 1968 national election so that Branscomb could be nominated and installed as Director without regard to whether the Republicans or the Democrats won the Presidential election.[20]

Two little problems stood in the way of this solution. Allen Astin was not interested in retiring from a position of "senior advisor," as Kincaid suggested in his memo; Astin would be the boss until the day he left government employment. Furthermore, Branscomb was not interested in being a party to an attempt to finesse the next national administration. He wrote:

> I think it is not useful to the Bureau of Standards for me to undertake a commitment at this time which might serve to tie the Secretary's hands should there be a change in administration or for any other reason.[21]

Branscomb was not even sure that he wanted to be NBS Director. In a conversation with Astin, Branscomb remarked that,[22] in fact, he did not want the Directorship—he wanted to stay at JILA. He felt that accepting an NBS administrative job above the level of Division Chief would bring to an end his active participation in science.

Yet, said Branscomb later, he could not dismiss Astin's request to consider the Directorship. Astin had been too helpful to him, in bringing JILA to life and in other ways. If Astin could make the nomination happen somehow, Branscomb would serve.

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[20] Memo to Secretary Trowbridge from Assistant Secretary Kincaid, September 26, 1967. (DOC, Assistant Secretary for Science and Technology, Accession 40-72A-7166, Box 8, Folder Chron File (August-September 1967) JFK).

[21] Letter from Branscomb to Kincaid, January 27, 1968. Same accession data as Kincaid-Trowbridge memo.

[22] L. M. Branscomb, Oral History, July 12, 1988.

The issue of succession to the leadership of NBS became a very murky one indeed when the Presidential election votes were counted.

Republican candidate Richard Nixon and his running mate, Spiro Agnew, former Governor of Maryland, captured the Presidency in 1968 by winning 31.8 million votes to 31.3 million for the Hubert Humphrey-Edmund Muskie Democratic ticket and 9.9 million for the American Independent Party standard-bearers, George Wallace and Curtis LeMay. Despite their narrow popular plurality, Nixon and Agnew won 301 electoral votes of the 538 votes available.

Now there was a difficulty for the potential Branscomb nomination. Branscomb was a registered Democrat. More problematic was the fact that his wife Anne, a lawyer, had for some time been quite active in Colorado politics and in 1968 was a member of the Democratic National Committee. While the position of Director of NBS had never been a political job, the new administration might well go looking for a nominee who was less obviously a member of the defeated party.

During the early months of 1969, friends of Astin in Congress and elsewhere tried to convince the incoming administration that Branscomb was the best choice for the next Bureau Director, despite any little political flaws. The Republican establishment in Colorado was particularly hard to convince of this idea, because they already had permitted one Colorado Democrat to be appointed over their objections.[23]

It is rare in such cases that more than a trace of the pre-nominative process—telephone calls, memos, visits, cajoling, "horse trading"—would become available to historians. Branscomb certainly knew few of the details. He recalled that only later did he learn that one Peter Flanigan, friend of Richard Nixon and brother of the Colorado Republican State Committee Chairman, intervened on behalf of the Branscomb nomination. Whether that intervention tipped the scales in Branscomb's favor, whether Branscomb's brief service to the new administration as a scientific member of one of the new President's "transition teams" carried the day, or whether the newly appointed Secretary of Commerce, Maurice Stans, and other powerful members of the incoming administration simply agreed that Branscomb was a good choice for the job, the result was that Branscomb, one day in the early summer of 1969, was asked to meet with Secretary Stans at the Department of Commerce offices downtown.

Branscomb recalled that meeting with some pleasure. Secretary Stans said something like, I am told that you are a very good scientist and show great promise as Director of the Bureau of Standards and that it would be a mistake for me not to appoint you to that job. I am prepared to make the appointment. I don't know what all you do at NBS, but if you do it well, stay out of trouble, and agree not to interfere with my primary job, which is to help raise the money to get President Nixon re-elected in 1972, we'll get along just fine. Branscomb assured the Secretary that he could readily promise not to get involved at all in Republican fund-raising, and the nominating process was essentially complete.[24]

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[23] L. M. Branscomb, Oral History, 12 July, 1988.

[24] L. M. Branscomb, Oral History, 12 July, 1988.

According to a special edition of the *NBS Standard* issued on June 23 1969:

> Secretary of Commerce Maurice H. Stans today (June 17, 1969) announced that the President has nominated Dr. Lewis M. Branscomb, 42, of Boulder, Colorado, as Director of the National Bureau of Standards.
>
> Secretary Stans said that Dr. Branscomb, an internationally known atomic physicist and a career Federal scientist-administrator, would assume his new duties on the retirement on August 31 of Director Allen V. Astin.

Astin was content. In the same edition of the *NBS Standard,* he wrote a note to the Bureau staff:

> I am sure that you will be as pleased as I am to know that Dr. Lewis M. Branscomb is being nominated.[25]

Branscomb was given an early opportunity to show what grasp he might have of Bureau policies and programs. On July 31, 1969, he was interviewed by the Committee on Commerce of the U.S. Senate, Warren Magnuson presiding. Two aspects of the record of that nomination hearing are interesting. First, the hearing was short and therefore presumably non-controversial in the eyes of the Committee. Second, Branscomb was asked to defend the budget request for the Bureau's National Standard Reference Data program, as well as to explain why he—as an employee of NBS—should have been performing basic research in the field of astrophysics. His response to the first request showed considerable familiarity with the NSRD program and an intense support for its goals. His response to the second request sounded a theme that was to become Branscomb's guiding principle during his short tenure as Director of NBS:

> I believe the Bureau has an important job beyond commerce to insure that it provides, if you like, the infrastructure of the Nation's science and technology. Without a vital and high-quality, reliable measurement capability the country's science and technology cannot be effective in application.

The Committee was quickly satisfied that Branscomb's nomination should be confirmed. The Senate ratified the nomination on August 7th, with three weeks to spare before Astin's retirement.

The prospects for NBS looked bright indeed—one of its most exciting young scientists had been appointed its sixth director. With an eloquent spokesman—one well-connected to the Washington scientific establishment—to lead the way, could there be any but good times ahead for the Bureau?

[25] A. V. Astin, The *NBS Standard* Special Edition, June 23, 1969, p. 2.

Taking Charge

Once he became Bureau director, Branscomb had work to do. Although he was very familiar with the major policies and programs of the Bureau, there were many people—both technical and administrative—that he didn't know at all. One need only refer to the previous chapter of this book to realize that considerable effort would be needed even to approach a comprehensive acquaintance with the Bureau staff and its diverse activities.

The senior management team that Allen Astin had left to Branscomb was composed in the main of "old hands." Lawrence Kushner, Ernest Ambler, John Hoffman, Carl Muehlhause, Howard Sorrows, Robert Walleigh, Bascom Birmingham, Edward Brady, and Robert Ferguson had served NBS in aggregate for more than a century. These men, Branscomb knew and they knew him; their immediate subordinates he did not know well.

Branscomb recalled that he spent his first day on the job visiting the Institute and Center Directors—Ambler in Basic Standards, Hoffman in Materials Research, Sorrows in Applied Technology and Muehlhause in Radiation Research—and their principal managers.[26] This was to be a series of get-acquainted meetings, an exercise in "team-building." Mostly, the day passed quickly, pleasantly and without incident. There was one exception, however. One of the managers noted that he hoped that Branscomb would "... stay out of my hair, and we'll get along fine." Branscomb, astounded at the man's unwillingness to meet the new director halfway, quickly reassigned him to a non-management position.

From his new vantage point, Branscomb reviewed the scientific literature for the journal *Measurements and Data.*[27] He called for a clearer separation of scientific publications into categories such as news, conference proceedings, archives, and critical reviews, with emphasis on specifying the quality of particular measurements and thus their subsequent value as components of theoretical or engineering design. These ideas, long on Branscomb's mind, had come to sharper focus over the past two years during his service as Editor of the journal *Reviews of Modern Physics.*

Some five weeks after taking office, the new director addressed the NBS staff for the first time. In his remarks, Branscomb showed his confidence that Allen Astin had left the Bureau healthy, and his own intention that the course should not waver. He urged Bureau employees to continue the dedication to accuracy and integrity fostered by Astin, to continually be conscious of the national welfare in their work, to look for ways to enhance the nation's economic and social progress through measurement science, and to observe their responsibilities as the Nation's measurement laboratory. He took note of the 1967 Flammable Fabrics Act, the Metric System Study, the bottle-neck in national building codes, and the fundamental importance of the National Standard Reference Data System. In each of these applied-science projects, he ascribed a significant role for new achievements in measurement, the Bureau's strength.

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[26] L. M. Branscomb, Oral History, 12 July, 1988.

[27] L. M. Branscomb, *Truth in packaging of scientific information*, Measurements & Data 3, No. 5, 104-105 (1969).

In November of 1969, Lee A. DuBridge, the Science Advisor to the President, released for publication a report of the Space Science and Technology Panel of the President's Science Advisory Committee; the panel was chaired by Branscomb. Entitled *The Biomedical Foundations of Manned Space Flight,* the report was prepared by a working group on Space Medicine. It contained several recommendations intended to optimize the benefits of manned space flight, given the tension between the high cost of manned flight and the limited resources available for the project. Publication of that report marked the end of Branscomb's service on PSAC.

The changes made by Branscomb in his 1972 budget request had more immediate impact upon Congress than they did on the Bureau staff, perhaps because he could take his time in creating the structures that would give life to his vision of NBS. Astin had left behind an organization managed mostly by experienced leaders who knew the Bureau and its clients from long personal association. They were themselves scientists with solid records of accomplishment, and they had faith in the quality of their service to America. Nearly a year would pass before Branscomb's views on organizing the Bureau around consumer issues would be assimilated within NBS.

Establishment of NBS Executive Board

One of Branscomb's first acts as director was to establish an Executive Board "to assist me in managing Bureau affairs." He envisioned a group that would meet with him in executive session for decision-making discussions, and in regular sessions for program planning. Initial assignments to the board included:

- Lawrence Kushner, Deputy Director, NBS.
- Edward Brady, Associate Director for Information Programs.
- Robert Walleigh, Associate Director for Administration.
- Ernest Ambler, Director, Institute for Basic Standards.
- John Hoffman, Director, Institute for Materials Research.
- Howard Sorrows, Acting Director, Institute for Applied Technology.
- Carl Muehlhause, Director, Center for Radiation Research.
- Herbert Grosch, Director, Center for Computer Sciences and Technology.

Meeting with the board during regular sessions would be:

- Robert Ferguson, Coordinator for Program Planning.
- Robert Huntoon, Coordinator for Policy Planning.
- Bascom Birmingham, Deputy Director for Boulder, IBS.[28]

Establishment of NBS Program Office

One of Branscomb's first appointments changed NBS markedly. Branscomb created the position of Associate Director of NBS for Programs (ADP). He placed Howard E. Sorrows, Acting Director of the Institute for Applied Technology, in command and gave him the assignment of establishing "an office responsible for the analysis,

[28] NBS Admin, Bull. 69-59, September 2, 1969: "Executive Board Established."

planning, budgeting, documentation, and communication of programs at the Bureau level."[29] Robert E. Ferguson, Special Assistant to the Director for Program Planning, was assigned to the office as well. Malcolm W. Jensen was assigned to the position of Acting Director of IAT to replace Sorrows.

Sorrows was an excellent choice for program director. He had plenty of experience with scientific work and with the Bureau. NBS had provided his first scientific position—with the NBS Electricity Division in 1941. By 1950, he was head of the ultra-high-frequency standards group in the Central Radio Propagation Laboratory. He then left NBS to take sequential positions at the Naval Ordnance Laboratory, at the Office of Naval Research, and at the Navy Bureau of Ordnance. But perhaps his most useful preparation for organizing an NBS program office was his experience from 1959-63 at Texas Instruments, Inc., where he initiated and managed a department for technical intelligence, long-range planning, and new product development.

Sorrows knew well the need of technical groups to understand their products, their customers, and their organizational goals.[30] This approach was just the one that Branscomb wanted—a unit to bundle disparate projects in disparate divisions of the Bureau into a coherent attack on "national needs" that could trigger a shower of dollars from Congress, and, at the same time, encourage the divisions to shed provincial perceptions regarding their own programs.

Within 6 weeks, Sorrows had fleshed out the ADP role sufficiently that Branscomb was able to describe it for Larry A. Jobe, Assistant Secretary of Commerce for Administration:

> The Office of the Associate Director for Programs performs the functions of policy development and program analysis, program promotion, and financial interpretation: the Office sponsors and coordinates the performance of issue and impact studies; relates Bureau programs to national needs; generates planning formats and develops information on NBS program plans and status for internal and external audiences; administers advisory panels; defines alternatives for the allocation of resources and advises Bureau management on their implications; and directs the formulation of the budget.[31]

The Program Office quickly became a force at NBS. Young scientists—"program analysts"—soon found a tour of duty there to be physically exhausting, but ultimately rewarding in terms of advancement to managerial positions. Some of the old-line scientists soon found young gate-keepers (paid with money that could have been used for metrological or other technical projects!) standing in the way of needed funds and personnel slots and demanding justifications in terms of product marketability. Occasionally they seemed to discount or to disregard entirely scientific merit in making

[29] NBS Admin. Bull. 70-21, April 16, 1970.

[30] Bio file, Howard Sorrows.

[31] Memo, LMB to Larry Jobe, Asst Sec for Admin: "Revision of Department Organization Order 30-2B," May 28, 1970. RHA, RG 167, Director's Office, Box 389, Folder Chrono May 1-31, 1970.

funding recommendations. Adversarial relationships, based on need for resources—funds, people, or equipment—developed between scientific groups that had been natural colleagues. On the other hand, ties to the Nation's technical life became closer and clearer than they ever had been before the creation of the Program Office. Times at NBS were changing.

Gradually, the trend toward problem-oriented organizational units at NBS would become a flood. In time, the old-line metrological-standards units would wonder whether they still had a place at the Bureau.

In July 1970, Branscomb assigned to James R. Wright, Chief of the Building Research Division, the additional responsibility of cooperating with the Program Office to coordinate NBS efforts with the Department of Housing and Urban Development. The relatively new department—formed in 1965—worked closely with the Bureau on many housing-related projects. Wright's new duty was to provide a continuing point of contact between the organizations, although no management function was involved.[32]

Towards the end of 1970, Robert Ferguson, Sorrows' Scientific Assistant, was given the responsibility of coordinating all NBS work on the Water Pollution Control and Abatement Program.[33] Ferguson also was directed to monitor all environmental programs other than the Measures for Air Quality, which was administered by James McNesby.

By 1974,[34] one or another of Sorrows' program analysts was assigned to each of the Bureau's new budgetary program areas:

- Scientific and Technical Measurements.
- Use of Science and Technology.
- Equity in Trade.
- Public Safety.
- Technical Information.
- Central Technical Support.
- Experimental Technology Incentives Program, a new category.

The analysts so involved in June 1974, included Martin J. Cooper, Thomas Dillon, Cary Gravatt, Sanford B. Newman, Stanley Rasberry, and Norman F. Somes.

Measures for Air Quality

Early in 1970, Branscomb became aware that a small group of chemists and physicists shared an interest in scientific work that could be used to evaluate or mitigate air-pollution problems. James R. McNesby, Chief of the Physical Chemistry Division, had created an informal study group to interact with like-minded scientists, mostly within the U.S. government.

This effort struck Branscomb as just the kind of consumer-oriented project that he envisioned for NBS. Immediately, he asked McNesby to organize a program-management office for airpollution studies. The new office was called Measures for

[32] NBS Admin. Bull. 70-49, July 23, 1970.

[33] NBS Admin. Bull. 70-49, July 23, 1970.

[34] NBS Admin. Bull. 74-44, June 25, 1974.

Air Quality.[35] McNesby would report to John Hoffman, Director of the Institute for Materials Research. Radford Byerly, Jr., one of Howard Sorrows' first Program Analysts, was designated deputy to McNesby.

Milton Scheer was detailed to replace McNesby as chief of the Physical Chemistry Division.

As an NBS entity, Measures for Air Quality (MAQ) bore considerable similarity to the Office of Standard Reference Data (OSRD) and the Office of Standard Reference Materials (OSRM). There was no re-assignment of participants in the program; collaborating scientists would remain with their technical divisions, where they could maintain their usual mix of professional activities.[36] At that time, these three programs—MAQ, OSRD, and OSRM—made up the entirety of the "matrix management" activities at the Bureau that were described in Chapter 1.

A study of Bureau projects by the MAQ scientists turned up even more work, in several different divisions, that could be applied to air pollution measurements or abatement. One of these efforts followed a 1972 meeting sponsored by NBS and the Environmental Protection Agency; its purpose was to pinpoint standard gases needed to monitor pollution from automobile exhaust. As a result of the discussion, the Bureau began to prepare four gas mixtures—propane in air, carbon dioxide in nitrogen, carbon monoxide in nitrogen, and nitric oxide in nitrogen. Soon, these reference gases were part of the Standard Reference Materials program.

As these projects developed, McNesby was given access to funds to stimulate work in each area. Gradually, other government agencies assisted with funding. McNesby and his tiny staff coordinated NBS efforts with those of other organizations interested in the problem of air pollution and facilitated attendance at conferences and publication of papers. Eventually the program produced nitric oxide and sulfur dioxide monitors for use in field stations.

Change in the Center for Radiation Research

Concerned that the component divisions of the Center for Radiation Research were not flourishing in their current structure,[37] Branscomb revised that structure considerably in September 1970.[38] In one move, the Reactor Radiation Division was taken out of the Center and placed in the Institute for Materials Research under John Hoffman; Branscomb opined that, in this move, the RRD would "benefit from the broad scientific and technical base and the considerable managerial strength of [the IMR]."

James E. Leiss, former chief of the Linac Radiation Division, was named Acting Director of the Center. The Center itself was shifted to the Institute for Basic Standards, under Ernest Ambler.

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[35] NBS Admin. Bull. 70-42, June 30, 1970.

[36] "Measures For Air Quality," NBS Technical News Bulletin, Vol. 57, No. 1, January 1973, pp. 10-13.

[37] Letter to members of the CRR Advisory Panel from LMB, September 1, 1970. RHA, RG 167, Director's Office, Box 389, Folder September 1-30, 1970.

[38] NBS Admin. Bull. 70-57, September 1, 1970.

In 1972, during a meeting jointly sponsored by the Environmental Protection Agency and NBS, it was decided that Standard Reference Materials (SRMs) were needed to monitor compliance with auto emission laws. As a result, NBS developed four gas-mixture SRMs. Ryna B. Marinenko prepared these primary reference standards.

Carl Muehlhause, Director of CRR, was re-assigned to serve on Branscomb's staff. These changes reduced by one the number of managers that reported directly to Branscomb and, he hoped, strengthened both the Reactor Research Division and the Center for Radiation Research.

Clearinghouse for Federal Scientific and Technical Information Transferred to the National Technical Information Service

A Department of Commerce Organization Order mandated the transfer of the Clearinghouse for Federal Scientific and Technical Information to the National

Technical Information Service on September 2, 1970.[39] In early April of that year, Branscomb and Edward Brady, NBS Associate Director for Information Programs, responded to a request from Myron Tribus, Assistant Secretary of Commerce for Science and Technology, for information on the activities of the Clearinghouse.

At issue was the variety of publications prepared and circulated by the Clearinghouse, as well as its methods of distribution. Department officials were disturbed that it was necessary to subsidize the operations of the clearinghouse despite the fact that its publications were sold, not given free of charge, to the public.[40]

Management of the NBS Instrument Shop

Administrative management of the instrument shop, the central NBS facility for the manufacture of specialized apparatus used in research projects in all the technical divisions, was changed in August 1970 from the control of the Director of the Institute for Applied Technology to that of the Associate Director for Administration.[41] Branscomb hoped, by this move, to make the operation and financial support of the shops more equitable for the many divisions that made use of shops resources.

Ruth M. Davis, A New Leader for the Center for Computer Science and Technology

One of Lewis Branscomb's early priorities was to obtain new leadership for the Center For Computer Science and Technology to improve its effectiveness in cooperating with its many colleagues in government and industry. For this post, Branscomb was able to recruit Ruth M. Davis, an applied mathematician trained at the University of Maryland. Davis was the first woman to head a technical organization at the level of division or higher within the Bureau.

Davis was by all accounts a "whiz kid," having accomplished many feats in computer science in the space of perhaps 15 years. She taught the first advanced computer-programming and numerical-analysis courses ever given at the University of Maryland. She developed the first computer programs for nuclear reactor design while working with the U.S. Department of the Navy. And she improved the Navy's military command and control systems by preparing automated display-centered information systems.

From 1967 until coming to NBS in October 1970, Davis worked for the National Library of Medicine, part of the National Institutes of Health, where she was Director of the Lister Hill National Center for Biomedical Communications.[42]

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[39] NBS Admin. Bull. 70-59, September 3, 1970.

[40] Letter, LMB to Myron Tribus, April 8, 1970, RHA, RG 167, Director's Office, Box 389, Folder Chrono April 1-30, 1970. Letter, Edward Brady to Myron Tribus, April 17, 1970, RHA, RG 167, Director's Office, Box 389, Folder Chrono April 1-30, 1970. Letter, LMB to Myron Tribus, May 26, 1970, RHA, RG 167, Director's Office, Box 389, Folder Chrono May 1-31, 1970.

[41] NBS Admin. Bull. 70-54, August 12, 1970.

[42] NBS Admin. Bull. 70-69, "Dr. Ruth M. Davis Named Director, Center for Computer Science and Technology," November 4, 1970. See also *NBS TNB* December 1970, p. 282.

Davis continued her winning ways at the Bureau. In 1972, she was presented the Federal Woman of the Year Award,[43] the Association for Systems Management Systems Professional of the Year award, and the Department of Commerce Gold Medal Award. In 1973, she received the Rockefeller Public Service Award, earned by Astin and Branscomb a decade or more earlier. In 1974, Davis was elected to membership in the National Academy of Public Administration.

In 1977, Davis resigned her position at NBS to accept the post of Deputy Under Secretary of Defense for Research and Engineering. She left behind a seven-year tenure as director of the CCST that was marked by creative leadership.

Willenbrock Recruited to Head IAT

When Howard Sorrows left the Institute for Applied Technology to create the NBS Program Office, Malcolm Jensen—former Manager of Engineering Standards—was appointed Acting Director of IAT. A nation-wide search for a permanent director ended with the appointment of F. Karl Willenbrock, a Harvard-trained physicist, in November 1970.[44]

Willenbrock was Provost and professor of engineering and applied science at the State University of New York prior to coming to NBS. He was especially active in the Institute of Electrical and Electronics Engineers (IEEE), serving as its President in 1969. He also was a member of several government panels, and he represented the United States during the Second World Congress of the World Federation of Engineering Organizations. Willenbrock was at that time a member of the Information Council of the National Science Foundation. In 1976, he would leave his post as Director, IAT, to accept an engineering professorship at Southern Methodist University.

Although Willenbrock's tenure at NBS was not a long one, he left a lasting legacy—largely through his recruitment of John W. Lyons, Jack E. Snell, and Richard N. Wright, all future leaders at the Bureau.

Equal Employment Opportunity for Minorities and Women

We mentioned in Chapter 1 that Allen Astin helped stimulate passage of a Public Accommodations Ordinance in Montgomery County, Maryland, soon after NBS moved its main laboratory facility to Gaithersburg. Astin also established an Equal Employment Opportunity committee for the Bureau, to handle discrimination grievances and to combat discrimination in NBS recruiting and employment. Initially, those programs focused on the problems of African-Americans, who were victims of active racial segregation in the United States well after the Bureau passed its half-century mark. Housing, public facilities, and employment were still areas of concern for blacks in the 1960s.

[43] "Dr. Davis Wins Federal Woman's Award," *NBS Standard,* Vol XVII, No. 3, April 1972, p. 1.

[44] NBS Admin. Bull. 70-72, "Dr. F. Karl Willenbrock Named Director, IAT," December 2, 1970. See also *NBS TNB* December 1970, p. 282.

Karl F. Willenbrock was director of the NBS Institute for Applied Technology from 1970 to 1976.

In December 1969, President Nixon strengthened the Executive Branch position on equal employment by issuing a new Executive Order urging, among other actions:

> Special efforts must be made to assure that opportunities in the Federal Government at the professional levels are made known to men and women of all races, religions, and ethnic backgrounds.[45]

By 1970 NBS had an active EEO effort. A nine-member EEO Committee with access to upper-level Bureau managers, an affirmative action plan, and grievance procedures combined to substantially improve the lot of black employees. Branscomb created the post of EEO Counselor to facilitate the grievance process; Wiley A. Hall, Jr. was the first to occupy that post.

Esther Cassidy, a physicist in the Electricity Division, was appointed by Branscomb in March 1970 as NBS representative to the Department of Commerce Federal Women's Committee. Her responsibilities extended across NBS in regard to equal employment opportunity for women.

As part of his program for employee development, Branscomb also created the post of Vocational Guidance Counselor. Roberta Hatwell, who filled the post, was charged with helping non-professional employees obtain vocational training in order to qualify for advancement at NBS.[46]

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[45] "President Nixon Issues new EEO Order," *NBS Standard,* Vol XIV, No. 12, December 1969, p. 5.

[46] "NBS Has New Vocational Guidance Counselor," *NBS Standard,* Vol XV, No. 2, February, 1970, p. 3.

In May 1970, the "barbershop case" mentioned in Chapter 1 again made the news in Gaithersburg:

> Late in May a Howard County Circuit Court judge dismissed a $600,000 suit filed by a Gaithersburg barber against Avery Horton and James Walker, both chemists in the Bureau's Institute for Materials Research, and Bertram L. Keys, Jr., Executive Secretary for the Montgomery County Human Relations Commission. (The barber) had charged that the defendants had conspired to hurt his barbershop business by processing complaints of racial discrimination against him. Judge T. Hunt Mayfield ruled that (the barber) had failed to demonstrate anything but that the defendants were attempting to enforce Montgomery County's public accommodations ordinance, as they understood it.[47]

In June 1970, Horton received the first EEO award ever given by the Bureau. The award was given by Director Lewis Branscomb during an NBS staff meeting held specifically to discuss EEO policy. In his remarks, Branscomb called attention to Horton's personal commitment to eliminating racial discrimination.

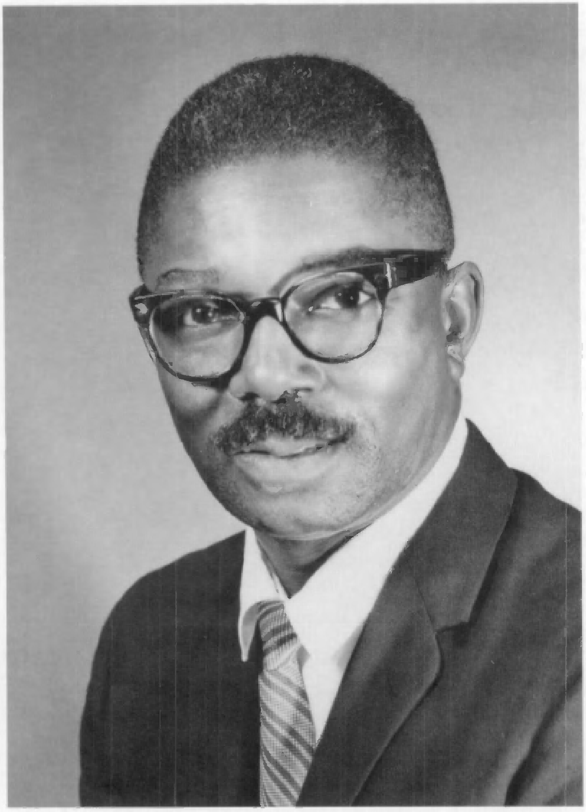
Speaking in his role as master of ceremonies, Horton noted the painfully slow progress of the EEO movement at NBS and called for the development of standards against which progress could be measured. He also took note of the silence of the Bureau's EEO apparatus on the subject of discrimination against women:

> Before getting into this morning's discussion, I would like to relate to you a complaint that I received. No profile of a woman appeared in the (printed) program. Since by definition, Equal Employment Opportunity in government refers to minorities and women, I had no rebuttal. The committee is not insensitive to problems of women, but our determination of the problem of job inequities at the National Bureau of Standards concerns black employees, and our major corrective efforts have been in that direction.

In a separate talk given at the same meeting, Karl Bell, another EEO committee member, urged that a "climate of credibility" be created at NBS by employing more blacks at professional levels. Forget the "Super Black," he said, and concentrate on hiring the best available black employees and training them to realize their full professional potential. He emphasized that the promotion of black employees to management positions was an important yardstick for progress in EEO. Bell drew attention to statistics to bear out his concerns. NBS employed 473 blacks in 1965, but only 410 in 1970, following the move of the main campus to Gaithersburg. Most of the 410 still occupied the lowest-paid jobs; blacks comprised only 6 % of the NBS workforce in the professional ranks, with 19 technical divisions employing no blacks at all; and at the Section Chief level or above, only two blacks were to be found at NBS.[48]

[47] "Barbershop Case News," The *NBS Standard,* Vol. XV, No. 5, May-June 1970, p. 5.

[48] "Special EEO Issue," *NBS Standard,* Vol XV, No. 6, July 1970.



Avery T. Horton, a physical chemist, studied crystal chemistry in the NBS Inorganic Materials Division. He also worked in the Bureau's Law Enforcement Standards Laboratory.

NBS had a better record with respect to women as professional employees. It is difficult to say how good it was, because gender was not recorded in Bureau statistics. But with respect to the "glass ceiling," which historically kept women from positions of leadership, the NBS record could not be praised: until Ruth Davis was appointed director of the Center for Computer Sciences and Technology in 1970, no woman led a technical division, and only one occupied a position as high as section chief in a technical division.

The paucity of women in scientific and technical management roles merits further comment. During this period, relatively few women were encouraged to seek careers in technical fields.[49] Fewer still were able to pursue such careers on a full-time, long-term basis, mainly because family obligations still rested disproportionately on women. Since higher-level managers typically selected new managers from the pool of career scientists with long experience and long-term prospects, only careful consideration

[49] Although the outright prejudice against women ascribed to the Bureau's first director by Cochrane (*Measures for Progress*, p. 54) was long gone by mid-century, the decade of the 1970s still featured contests for "Miss NBS."

and special effort by the higher-level managers could introduce "gender equality" to leadership positions at NBS. Nevertheless, the time for Bureau-wide action on behalf of women had come.

During August of 1970, the 50th anniversary of the Women's Right to Vote amendment (the 19th amendment to the U.S. Constitution, ratified August 18, 1920) was reached. Both the Commerce Department and NBS took notice of the anniversary. Director Branscomb met with a group of senior women staff members to discuss their special problems. The talk quickly focused on the availability of day-care facilities and the significance of child care for working women. Branscomb, reporting on the meeting in a memo to the NBS staff, noted the existence of the Bowman house—left standing for experimentation by the Building Research Division when NBS occupied its new Gaithersburg site—and its possible adaptation to yet another worthwhile purpose.[50]

The Bowman House, purchased from its former owners when NBS obtained the surrounding property for the Gaithersburg site, was used by the Building Research Division until it was converted into a day care center in 1983.

[50] Memo, LMB to all employees, "Equal Employment Opportunity for Women," September 2, 1970; RHA; RG 167; Director's Office; Box 389; Chron file.

Subsequent to use of the Bowman House for a study of the effectiveness of insulating older homes (see Sect. Energy Conservation, p. 557), the Bureau's Plant Division adapted it for use in the child-care program in cooperation with the Standards Committee for Women.[51] The first "crop" of children—sons and daughters of NBS staff members, ages 2 years to 5 years—was welcomed in September 1983. Besides providing a day-care option for working parents, the Bowman House staff offered learning activities for all the children under the guidance of a Board of Directors elected from the families making use of the facility.[52]

During May 1988, an open house was held at the Bowman House to celebrate the addition of a new wing. The addition allowed further expansion of the day-care program. As this history was completed, the building still housed pre-school children at play.

In 1988, Deputy Director Raymond Kammer joined young clients of the NIST Day Care Center in a ribbon-cutting ceremony for the center's new wing as Director Lori Allen and Board President Kathy Stang looked on.

The appointment of Ruth Davis and planning an NBS center for child care were two steps in the direction of providing equal employment opportunities for women.

[51] The author is indebted to DeForest Z. Rathbone, Jr., former Plant Division employee in charge of special projects, for details on the Bowman house renovation.

[52] Jennie Covahey, "NBS child care center opens in September," *Commerce People*, August 1983, p. 6.

The NBS Budget

Branscomb's first order of business as Director was to understand the people and programs of the Bureau and to represent them effectively in budget hearings before the Committee on Appropriations, House of Representatives, Subcommittee on Departments of State, Justice, and Commerce, The Judiciary, and Related Agencies, John J. Rooney, New York, Chairman.[53]

Branscomb was well aware that Congressman Rooney vigorously protected the public purse from attacks by profligate agency heads who sought government funds for purposes not authorized by law—indeed, Rooney was not overly fond of approving appropriations even for projects specifically authorized by the House Committee on Astronautics. Branscomb later recalled:

> When I was Director, John Rooney of Brooklyn chaired—maybe I should say owned—the Subcommittee on Appropriations for Commerce, State, and Justice. Preparing for testimony before John Rooney was an agonizing affair, though not quite so agonizing as the experience of testimony itself. He ate government officials for lunch.[54]

Congressman Rooney expressed outrage frequently during his hearings, and he denounced in clear terms the efforts of those misguided or malicious public servants who offended his sense of fiscal integrity. The casual reader of the committee record might well wonder that any of Rooney's targets stayed out of jail, let alone survived in office to run—in perhaps most cases—quite effective organizations.

Despite the lurking dangers, Branscomb may have smiled a tiny smile as he contemplated his inevitable encounters with the House Subcommittee on Appropriations for State, Justice and Commerce. He knew that the cards were stacked against him in several respects. The Department of Commerce was not the ideal home for a technical agency such as the Bureau. The Bureau's importance to the Nation had always been hard to express in common terms, let alone to quantify to hostile laymen. And, of course, the Subcommittee members had no particular need to be civil to the people whose budgets they could influence so drastically.

However, Branscomb had a few cards to play, too—and the game interested him.

With Astin having completed the defense of the 1970 budget on May 13, 1969, Branscomb had a little time to prepare for his first encounter with the Subcommittee. He used it well.

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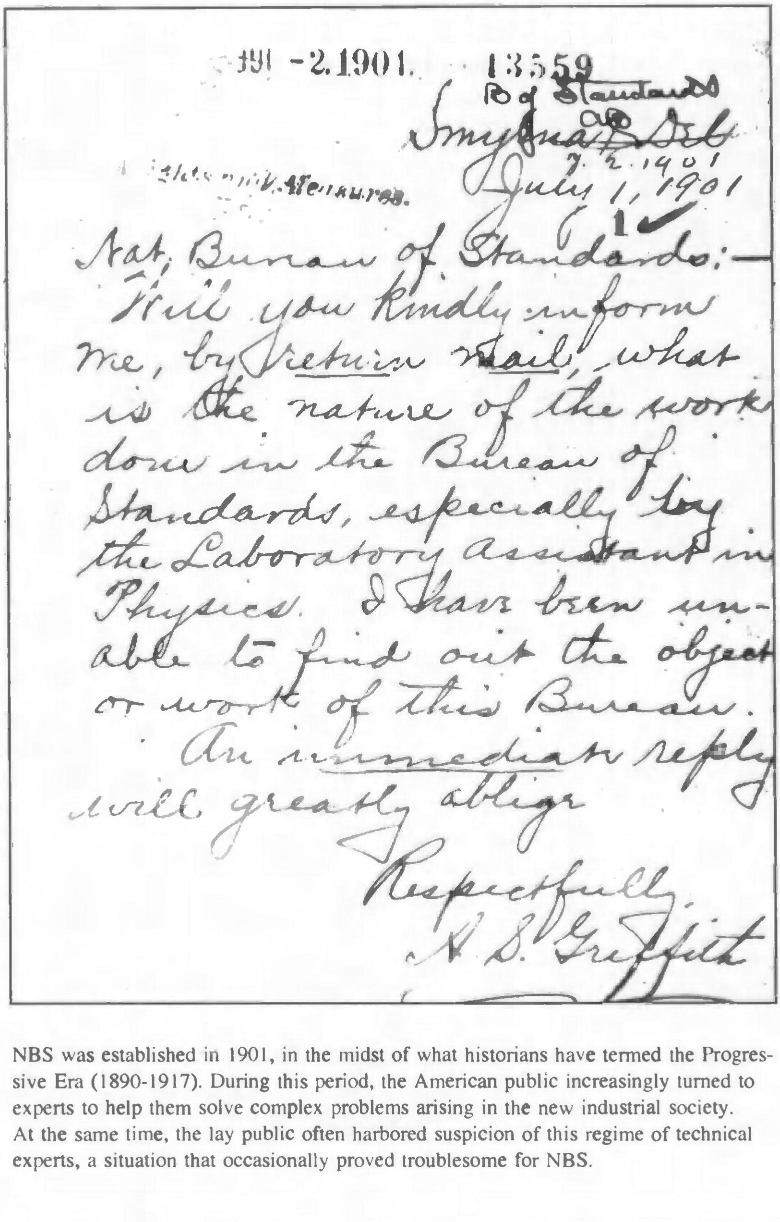
[53] The U. S. Senate Appropriations Committee had a similar subcommittee, chaired at that time by Sen. John L. McClellan. McClellan's subcommittee also had to approve the Bureau's appropriations. However, it was the House subcommittee that conducted hearings involving NBS testimony on its budget and initiated the appropriations process.

[54] Lewis M. Branscomb, "Historical Perspective: 1969-1973," in *NBS/NIST A Historical Perspective: A Symposium in Celebration of NIST's Ninetieth Anniversary, March 4, 1991, NIST Special Publication 825,* April 1992, p. 25.



JUL -2 1901. 13559

B of Standards

Smyrna Del

7.2.1901

July 1, 1901

Nat. Bureau of Standards:—

Will you kindly inform me, by return mail, what is the nature of the work done in the Bureau of Standards, especially by the Laboratory Assistant in Physics. I have been unable to find out the object or work of this Bureau.

An immediate reply will greatly oblige

Respectfully,

H. S. Griffith

NBS was established in 1901, in the midst of what historians have termed the Progressive Era (1890-1917). During this period, the American public increasingly turned to experts to help them solve complex problems arising in the new industrial society. At the same time, the lay public often harbored suspicion of this regime of technical experts, a situation that occasionally proved troublesome for NBS.

Fiscal 1971 Budget Hearings, March 1970

Branscomb's first budget presentation before Congress occurred on March 24, 1970. The NBS budget that he presented—the Fiscal 1971 edition—followed the format and emphasis of previous Astin budgets. "No substantial change in mission or objectives," despite the change in directors, read the introductory statement.[55] In his preparations, Branscomb had selected three programs—the metric study, flammable fabrics, and fire research and safety—for priority funding requests. These programs, he announced, were in great need of increased support.

Branscomb's other preparatory work had been to study the budget document almost to the point of memorization.[56] He was aware that Congressman Rooney often asked questions requiring precise knowledge of budget details and dollar figures; witnesses without ready responses could expect a rebuke. Thus, when Rooney asked for numbers, Branscomb—well prepared and well rehearsed—was able to supply many from memory and could find the others quickly. As usual, one of the numbers requested was the cost of the flagpole (in reality, the cost of the flagpole and its environs) in front of the Gaithersburg Administration building; without hesitation, Branscomb quoted the five-digit number.

The Bureau was allowed to ask for a $5 million increase for Fiscal 1971. Its total appropriation for the year, $44.2 million, reflected an increase of $3.6 million.

As Branscomb defended the Bureau's fiscal 1971 budget, he was already deep into plans for the following year's presentation. He felt that he needed to make much more clear the nature of the Bureau's contribution to the Nation's welfare.[57] He hankered for the kind of strategy used by the National Institutes of Health (NIH) and the Social Security Administration (SSA). The NIH named its institutes for medical problems (Cancer, Aging, Mental Health, etc), not for types of molecules that dominated the work in the various laboratories. The SSA, given its intensive use of computers for "number-crunching," could justifiably have named itself the "National Computer Center" but wisely chose to emphasize its area of public service.

How could Branscomb redefine Bureau programs to show their impact on the public? In the Institute for Basic Standards and in the Institute for Materials Research, its technical divisions had been organized to attack individual areas of measurement science for decades—Applied Mathematics, Electricity, Metrology, Mechanics, Heat, Atomic Physics, Radio Standards, Time and Frequency, Cryogenics, Analytical Chemistry, Polymers, Metallurgy, Inorganic Materials, Physical Chemistry. Still, there were exceptions. IBS and IMR contained consumer-oriented offices in Standard Reference Data and Standard Reference Materials, for example, and the Institute for Applied Technology incorporated many consumer-focused units—Engineering Standards Services, Weights and Measures, Invention and Innovation, Vechicle Systems, Product Evaluation, and Building Research.

Branscomb's solution to this challenge was to revise entirely the way in which NBS programs were presented to the House Appropriations subcommittee, and to introduce additional problem-oriented units to the NBS organization as the situation permitted.

[55] Hearings, House App. Subcommittee, March 24, 1970, p. 1021.

[56] Branscomb, Oral History, July 12, 1988.

[57] Branscomb, Oral History, July 12, 1988.

Working with his managers, with consultants, with the Department of Commerce, and with the Office of Management and Budget, Branscomb fleshed out a new budget-presentation scheme and prepared a "crosswalk" to correlate entries in previous budgets with items in the new one. After some months of effort, he sent his "homework" to Charles H. Alexander, Director of the Office of Budget and Program Analysis for the Department of Commerce, and requested permission to use it in the Fiscal 1972 budget.[58]

Fiscal 1972 Budget Hearings, April 1971

The new activity structure for the 1972 budget hearings was meant to convey a picture of NBS as a problem-solving, consumer-oriented institution:

- Providing the basis for the Nation's physical measurement system.
- Providing scientific and technological services for industry and government.
- Providing the technical basis for equity in trade.
- Providing technical services to promote public safety.
- Providing technical information services.
- Providing one-of-a-kind facilities for use by NBS and visiting scientists.

In presenting the new structure to the Bureau staff, Branscomb had been typically candid:

> There is nothing sacred about this program structure. Some of the elements are frankly experiments; we will have to see how they work out.[59]

It is interesting to notice that, by 1974, each of the operating units of the Bureau was assigned responsibility in one or another unit of Branscomb's program structure.[60]

Congressman Rooney, during the Fiscal 1972 hearings, appeared to surprise even himself by praising Branscomb's presentation of the new description:

> This is one of the better statements from the Department of Commerce . . . The statement is in language that represents the doctor's thoughts and he conveys those thoughts to the committee. I think this is very well written . . . However, don't rest on your laurels on that one, Doctor.[61]

The *repartee* during the April 1971 budget hearings would not be confused with the soft banter of old friends, but Branscomb had made a good start on his task of creating a new image for NBS. And, it should be noted, NBS received all the funding

[58] Memo, LMB to C. H. Alexander, Dir. , Office of Budget and Program Analysis, DoC: "Request for change in budget activity structure," RHA, RG 167, Director's Office, Box 389, folder Chrono, September 1-30 1970. Attachments, 12 pp.

[59] "From the Director's Office," *NBS Standard,* vol XV, No. 5 May-June 1970, p. 2.

[60] NBS Admin. Bull. 74-44, June 25, 1974.

[61] Hearings, House Committee on Appropriations, Subcommittee on Commerce, etc, 92nd Cong., 1st sess., April 20, 1971, pp. 1117-1140.

requested in the fiscal 1972 budget, increasing the Bureau's Congressional support level by some $5 million, to $49 million.[62]

Fiscal 1973 Budget Hearings, March 1972

The fiscal 1973 budget appropriation hearings, held on March 28, 1972, were remarkable for several reasons.

First of all, where was Congressman Rooney? Still the Chairman of the Subcommittee on Departments of State, Justice, and Commerce, the Judiciary, and Related Agencies of the House Committee on Appropriations of the 92nd Congress, Second Session, Congressman Rooney neither spoke nor sat during the hearings.

Rooney had been in charge 8 days earlier, when Peter G. Peterson, named Secretary of Commerce on January 27, 1972, by President Richard M. Nixon and confirmed by the U.S. Senate on February 21st, made his first appearance before Rooney's subcommittee. As part of his testimony on budget requests by the Department of Commerce, Peterson had suggested that a $14 million Experimental Technical Incentives Program be lodged within NBS. Rooney had been in fine form that day, asking:

> Do you think this is the right place in which to put this kind of trust?[63] You know, these great scientists out there were so wrong in figuring the cost of the building at Gaithersburg that I think it is the No. 1 white elephant in Government. Is there anything worse than that?

But on March 28, Mr. Rooney was missing, through illness or press of business elsewhere; no duel of words and numbers with the new Bureau Director would take place on that day. Rooney's position was filled by Congressman John M. Slack of West Virginia, a competent questioner and one not given to rancor.

The second unusual feature of the 1972 hearings was the enormous increase in appropriations that NBS was allowed to request for fiscal 1973. The total came to $79 million, an increase over the previous year's budget by a whopping $30 million. After Branscomb made his formal presentation, Mr. Slack felt a need to check the facts:

> Mr. Slack: We realize that you are requesting funds here for some very worthwhile programs. However, when I read the amounts requested this year and compare those with the appropriations made last year I find this is an increase of almost 60 %. Is that correct?
>
> Mr. Branscomb: That is correct, Mr. Chairman.
>
> Mr. Slack: That is a very sizable request.
>
> Mr. Branscomb: It is, Sir.

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[62] 1972 Funds-requested data from Hearings, House Approp. Subcomm, April 20, 1971, p. 1118, "1972 Estimate; $47. 5 million." 1972 Funds-appropriated data from Hearings, House Approp. Subcomm., March 28, 1972, p. 1076, "1972 Approp.; $49.8 million."

[63] Hearings, Subcommittee, Part 3, Commerce, March 20, 1972, p. 15.

A third remarkable feature of the 1972 hearings only became known a week later, when Branscomb's resignation as NBS Director reached the White House. Having created momentum for recognition of the Bureau's present and potential role as a leader for technological progress in the U.S. government and having obtained executive-branch support for a notable increase in funding to help fulfill that role, Branscomb had set a stage that he would occupy no longer.

The $79 million budget request for NBS, Branscomb's narrative stated, was an unusual expansion meant to attack national problems of unusual magnitude—the decline in growth of U.S. productivity, the first trade deficit of the century, environmental pollution, and public safety.

Largest of the new program proposals originated with "the President's initiative to focus scientific research and technology more directly on solving national problems."[64] In fact, it was one proposal that had not been initiated by Branscomb—nor by anyone at NBS, for that matter. Lawrence Kushner, Deputy Director of NBS, remembered receiving a telephone call from the Office of Management and Budget while Branscomb was on foreign travel; the caller announced that $8 million would be added to the fiscal 1973 budget for a program that would help innovation in U.S. industry by eliminating barriers to technological progress. Kushner promised to begin immediately to design such a program, but the caller needed a program title at that moment. During that call, the Experimental Technology Incentives Program (ETIP) was born.[65]

The nature of the ETIP program was developed principally by Edward J. Istvan, a newcomer to NBS[66] who was Associate Director for Teleprocessing in the Center for Computer Science and Technology. The main idea of the program became part of the NBS budget narrative for Fiscal 1973, with a price tag expanded to $14.4 million.[67]

Besides the ETIP program, an increase of $3 million was requested in programs collected under the heading "productivity enhancement." These included a new neutron-standards capability ($407,000), extension of the standard reference data program ($534,000), expansion of the computer science and technology program ($1.05 M), and a new cryogenics-based electric-power project ($1 M).

$1.5 M was asked in the area of environmental-pollution abatement. The Measures for Air Quality program was to receive about one-third of that increase, another third was earmarked for water-pollution work, and the rest was intended for studies in noise pollution.

[64] Hearings transcript, p. 1077.

[65] Lawrence Kushner, Oral History, June 7, 1988.

[66] Istvan joined NBS in 1971. He was an expert in the use of radar for meteorological work. He had experience in the Air Weather Service, in the Guided Missile office of the U.S. Air Force, in the Department of Defense Office of Space Systems, and at the Communications Satellite Corporation.

[67] Hearings, House Subcommittee, March 28, 1972, p. 1085.

Programs in public health and safety were scheduled for increases totaling $6.4 M. Research projects in the areas of materials measurements ($725,000), failure avoidance ($1.2 M), fire research and safety ($3.8 M), and radiation safety ($400,000) were intended to share in this funding.

Improvements in the NBS plant and equipment were scheduled to cost $5.3 M; of that amount, $4.2 M was intended to augment the NBS Working Capital Fund used to purchase general equipment. The rest was intended for a new volt standard, the time and frequency program, and reactor-facility plant improvements.[68]

The state of the Bureau's equipment had been found wanting in the extreme during a survey taken in preparation for the July 1970 meeting of the statutory Visiting Committee. Over the previous half-decade, the annual equipment expenditure for the Bureau's technical staff had dropped from roughly $1000 per scientist to $600. The Visiting Committee report stated:

> Although maintained with great care and devotion, the most that can be said of much of the equipment is that it has the beauty of a well-varnished buggy.[69]

Noting that the Committee had recommended an increase of three to five times the amount usually spent by NBS to bring its spending level for equipment up to the rate routinely allocated by comparable private-sector laboratories, Secretary of Commerce Maurice Stans urged Congress to fund a five-year modernization program.

NBS Staffing and Funding Levels under Branscomb

It is fair to guess that it was the care with which Branscomb prepared his testimony before Congress, coupled with his vision of NBS as a greater force in the day-to-day technological life of the United States, that provided much of the impetus for the Bureau's Fiscal 1973 Congressional appropriations. Too, Branscomb's efforts coincided with a growing awareness in both the Executive Branch and Congress that NBS could be of considerable service to the Nation's economic health, as we shall see.

Such are the thrills of government funding that, in March of 1972, NBS happily found itself allowed to seek $79 M (an increase of $30 M) in direct appropriations for Fiscal 1973. When the budget finally passed both houses of Congress, NBS had been granted over $69 M (including $10 M for the ETIP program).

However, before the Bureau could spend the $20 M increase over its Fiscal 1972 appropriation, President Nixon announced that $13 M of the increase would be required of NBS as part of a general economy drive in government spending.[70] The ETIP program—suggested, as noted above, by the President's own productivity-enhancement effort—gave up only $3.8 M. Entirely gone were the increases for

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[68] House Subcommittee hearings, March 28, 1972, pp. 1078-1087.

[69] Letter to Stans from Robert L. Sproull, Chairman of the Visiting Committee, June 22, 1971. RHA Director's Files, Box 390, Folder July 1971.

[70] News accounts at the time referred to the cuts as "impoundments" or "rescissions." The transcript in the 1974 House Subcommittee hearings recorded the cuts as "savings and deferrals."

neutron standards; for standard reference data; for computer sciences; for radiation safety; and for the volt standard, reactor, and time and frequency dissemination facilities. The environmental pollution standards program increase was cut back to $675,000. The cryogenic power program increase was reduced to $300,000. The appropriated increase to the fire program was cut by two-thirds.[71]

A worse problem than President Nixon's rescission of two-thirds of its Fiscal 1973 budget increase was his imposition, late in 1971, of 5 % reductions in both total numbers of Bureau employees and their average grade level. Through no fault of Lewis Branscomb, the Bureau lost more than 100 staff members during 1971-72, the equivalent of one of its technical divisions.

What to do about the budget, by the time the President's cuts in it were announced, was no longer the problem of Lewis Branscomb.

New Congressional Oversight Hearings for NBS

Even prior to his appointment as director, Lewis Branscomb held the view that NBS program support in Congress suffered because its work was so little known by individual Congressmen. In order to make ends meet, NBS managers were more and more often forced to accept funding from other government agencies as a means to pursue projects that could advance the Bureau's basic mission. Other-agency funds then constituted about 42 % of the total Bureau support—too high a figure by far, by Branscomb's reckoning.

If only members of Congress were better informed about NBS, they would be more likely to provide the agency with adequate support through direct appropriations, thought Branscomb. As its new director, he already knew well the high quality of the NBS staff and the broad range of its programs, and he welcomed the visibility that public scrutiny would bring.

Tickling the system in September of 1971, Branscomb inquired whether the House Committee on Science and Astronautics would be interested in celebrating the Bureau's 70th anniversary "by undertaking an in-depth review of the Bureau of Standards—the goals, structure, operations, strengths, problems, and opportunities."[72] Allen Astin also urged the Committee to act.

Extensive familiarization hearings had been undertaken by the House Committee on Science and Astronautics in 1959, during the year following its establishment. These had been the last comprehensive Congressional reviews of the Bureau, although limited hearings had occurred numerous times since then. Perhaps most significant were those held in 1961 in connection with the provision of large-force calibrations for the space program, in 1964 to accompany the initiation of the Standard Reference Data program, and in 1967 as part of the development of the Metric Study legislation.

[71] House Subcommittee hearings, April 17, 1973, p. 772.

[72] LMB, "Perspective" *SP 825*, p. 25.

Branscomb's inquiry was received with enthusiasm. The Congressional Research Service (CRS), the investigative arm of the Library of Congress, was directed by the House Committee on Science and Astronautics to prepare a study of the Bureau for its Subcommittee on Science, Research, and Development.

Lester S. Jayson, Director of the CRS, assigned analyst Dorothy M. Bates to conduct the study. She collaborated in the review with Warren H. Donnelly and with Charles S. Sheldon II, Chief of the Science Policy Research Division. Their report was submitted to John W. Davis, chairman of the subcommittee, on August 18, 1971.[73]

The CRS report, intended to provide background information for the use of the subcommittee in conducting its oversight hearings, was detailed and thorough. One topic treated early in the report summarized the previous reviews of NBS by the Science and Astronautics Committee; it is worthwhile to note the highlights of those reviews.

Previous Reviews of NBS

The Congressional Research Service briefly recounted the findings of the Science and Astronautics Committee in hearings from 1959. The esteem with which NBS was perceived by the committee during those earlier hearings was indicated by the relatively few criticisms of the Bureau in the CRS summaries. For the most part, the committee members simply reported that NBS needed funding, or that NBS would be required to develop a new capability.

1959 Review

The latest comprehensive Congressional reviews of the Bureau, as noted above, had been performed by the House Committee on Science and Astronautics. The 3-day review in May 1959 had elicited a 13-page report by the Committee.[74] Committee members found no fault with NBS, only observing that:

> The Bureau's major problems related to the inadequacies of its physical plant and research and testing facilities at its old site on Connecticut Avenue in Washington. Major equipment critically needed in 1959 were larger 'dead-weight' machines to calibrate force measurements for the missile and rocket program, and a nuclear research reactor.[75]

[73] Congressional Research Service, Science Policy Research Division, Library of Congress, *National Bureau of Standards: Review of Its Organization and Operations: A Study Prepared for the Subcommittee on Science, Research, and Development of the Committee on Science and Astronautics, U.S. House of Representatives*, 92nd Congress, First Session, September 8, 1971, 222 pp.

[74] Briefing by the National Bureau of Standards, 86th Cong. 1st sess. 1959 (May 7, 8, and 21), 78 pp.

[75] Briefing by National Bureau of Standards, 86th Cong. 1st sess., Aug. 21, 1959, 13 pp.

1961 Review

A second Committee hearing—in May 1961—had focused on the responsibilities of NBS to help the space program, testifying to the urgency of a technical response to the Soviet launch of Sputnik. In its report on the review, the Committee had noted that NBS was hard-pressed to keep pace with demands for its services, for numerous reasons:

- Lack of adequate funding.
- Limited and inadequate laboratory facilities.
- Necessity to perform work for other agencies to the detriment of its primary measurement-standards mission.
- Difficulty in recruiting and retaining additional senior scientists because of a lack of high-level positions.
- Inability to invest in backup research.

In view of these problems, the 1961 Committee recommended doubling the 1959 level ($15 M) of NBS appropriations in order to shift NBS staff from other-agency work to projects in the basic NBS mission areas.[76]

Subsequent Congressional Reviews

The CRS report noted that other Congressional hearings on NBS in subsequent years had been confined to specific aspects of its programs. These included the following:

- Amendment of the Organic Act in 1963 to give NBS authority to carry funds past the end of the fiscal year, to allow visiting scientists to work at the Bureau, and to allow NBS to receive and spend gifts and bequests.
- Hearings in 1966 that led to the establishment of the Standard Reference Data System.
- Hearings in June, 1967, that led to an amendment of the Organic Act to authorize a Fire Research and Safety program.
- Hearings that led to enactment of Public Law 90-472, the Metric Study Act, in 1968.

[76] Direct Congressional support for NBS research and technical services during the three-year period 1959-61 did rise dramatically, although it did not double:

Year	1959[a]	1960[b]	1961[c]
Res. & Tech. services	$11.5	$17.3	$18.8
Plant & Constr.	$ 3.7	$ 2.1	$25.5
Total Amount (millions)	$15.2	$19.4	$44.3

Notes:
[a] Hearings, House Appropriations Subcommittee, 86th Cong., 1st sess., May 1, 1959, pp. 250-251.
[b] Hearings, House Appropriations Subcommittee, 86th Cong., 2nd sess., January 13, 1960, pp. 234-236. Across-the-board increases for all technical areas averaged 30 %.
[c] Hearings, House Appropriations Subcommittee, 87th Cong., 1st sess., May 3, 1961, pp. 807-808. The "Plant and Construction" item includes new facilities—nuclear reactor, deadweight-testing building, and linac—at the Gaithersburg site.

Executive Branch Reviews

The Executive Branch conducted its own reviews of NBS. The CRS report duly summarized these reviews:

- Annual reviews by the statutory Visiting Committee, for the Secretary of Commerce.
- Annual reviews of technical divisions by evaluation panels administered by the National Research Council.
- Occasional reviews by the General Accounting Office.
- Two major reviews made at the request of Secretary of Commerce Sinclair Weeks; an Ad Hoc Committee review following the AD-X2 battery-additive controversy (the first Kelly Committee review, in 1953), and a follow-up review (the second Kelly Committee review, in 1958).[77]

The CRS report identified the total paid staff at NBS in June 1970 as 4053 persons, including full-time permanent staff, Postdoctoral Research Associates, and part-time staff; 650 of these worked at the Boulder site.

More than 40 % of the overall Bureau support came from funding provided by other government agencies and from testing fees. (Branscomb believed that outside support should be capped at about one-third of the total support level.)[78]

NBS appropriations were authorized by the House and Senate Appropriations Committees, Subcommittees for the Departments of State, Justice, Commerce, the Judiciary and related agencies. The subcommittees were chaired by Sen. John L. McClellan and John J. Rooney. The fiscal 1972 appropriation for NBS totalled $48 million, including $47 million for research and technical services; overall NBS support was in excess of $85 million.

The report took notice of the new budgetary line items used by Branscomb during the House Appropriations Subcommittee hearings in April 1971.

In the CRS overview of the quality of NBS as a federal agency, the authors stated that they found:

> . . . no serious shortcomings or inadequacies for which the Bureau can be held responsible. But there are problems confronting the Bureau which, if left unattended, may result in difficulties not only for the Bureau, but for the Nation as a whole.

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[77] Extensive discussion of the two Kelly Committee reports on NBS programs and management can be found in Passaglia, *A Unique Institution*. See, for example, p. 173 and p. 304.

[78] LMB, Oral History, July 12, 1988.

The authors alluded to difficulty in "getting a grip" on the Bureau because, as Branscomb had surmised, outsiders knew relatively little about its work.[79] In addition, it appeared that the Bureau's operations—already more technical and diverse than the average citizen could follow—changed quickly in response to requests from governmental or technical organizations. The result was the relative obscurity that Branscomb wished to overcome.

The existing and foreseeable "Bureau problems" mentioned in the CRS report derived in the main from sources external to NBS. One such was uncertainty and, often, inadequacy in funding, arising in part from the fact that the NBS mission—while important to the Nation's technological well-being—often lacked the glamour of, say, a space trip to the moon. Another lay in the diversity of its responsibilities to government and industry. A third reflected hesitancy on the part of Congress to increase support of civilian technology as the Nation's technological expenditures increased. Finally, the report mentioned the continuing demand that the Bureau should provide the measurement infrastructure to support these technological changes despite the difficulties of expanding or quickly adapting its staff to new projects.

The authors found a few areas where NBS efforts had been criticized during the past decade. There had been Congressional or industry dissatisfaction with certain features of the Bureau's work on Operation Breakthrough and the Flammable Fabrics project. A panel of the National Academy of Science had determined that the NBS materials-research facilities were inadequate. Demographic data had indicated that minorities were under-represented on the Bureau staff. Progress in deriving standards for automatic data processing had been slow. Differences with the General Accounting Office on fiscal procedures had occurred. And in certain cases, inequitable calibration-fee charges had been levied by NBS. All of these were suggested as suitable subjects for discussion during oversight hearings.

A number of additional avenues for Congressional inquiry were suggested in the report. These covered a multitude of thorny issues: adequate planning for the future of programs and standards; the continuing problem of the proper role of NBS in U.S. metric conversion; developing techniques for maintaining suitable levels of funding and laboratory facilities; questioning whether the Department of Commerce still provided the best "home" for NBS within the Executive Branch; and possible changes in Bureau authority and policy to help it to meet its responsibilities.

Oversight Hearings Testimony

The oversight hearings themselves took place September 16, 21, 22, 23, and 28, 1971 before the House Subcommittee on Science, Research, and Development. The record of the hearings ran to more than 380 pages.[80] Besides Branscomb, a host of witnesses testified on one topic or another. The list included the following people:

[79] Branscomb was surprised that the authors of the CRS report did not consult with NBS managers in preparing it. The report would have been improved in several aspects, in Branscomb's opinion (see L. M. Branscomb, Oral History, July 13, 1988), had the authors buttressed information gleaned from external sources with amplifying material from NBS.

[80] House Subcommittee on Science, Research, and Development of the Committee on Science and Astronautics, *National Bureau of Standards Oversight Hearings*, 92nd Congress, First Session, September 16, 21, 22, 23, and 28, 1971, 387 pp.

- James H. Wakelin, Jr., Assistant Secretary of Commerce for Science and Technology.
- Vico E. Henriques, Director of Standards, Business Equipment Manufacturers Association.
- Nathan Cohn, Executive Vice President, Leeds & Northrup Company.
- Robert S. Walleigh, NBS Director for Administration.
- Ernest Ambler, NBS Director of the Institute for Basic Standards.
- John D. Hoffman, NBS Director of the Institute for Materials Research.
- F. Karl Willenbrock, NBS Director of the Institute for Applied Technology.
- Edward L. Brady, NBS Associate Director for Information Programs.
- Former NBS Director Allen Astin.
- Ruth M. Davis, NBS Director of the Center for Computer Sciences and Technology.
- Lawrence M. Kushner, NBS Deputy Director.

All witnesses gave written and/or oral testimony. In addition, written statements were inserted into the hearings record by 11 other individuals.[81]

The Bureau had a good friend in James Wakelin, the Assistant Secretary of Commerce for Science and Technology. Wakelin, formerly a manager at the Office of Naval Research and the Naval Research Laboratory, was well aware of the close cooperation between NBS and the National Oceanographic and Atmospheric Administration in the area of data acquisition and analysis. In his testimony, he gave glowing praise to the work of NBS, stressing its importance to the technical aspects of U.S. industry and commerce.

By the time of the oversight hearings, Branscomb was 2 years into his term as Director. He had quickly become familiar with most of the Bureau's programs, and he spoke with equal eloquence regarding his own view of the significance of NBS work to the Nation's technical enterprise. On this subject, he had well-developed views that greatly interested the members of the Subcommittee.

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[81] These individuals included Bernard M. Oliver, vice president of research and development, Hewlett-Packard Co.; C. Sutton Mullen, Jr., chief fire marshal, Bureau of Insurance, Virginia State Corporation Commission; N. Bruce Hannay, executive director of research, Bell Telephone Laboratories, Inc.; Michael M. Schoor, legislative assistant, American Dental Association; Harold B. Finger, Assistant Secretary for Research and Technology, Department of Housing and Urban Development; John E. Mock, Georgia Science and Technology Commission; Arthur M. Bueche, vice president for research and development, General Electric Co.; W. O. Baker, vice president for research, Bell Telephone Laboratories; W. T. Cavanaugh, managing director, American Society for Testing and Materials; Sava I. Sherr, manager, standards operations, Institute of Electrical and Electronic Engineers; and Roy P. Trowbridge, president, American National Standards Institute.

Branscomb's testimony in the oversight hearings was important principally because it placed before the Congressmen a multitude of ideas on how the Bureau perceived its mission and its relation to other government entities. Following are a few of his comments:

> ***Mission of NBS***
>
> Our cornerstone responsibility is to provide for the United States the single authoritative source of accurate, compatible, and useful physical measurements and further to ensure their international compatibility.
>
> No nation in the modern world, much less the world's leading scientific and technological society, can prosper and function effectively if the national system of measurement is in a state of anarchy.
>
> The commercial life of this country depends upon the Bureau's help with such measurement problems, not alone because the Bureau's staff bring to bear scientific talents not usually found in industry, but more importantly because both buyer and seller need an unbiased, honest third party with the technical capability to say 'This measurement is a fair and accurate one; that one may not be.'[82]
>
> ***NBS Operating Goals and Objectives***
>
> - Measurement Services for Science and Technology.
> - Science and Technology for Industry and Government.
> - Technical Services for Equity in Trade.
> - Technical Services for Public Safety.
> - Technical Information Services.
> - Central Technical Support.
>
> ***NBS Budgeting Methods***
>
> The National Bureau of Standards was established and has operated much like a central corporate laboratory in the Federal Establishment.
>
> The National Bureau of Standards does not have a line appropriation for administrative operations and research in addition to its program budget. Nor does the Public Building Service budget for the maintenance of our facilities, which we operate out of project funds. Every dollar spent at the National Bureau of Standards is accounted for as a program cost.
>
> In addition, we provide a variety of reimbursable services for which we must incur no profit and no loss. For these programs, we require access to working capital to invest in inventory of both materials for sale and labor for services in progress.[83]

[82] Hearings Committee print, pp. 20, 22.

[83] Hearings Committee print, p. 38.

NBS Staffing Levels

During a time of rapid priority change and laboratory reorganization, our staff has been admirably adaptable. An annual reduction-in-force averaging about 1.5 % of our total personnel each of the last two fiscal years has been regrettable, but unavoidable.

Here is a chart that shows the rapidly growing Institute for Applied Technology, where, of course, a number of programs with pressing social priorities are located. If you will consider the tremendous efforts we have made to focus our talents on priority technical problems, not only to respond to changing social needs, but the changing requirements of science itself within the Institute for Basic Standards and the Institute for Materials Research, whose staffs have been declining slowly, you will appreciate that our staff has been called upon for adaptability.

We have also seen severe attrition in discretionary operating funds over and above our basic technical and support payroll. This, in part, has forced the reductions-in-force as managers reduce staff to keep operational efficiency.[84]

Between 1965 and 1971, the Bureau staff grew slightly, from 1369 to 1384. But the Institute for Applied Technology in that interval grew from 139 to 349, the Institute for Materials Research held almost exactly constant, and the Institute for Basic Standards—concerned with the provision for the central basis for measurement in this country—dropped from 687 to 562.

This trend in itself is simply descriptive of the narrowing of our base of measuring services for science and technology, and it does give me pause. The static nature of the total professional staff simply spells a picture of a talented, experienced staff slowly growing older and failing to replenish itself adequately with recently educated younger graduates. We are attempting to do whatever we can within the constraints of a more or less constant staff to insure our vitality.[85]

NBS Equipment

At the same time, we have permitted the state of the Bureau's equipment to fall far below the standard to which industrial laboratories maintain themselves, notwithstanding the fact that it is our responsibility to be the measurement laboratory for them.[86]

In our Metallurgy Division, for example, we feel that a very high priority should be given to fracture mechanics, fatigue, and related problems. We are now trying to strengthen our capabilities in this area under the general heading of failure avoidance services.

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[84] Hearings, Committee print, p. 40. From Branscomb's answers to questions by the Committee, it is clear that "social" projects at NBS refer to relatively short-term programs such as flammable fabrics, fire research and safety, and building codes. Most of this work was mandated by Congressional legislation.

[85] Hearings, Committee print, p. 317.

[86] Hearings, Committee print, p. 40.

I have looked at the age of equipment used in this program. We have all of our equipment on a computer roster and can query this roster for the acquisition date. My staff provided me with a page and a half of equipment items, starting with the first one acquired, and the list ends in 1909. Several items on that list are fatigue testers and tensile testers still in use. My staff informs me that although we do have the personnel in metallurgy, we are not in a position to undertake work in fracture mechanics because of the lack of, or the total obsolescence of, appropriate test equipment.

If I may show the committee one figure, I would like to indicate that our National Academy of Sciences' evaluation panels have been very helpful in calling this problem to our attention. They also have helped to provide us with some base of overall judgment by which we can calibrate our impression, based on the individual requirements of the laboratories, that we are underfunded in equipment. We obtained information from a number of industrial laboratories with similar types of research programs.

Examples would be Bell Telephone, General Electric, or Westinghouse. They invest 10 % in general equipment for the laboratories. That is indicated by the horizontal line. The vertical bars give the percentage that NBS has invested in equipment over recent years. The number has risen and fallen (in the range 2 % to 8 %).[87]

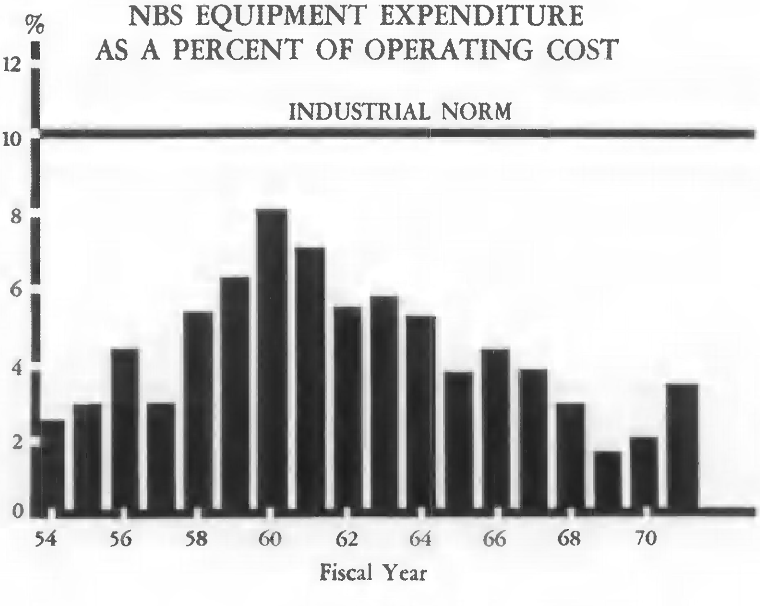

Chart shown by Lewis Branscomb to the House Subcommittee on Science, Research, and Development during 1971 Oversight Hearings. It demonstrated the relatively low investment in NBS laboratory equipment from 1954 to 1971 compared with expenditures by major private-sector laboratories.

[87] Hearings, Committee print, p. 319-320.

Prospects for NBS

I am a strong advocate of a businesslike mode of operation in which all costs are charged to projects. I would only like to make it clear to the committee that the fiscal pressure under which we have operated in the last several years—and will probably continue to operate—will require continued cancellation of both programs and competences in many significant areas, areas where sections of our scientific and engineering community have depended upon us for continued assistance. Your oversight of these choices is appropriate too.

Despite these difficulties I believe the National Bureau of Standards faces the most challenging opportunity of any large research laboratory in this Nation. We have the right competence in the right organization at a right time. We are effectively engaged in a way that I think is unique in bringing science and technology to bear on national social and economic problems as well as on our scientific achievement.

Our scientists understand the complexities of the social context within which their research must find application. We enjoy a generally excellent reputation among those who know our work, even though we have not been very active in making ourselves known to the general public.

The public's expectations from science and technology multiply every day. But I am deeply concerned that disillusionment may follow if government fails to promote innovation and the productivity of our technology, and fails to guide the regulation of technology on the basis of objective evidence and fair and accurate measurements.

We see the national measurement system and a system of industrial and engineering standards as dynamic systems calling not for more stewardship, but for leadership. The National Bureau of Standards welcomes the guidance of this committee in how it can better provide that leadership.[88]

Branscomb's comments made it clear that NBS was doing more with fewer resources. His words were cogent testimony that the Bureau was running out of flexibility in the face of dwindling professional staff and insufficient or outdated equipment. The Committee questions indicated that they agreed with his assessment.

Ambler, Hoffman, Willenbrock, and Davis took turns explaining to the committee the nature of NBS programs under their care. The committee members expressed interest in the details of the Bureau's technical work and complimented the managers on the clarity of their presentations.

Edward Brady, NBS Associate Director for Information Programs, gave an overview of NBS activities, lodging them within the framework of national needs. Brady noted the benefits to society from the Bureau's work—enhanced productivity, improved health and safety, and better-made consumer products. He closed with a brief exposition of NBS technical communications—publications, conferences, and seminars.

[88] Hearings, Committee print, p. 40.

On the third day of the hearings, Allen Astin testified. In his written remarks, the former Director addressed a recurring question: Should NBS be moved from the Department of Commerce? His view was that, while the Bureau's scientific cooperation with organizations such as the National Science Foundation and the National Aeronautics and Space Administration could not reach their full potential while NBS was lodged within DoC, Bureau programs were vital to the success of so many DoC activities that only an Executive-branch reorganization could improve the present situation.

Astin reminded the committee members that the Bureau had served as a veritable hothouse of innovative technology during his 17-year term as director, creating new technical organizations and then spinning them off to other agencies. These included the guided-missile laboratory, sent complete with equipment and staff to the U.S. Navy; the Diamond Ordnance Fuze Laboratory, similarly given to the U.S. Army; the Institute for Numerical Analysis, which became part of the University of California at Los Angeles; an integrated-circuit electronics laboratory that became an industrial activity; the Central Radio Propagation Laboratory, which helped to create NOAA; and a product-testing laboratory that became part of the General Services Administration. He noted that, under new Director Branscomb, another spin-off had already taken place—the Bureau's vehicle-safety laboratory had been transferred to the Department of Transportation. All of these creations and divestitures, Astin stated, showed the determination of NBS to avoid accretion of staff and functions beyond its own view of its rightful mission.

Astin identified as a serious problem the tendency of Congress to assign programs to NBS with inadequate support. He noted that Congress had funded only 10 % of the amounts deemed essential to the success of six programs recently assigned to the Bureau, with the result that the programs had fizzled or the core competence of NBS had been eroded as its managers had struggled to implement them.[89] He also reminded the Committee that the Bureau's lack of adequate equipment had been noted by the Kelly Report in 1953, but that the revolving fund for equipment had hardly been augmented during the intervening decade. Certainly, he said, NBS was well below the average for a modern U.S. laboratory in terms of its per-scientist equipment allocations.

Significant in the light of the eventual change in the name of NBS was a comment by Astin that:

> Part of the difficulty in some of the lack of appreciation of the range of the Bureau programs and services is the name—The National Bureau of Standards. Some Secretaries of Commerce, on learning of the scope and importance of the Bureau activities, have suggested that we devise a new and more descriptive

[89] Charles A. Mosher, member of both the Subcommittee and the parent Committee, expressed disappointment later in the hearings (p. 227 of the official transcript) that there existed "a serious lack of coordination between the authorizing committees and the appropriating committees . . . that is at the very core of failure of congressional effectiveness in this field."

name. I have viewed such suggestions with mixed thoughts. I can definitely see several advantages to a broader name. On the other hand, the present name is held in high regard by the Bureau's specialized clients and there is danger of losing some of this with a new name.

I would want to retain the word "Standards" in any new title. However, our counterpart laboratories in England and Germany have the names National Physical Laboratory and Physikalisch-Technische Bundesanstalt, respectively, and the word "standards" does not appear.

Perhaps, nearly two decades later, Astin's remark played a role in Congress' decision to rename the Bureau.

NBS Deputy Director Lawrence Kushner spoke on the fourth day of the oversight hearings. He responded to the committee's desire for more specific information on the NBS role in the development of engineering standards. He carefully drew the distinction between standards of physical measurement—the lifeblood of the metrological sciences and the benchmarks of the laboratory sciences—and engineering standards, which undergird industrial practices regarding product manufacture and performance, safety, pollution-generation, and dozens of other commercial areas. He noted that, in the United States, most engineering standards were voluntary—their major influence being found in the agreements among companies and nations that their work should conform to the standards.

Members of the committee heard about the American Society for Testing and Materials, the American National Standards Institute, the Society of Automotive Engineers, the Institute of Electrical and Electronic Engineers, Inc., and a host of other organizations created to advance the cause of standard practices.

Kushner described the types of service given to engineering standards by some 350 NBS staff members, working with more than 900 committees in one or more of 400 standards-writing organizations. Mostly, he stated, Bureau participants provided technical expertise, lending their knowledge of measurement limits and instrumentation. Committee members expressed satisfaction with his clear discussion.[90]

After five days of detailed testimony, the Subcommittee on Science, Research, and Development of the House Committee on Science and Astronautics, 92nd Congress, had received an enormous amount of information about NBS. The picture painted for them by the speakers described an agency with a strong sense of its own mission and a willingness to fulfill that mission by dint of careful and diligent work.[91] NBS, both in Gaithersburg and in Boulder, was described as possessing a talented group of scientists and engineers housed in excellent facilities.

The Committee also heard much about the needs of the Bureau for more and better equipment and for amplified funding for its staff. Whether the oversight hearings would help the Bureau shed the cloak of invisibility that kept from it a more productive level of support, only time would tell.

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[90] Hearings, Committee print, pp. 281-294.

[91] Synopses of the testimony presented by NBS speakers were recorded in the 1971 Annual Report, published as *NBS Special Publication 360,* June 1972, 90 pp.

An Unexpected Departure

The news, reported in *Science* magazine, came with stunning swiftness:

> The President's technology opportunities program, which was unveiled early this year, assigned a lead role to NBS, marking what was probably the first time the bureau has starred in any program of national prominence. Lewis M. Branscomb, the man who aroused the low-profile and somewhat sleepy agency to such eminence after only 2 1/2 years as its director, announced last week he is leaving to become vice-president and chief scientist of IBM. This decision, which Branscomb explains as "a personal opportunity for me that is not likely to come again," will deprive the Washington science scene of one of its rising and brighter stars. IBM did not have to scour the length and breadth of the nation for its new executive. Emanuel R. Piore, present chief scientist at IBM and a doyen of American statesmen of science, is a member of the NBS visiting committee. An atomic physicist, not a computer technologist by trade, Branscomb will direct IBM's research on a strategic rather than a tactical basis. IBM spends roughly $500 million a year on research and development, compared with a total budget of less than $50 million enjoyed by the NBS. Branscomb thus steps into a job that is ten times larger and, it is said, will roughly double his present salary of $36,000. Since becoming director of the NBS in June 1969, he has turned down at least two university presidencies and has been in the running for the presidency of the Massachusetts Institute of Technology and the directorship of the National Science Foundation.[92]

One week later, the *NBS Standard* published a special edition containing copies of Branscomb's letter to President Nixon, resigning his position:

> It is with regret, even with misgiving, that at such a time of opportunity for further public service I ask you to accept my resignation at a date of your convenience. But my feelings of obligation to Government service are matched by my conviction that the private sector also offers significant opportunities to contribute to the national welfare.
> The knowledge that through your leadership the great capabilities of the National Bureau of Standards' scientific staff will be fully utilized in the public interest makes this difficult decision possible for me.[93]

The same issue continued with President Nixon's acceptance:

> Dear Dr. Branscomb: Your letter of April 4 has come to my attention, and it is with special regret that I accept your resignation effective upon a date to be determined. Few men in government have contributed so much to the Nation's well-being as you have done with such brilliance and dedication for the past twenty years.[94]

[92] Nicholas Wade, "NBS Loses Branscomb to IBM," *Science* **176**, April 14, 1972, p. 147.

[93] Letter, April 4, 1972, LMB to the President. Reprinted in *NBS Technical News Bulletin* Vol XVII, No. 4, April 20, 1972.

[94] Letter, April 5, 1972, President Nixon to LMB. Reprinted in *NBS Technical News Bulletin* Vol XVII, No. 4, April 20, 1972.

In a farewell to his division chiefs, Branscomb stated, "I leave only because of a unique opportunity for me and my family."

He expressed great confidence that NBS was on the brink of a new role in U.S. technology: a large budget increase pending; the absolute confidence of Peter G. Peterson, newly appointed as Secretary of Commerce, and of President Nixon; and a solid, competent management. He warned the chiefs that "If the Bureau's function is to assist in this [national technological, social, and economic] change, it is unthinkable that the laboratory itself would not change with the circumstances."[95]

By the end of May 1972, Branscomb was gone.

Assessing Branscomb's Directorship

Nearly every staff member at the Bureau was both surprised and disappointed by the news of Branscomb's sudden resignation. His personality and his ability to represent NBS effectively to congressmen and to other outsiders had created a vision of unprecedented stature for the agency. Many Bureau employees felt that Branscomb was justified to leave NBS, in view of the significance of his new position and the promise of financial well-being indicated by its title. Others, most definitely including former director Allen Astin,[96] were well aware that many senior Bureau scientists routinely received offers of prestigious and well-paying jobs elsewhere and felt that leaving NBS for such an offer was in some way a desertion in time of battle by Branscomb.

Old-timers on the NBS staff had been concerned immediately after Branscomb's appointment by his statements describing the Bureau in terms of solving short-range national problems, rather than stressing the purely scientific nature of the institution. Branscomb had addressed the paradox implicit in these criticisms directly, during his first address to the staff:

> I have been aware of the widespread view that the new activities in technology introduce an alien, and some would say incompatible, dimension into NBS—a set of programs essentially different in character from those that have gone before. But the more I look into the problem of fostering innovation—or, if you prefer, encouraging engineering creativity in the solution of practical problems—the more I find that the cure calls for the science of measurement once again, and often at a high level of sophistication.

Branscomb illustrated this idea with an example chosen from building technology's efforts on behalf of performance-based standards:

[95] "Excerpts from Dr. Branscomb's announcement to division chiefs," Reprinted in *NBS Technical News Bulletin* Vol XVII, No. 4, April 20, 1972.

[96] Recollection of Elio Passaglia from a personal interview with Astin.

> A performance standard is meaningless without a reliable, quantitative measurement to be used in certifying the performance. To develop such test methods is a demanding task, requiring original research and imaginative thinking.[97]

Thus, Branscomb refused to divide Bureau work into "basic" (i.e., good) and "applied" (i.e., less good) projects, preferring to look for creativity and challenge in any assigned or self-generated project.

Opinion of observers outside NBS on Branscomb's departure was typified by Daniel Greenberg, editor of *Science and Government Report*, a science-news periodical:

> Branscomb, much sought after by recruiters for university presidencies, was widely regarded as one of the most capable and innovative of government administrators, and at NBS there is no little annoyance about his leaving in the midst of the efforts he inspired to shake some life into that venerable establishment.[98]

Branscomb was an active, hands-on administrator during his brief tenure as NBS Director, though not spectacularly more involved in the Bureau's management than his predecessor. His genius was to devise new procedures to make the Bureau more effective in managing and presenting itself: an Executive Board explicitly charged to participate in total oversight of the Bureau; a Programs Office explicitly charged with measuring Bureau projects against a standard of effectiveness created by its own efforts; and a results-oriented set of NBS goals chosen to relate Bureau work to public problems that Congress could more easily support.

Beyond his innovations in management, his involvement in many national scientific committees—coupled with an unusual verbal facility—allowed him to present his ideas with great force. His circle of acquaintances extended far beyond NBS; when he spoke, they listened with interest. It is to his credit that Branscomb continued to pursue vigorously a more effective use of technology and better technical education throughout the U.S. technical establishment, both in his position at IBM and later, while a Professor of Public Policy and Corporate Management at Harvard University.

The Next Step

After swallowing their amazement and disappointment at the loss of a leader in whom great hopes had been placed, the realists who made up the great majority of scientists at NBS considered the logical next step. Not necessarily who should become the next Bureau director—the President's prerogative, after all—but what course the Bureau should take, and what strategy could succeed for it.

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[97] Lewis M. Branscomb, "Dr. Branscomb: The Future of NBS—Excerpts." *The NBS Standard,* Vol XIV, No. 10, October 1969, pp. 1, 3, 4.

[98] Daniel S. Greenberg, "Branscomb Leaves NBS For IBM Post," *Science and Government Report,* April 15, 1972, p. 3.

Leaders there were at NBS, and good ones. Perhaps most visible was Lawrence Kushner, Deputy Director under both Astin and Branscomb. Kushner's credentials were impressive. Armed with a doctorate in physical chemistry from Princeton University, he had practiced his science at the Bureau since 1948. Within a few years, he had created an innovative surface-chemistry group within the Physical Chemistry Division. He was similarly productive in establishing a metal-physics group shortly thereafter in the Metallurgy Division. He served as chief of the Metallurgy Division from 1961 to 1966; while so serving, he assisted the Organization for Economic Cooperation and Development in assessing the quality of graduate education in metal physics throughout the world. During 1964-65 he worked as Special Assistant for legislative activity under J. Herbert Hollomon, the Department of Commerce Assistant Secretary for Science and Technology. Prior to becoming NBS Deputy Director under Allen Astin in 1969 he served as Deputy Director and Director of the Bureau's Institute for Applied Technology for three years.

Also a veteran of service with the Federal Council for Science and Technology, with the National Research Council, and various interagency panels, Kushner was clearly a potential replacement for Branscomb.

The Bureau had other logical choices, too, for Director—Ernest Ambler, John Hoffman, Edward Brady, and Howard Sorrows perhaps first among them.

Even more important was the overall quality of NBS management. Chosen by Astin or Branscomb, all knew their jobs and were resourceful leaders. The Bureau would survive the loss of Branscomb.

It is instructive to hear Branscomb's later comments on the circumstances of his sudden departure:

> I was offered [in December 1971 or January 1972] the job as Chief Scientist of IBM—which is sort of a non-turn-downable job. It is the best technical job in America. I told Vensen Learsen, the Chairman of IBM, that if I came, I would have to postpone coming until after I had seen this budget through,[99] because I owed that to my colleagues, indeed to the President, who had put my 36 % increase in his budget.[100]

Branscomb was easily able to rationalize his decision to leave. Two factors came to his mind in later years: one was that, as a Democrat in an increasingly partisan Republican administration, he might well have been removed from his position as a routine election-year measure, as was the director of the National Institutes of Health; a second was that he had always felt that wise use of technology was crucial to human progress, and that his new position at IBM gave him the best chance to help in this process.[101]

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[99] Recall that the House Appropriations Subcommittee hearings on the fiscal 1973 budget were conducted on March 28, 1972, with Branscomb as the principal NBS witness.

[100] Branscomb, Oral History, July 12, 1988.

[101] Branscomb, Oral History, July 12, 1988 and July 13, 1988.

TECHNICAL WORK OF THE BUREAU, 1969-1972

The work done by NBS scientists and engineers during the period when Lewis Branscomb was director reflected only dimly his struggle to achieve greater notice for the Bureau's efforts on behalf of the American public. There was no lack of successful projects that directly benefitted U.S. citizens, but NBS was not yet accustomed to the idea of publicizing its work with that viewpoint in mind.

Perhaps the NBS project that represented most broadly the national interest was undertaken to satisfy the demand from Congress to ascertain the Nation's posture on the desirability of the metric system for its everyday life. As we note in the next section, more than 50 members of the Bureau staff contributed in one way or another to the success of that information-gathering task. As part of a three-year program, they queried citizens in nearly every occupation about their personal measurement habits and desires.

But the major activities in the NBS laboratories in the period 1969-1972 lay in traditional Bureau areas of science and engineering—many of them, to be sure, of immediate benefit to consumers. Fire studies, conspicuous at the Bureau since its beginning, continued under the special impetus of a new congressional mandate. Research on buildings and other man-made structures continued to play a highly visible role at NBS. Law enforcement and automotive standards addressed specific needs of Americans. Reflecting the personal interest of its new director, the technologies involved in space and astronautics received concerted attention. More arcane studies such as the properties of matter dominated the work of whole divisions of scientists, as did measurement standards and fundamental probing into the laws of nature.

As was always the case at NBS, its output reflected in part the expressed needs of the public, voiced through congressional, industrial, and standards organizations. In part, too, Bureau output represented the sum total of the individual priorities and capabilities of its staff; their views of the technical world, highly personal and often deeply detailed, inevitably influenced their choices of project and emphasis.

The willingness of scientists to delve into scientific puzzles is illustrated in the coming discussion by a note on polywater, a bright but brief shooting star in the firmament of science. This material turned out to be not a new state of an old substance, but a collection of unexpected results brought forth by the unusual properties of water. As often happens, the resolution of the puzzle lay in improved measurements.

In the brief notes that follow, we present merely a taste from the whole technical menu offered by NBS during this period. It is our hope that some indication of the breadth and depth of the scientific enterprise that the Bureau embodied at this time is conveyed by these notes.

NBS Completes a " Metric System Study" for Congress

"*Metrify*, (transitive verb); 2. To convert to or adopt the metric system."[102]

As it had periodically since President Thomas Jefferson's first recommendation in 1795,[103] the U.S. Congress began to consider in the early 1960s the question of making the metric system mandatory for all Americans.

Congressional interest in metrification (also known by the names "metrication," "going metric" and "metric conversion") was piqued once again when the International System of Units (SI) was adopted in 1960 by the 11th General Conference on Weights and Measures, a diplomatic organization established in 1875 by the Meter Convention.[104] Chauvinistic hesitation to discard the "American" half-inch wrench in favor of a "foreign" twelve-millimeter model warred with the fear that American businessmen would be at a disadvantage in selling their products to "metric" countries abroad. And no doubt about it, America was becoming isolated in the use of "customary" units of measure (inches, miles, gallons, bushels, ounces and degrees Fahrenheit). All other industrial nations either had adopted the metric system (now consisting of seven base units—meter, kilogram, second, ampere, kelvin, mole, and candela—and an unending list of units derived from the base units) or had set a timetable for adoption. Only the United States and a baker's dozen of third-world countries retained non-decimal measurement systems.

The Problem

Congress was in a difficult position. America's mechanics and engineers had enormous inventories of inch-based tools and btu-based industrial practices; America's home-makers had a similar trove of teaspoons, Fahrenheit thermometers, and ounce-and-pint measures. America's homes, offices and factories were full of people who did not want to hear that their lifelong measurement practices were obsolete and that they needed to begin again in measurement kindergarten. Yet the message conveyed by the trend in international trade was clear: Europe and Asia wanted metric-based products and metric-based commercial discourse. What to do?

Claiborne Pell of Rhode Island led a discussion on this topic in the U.S. Senate for several years. George P. Miller of California expended similar effort in the House of Representatives.

Allen Astin, Director of NBS, called to testify during the Congressional deliberations, declined to advocate adoption of the metric system for the United States or to lobby against it. The Bureau, he testified, could best serve the debate by providing objective factual information on the system itself and its advantages and disadvantages.[105]

[102] Webster's II New Riverside University Dictionary, 1984.

[103] MFP, p. 532.

[104] Comptes Rendus des Seances de la Onzieme Conference Generale des Poids et Mesures, Paris 14-20 Octobre, 1960, pp. 65-88.

[105] Letter from AVA to John M. Cabot, Ambassador to Poland, January 27, 1964; Records Holding, RG167; Dir Off, Box 381; Chrono 1/64-4/64, Drawer 10.

In April 1975, Deputy Director Ernest Ambler (left) testified on metric conversion in the United States before the Subcommittee on Science, Research and Technology of the House Committee on Science and Technology. Commerce Department Counsel Robert Ellert joined Ambler at the witness table.

Seeing the rising interest in metrication in the Congress, however, Astin decided to be prepared for eventual NBS involvement. On June 9, 1965, he assigned Robert D. Huntoon, then Director of the Institute for Basic Standards, to develop a Bureau position and a plan for action.[106] He detailed Alvin G. McNish, Clarence N. Coates, Robert L. Stern and Malcolm W. Jensen to assist Huntoon in this task, and directed James E. Skillington, Chief of the Budget and Management Division, to help prepare budget estimates for any Bureau work that the task group might recommend.

The Solution

By 1968, a useful course of action for Congress—time-worn but effective—had become clear: it would commission a study. This one would be accomplished by NBS to determine the consequences of the various possible Congressional metric-system actions.

By June of 1968, Alvin McNish held the position of Assistant to the Director, NBS, for Metric Study. Astin assigned McNish and two assistants to refine the action plan for NBS should the pending Congressional efforts come to fruition.[107]

[106] Memo, AVA to R. D. Huntoon, June 9, 1965. NIST Records Holding RG 167; Director's Office; Box 381; Folder 5/1/65–7/30/65; Drawer 10.

[107] McNish, known internationally for his work on metrology and measurement science, retired in July 1970 after 34 years' service to NBS. Among his awards were the Presidential Certificate of Merit (1948), the Department of Commerce Gold Medal (1960), and recognition by the U.S. Office of Scientific Research and the U.S. Bureau of Ordnance. See "Alvin G. McNish Retires," *NBS Standard,* Vol XV, No. 10, October 1970, p. 7.

On the 9th of August 1968, the Congress passed the *Metric System Study Act, (82 Stat. 693; Public Law 90-472, 9 August 1968).* The one-page text contained a mountain of work for the Bureau. It authorized " . . . the Secretary of Commerce to make a study to determine advantages and disadvantages of increased use of the metric system in the United States." Calling for a program of "investigation, research, and survey," the act directed the Secretary to accomplish a number of tasks:

- Evaluate the advantages and disadvantages of the metric system for international trade, for the military, and for other international activities, and also within the United States.
- Compare the efficacy of the present system with the metric system for educational, engineering, manufacturing, commercial, public, and scientific uses.
- Assess the difficulty of switching to metric in the United States.
- Bring into the process representatives of U.S. industry, science, engineering, labor and government at all levels, as well as foreign governments and international organizations.

The act further required the Secretary to assess the consequences of metrification on the design of various U.S. products, to determine the extent to which the metric system already was used in America, and to recommend means to minimize costs and problems involved in switching to the metric system.

The act set a date of 9 August 1971 for a final report to the Congress, along with " . . . such recommendations as [the Secretary of Commerce] considers to be appropriate and in the best interests of the United States."

Up to $500,000 could be spent during the first year of the study; more Congressional funds might be forthcoming to support the second and third years of the study, depending on the disposition of Congress when the subsequent appropriations would be considered. The projected cost to NBS of participation in the Metric Study was estimated to be $2.5 M. Ultimately, however, expenditures at NBS for the Metric Study totaled just over $1.2 M.[108]

The "Metric" Team

Doing an honest job of satisfying the exhaustive requirements of the Metric System Study Act within the stated 3-year life of the project was clearly going to demand lots of work. Commerce Secretary Cyrus R. Smith was happy to delegate the task to the National Bureau of Standards, where this strange metric language was spoken daily and with great fluency. The Bureau, with its many connections to technical America, would provide a good focus for the project.

NBS took a full year to plan the Metric Study. Then, in just one year, the Metric team obtained the requested information, utilizing a multitude of conferences and meetings devoted to the different constituencies that had to be consulted. The final year was given to preparing and consolidating the lengthy set of reports that Congress wanted.

[108] See House Hearings FY71, pp. 1022-1023; and House Hearings FY72, p. 1146; House Hearings FY73, p. 1118.

On the day of the act's passage, Allen Astin had only a year to serve as Director. He could "get the ball rolling" before he retired.

Secretary Smith did his part by appointing a Metric System Study Panel of 45 members from across the spectrum of U.S. measurement activities. The panel was chaired by Louis F. Polk, a Director of the Bendix Corporation. Francis L. LaQue, former Vice-President of International Nickel Company, served as Vice-Chair, and Leonard S. Hardland of the NBS Office of Invention and Innovation was the panel Executive Secretary.

Astin's small advance-planning group was succeeded by an Advisory Task Force comprised of Walter E. Cushen, Daniel De Simone, Alan J. Goldman, Robert Huntoon, and Howard E. Morgan. Its report was delivered to Astin on March 21, 1969.[109]

New Director Lewis Branscomb substantially augmented the NBS Metric Study Group late in 1969. Soon the group included many experienced Bureau hands detailed from other projects. It is illuminating to see whence came the Bureau participants in the various Metric Study sections. The previous work assignment for each person is included parenthetically:

- Director of the Study:

Daniel V. De Simone (Chief of the Office of Invention and Innovation).

- Consultants:

Robert D. Huntoon (Assistant to the Director of the Bureau).

With his NBS colleagues Robert D. Stiehler (Product Evaluation Division), A. Allan Bates (Chief, Office of Engineering Standards Liaison) and Myron G. Domsitz (Chief, Electronic Instrumentation Division), Huntoon prepared an interim report on developments in international standards.

Alvin G. McNish (Chief of the Metrology Division).

Chester H. Page (Chief of the Electricity Division).

- Special Assistants:

George A. W. Boehm.

Florence M. Essers (Research Assistant to De Simone).

- Program Managers and their staffs:

Louis E. Barbrow (Consultant in photometry, Metrology Division) and Alvin McNish were co-leaders of the Manufacturing Industry section. Other Bureau staff assisting Barbrow and McNish included George C. Lovell (Office of Invention and Innovation), Robert R. Rohrs (Technical Analysis Division), Carolyn L. Flood (Office of Invention and Innovation), Alice B. Margeson (Office of the Director, NBS) and Judy M. Melvin (Electricity Division).

Roy E. Clark was leader of the section on Federal Civilian Agencies. Other Bureau staff assigned to this section included John M. Tascher (Chief of the Engineering Education Program, Office of Invention and Innovation), Joseph D. Crumlish (Chief of the Innovation Studies Program, Office of Invention and Innovation), Joseph P. Alexa (Office of Invention and Innovation), Jeanine Murphy, and Sandra Wean.

[109] AVA to Metric Advisory Task Force, April 16, 1969. NIST Records Holding; RG 167; Director's Office; Box 388; Folder March-April 1969; Drawer 10.

June R. Cornog (Behavioral Sciences Section, Technical Analysis Division) directed Elaine D. Bunten (Technical Analysis Division) in carrying out the Non-manufacturing Business section of the Study. Other Bureau staff assisting them included Howard E. Morgan (Technical Analysis Division), William L. O'Neal (Analytical Chemistry Division), Lorraine S. Freeman (Supply Division) and Diane Beall.

Stephen L. Hatos (Office of Weights and Measures) carried out the Commercial Weights and Measures section of the Study.

Jeffrey V. Odom (Office of the Director, NBS) coordinated a series of conferences on the Metric Study. His NBS assistants included Bruce D. Rothrock, who headed the Labor and Consumers section of the Study; Robert W. Carson; Roy E. Clark: Joseph D. Crumlish (Chief of the Innovation Studies Program, Office of Invention and Innovation); Linda J. Luhn (Office of the Director, NBS); Jean M. Simon (Personnel Division); Debora L. Gilbert (Personnel Division); and Evelyn B. Tallerico.

Bruce D. Rothrock (Office of the Director, NBS; formerly in Length Section, Metrology Division) coordinated the section on Consumers. He was assisted by NBS employees Jeffrey V. Odom (Office of the Director, NBS); Robert W. Carson; Linda J. Luhn (Office of the Director, NBS); Jean M. Simon (Personnel Division); Debora L. Gilbert (Personnel Division); and Evelyn B. Tallerico.

Robert D. Stiehler (Consultant to the Chief, Product Evaluation Division) was responsible for the section on Engineering Standards. He was assisted by Bureau staff members Gustave Shapiro (Assistant to the Chief, Electronic Technology Division); Robert J. Klein (Electronic Technology Division); Harry Stoub; Arthur G. Strang (Chief of the Engineering Metrology Section, Metrology Division); and Theodore R. Young (Manager, Measurement Services Program, Metrology Division).

Charles F. Treat (Office of the Director, NBS) prepared a history of the metric system in America.

For many of the Bureau participants in the Metric Study, the assignment represented a full-time commitment for its duration. Others simply provided part-time advice or guidance on certain aspects of the study.

Not all the Study groups were composed of NBS staff members. A study on metrication in the Department of Defense was prepared by Leighton S. Lomas of the DoD and staffed from that department. Another study, on Metric Education, was prepared by the Education Development Center of Newton, Massachusetts; Berol L. Robinson of the EDC organization led the effort, assisted by professional educators and by Bruce Rothrock of NBS. A third, on Consumers, was prepared by the Survey Research Center of the University of Michigan under the direction of Professor George Katona. A fourth, on International Trade, was conducted by the Commerce Department Bureau of Domestic Commerce under the supervision of Thomas E. Murphy.

The Program

Details of the Metric Study plan, worked out by the original NBS group in concert with the Advisory Panel assembled by Commerce Secretary Smith, were completed in December 1969. It is interesting to note that, by then, the Secretary of Commerce was Maurice H. Stans and the new Director of NBS was Lewis Branscomb, both choices of new President Nixon. Despite this change in personnel at the top, the Metric Study continued on schedule.

The plan called for the Study to be carried out with the aid of questionnaires, personal interviews, and organized hearings in order to give every sector of U.S. society an opportunity to provide its information and to express its views on the questions raised by the Act. Some seven sets of hearings—called National Metric Study Conferences—and eleven special investigations were undertaken. Then the whole study project was digested and a massive report was submitted to Congress.

To properly carry out the wishes of Congress, each study group was required to probe deeply into its assigned area of the U.S.—or indeed the international—technical establishment. The various interest groups spanned the whole technical fabric of America:

- Labor.
- Consumers.
- Education.
- Construction.
- Engineering.
- Consumer Products Industry.
- Small Business.
- State & Local Government.
- Natural Resources.
- Health.
- Transportation.
- Other smaller groups.

Because of the tight schedule stipulated in the Act by Congress, barely one year was available in which the mass of factual data and opinion could be obtained. The third year was reserved for the actual preparation of the report and the recommendations of the Secretary of Commerce.

More than 700 organizations—labor groups, trade associations, professional societies, educational institutions, and consumer groups—were invited to participate in widely publicized hearings. The hearings occupied 20 full days during 1970; all but one were held in Washington, DC. Among some 200 individual presentations was one by Gordon Bowen, Director of the British Metrication Board, on the experiences in the United Kingdom with respect to "going metric."

Supplementing the hearings were special investigations in eleven areas. These investigations were conducted primarily through detailed questionnaires designed to elicit information about the use and attitudes of the queried organization, as well as more problematic estimates of the costs, benefits and disadvantages, and timing associated with the increased use of metric measures. Thousands of questionnaires were mailed to as many carefully selected representatives of the eleven sectors; follow-up questionnaires and personal contacts extended and verified the written results. Approximate numbers of responses are given in parentheses for each sector in which questionnaires were used:

- Manufacturing Industry (more than 3500 questionnaires).
- Non-manufacturing Businesses (more than 2000 questionnaires).
- Education (primarily based upon the results of a two-day conference held at NBS, augmented by detailed reports issued by the National Education Association and by the National Science Teachers Association).
- Consumers (about 1400 questionnaires).
- International Trade (over 400 questionnaires).
- Engineering Standards (based upon a comparison of International Standards Organization and International Electrotechnical Commission recommendations with the national standards of several countries, including the United States).
- International Standards.
- Department of Defense.
- Federal Civilian Agencies.
- Commercial Weights and Measures.
- History of the Metric System controversy in the United States.

As the various groups assessed the results of the thousands of individual and group queries undertaken during the Metric Study Act project, they found that most American manufacturers and nearly all scientists strongly favored a phased introduction of the metric system for America; these groups were using the system more and more each year. On the other hand, many small businesses and individuals expressed the fear that the changeover would be expensive for them. During 1971 these findings were documented in an exhaustive series of reports that were published as *NBS Special Publications.* It is instructive to briefly note the contents of these reports.

The first of the reports preceded the others by some months. It was a treatment of the impact of international standards on international trade and technology transfer.[110] The report was prepared by Huntoon and his NBS colleagues Stiehler, Bates and Domsitz with the collaboration of Allen Astin—by then the Director-Emeritus of NBS; Richard O. Simpson, Deputy Assistant Secretary of Commerce for Product Standards;

[110] "U.S. Metric Study Report: International Standards" U.S. Metric Study, Daniel V. De Simone, Director [Editor's Note: Although the title page does not so state, the text of the report was written by Robert D. Huntoon, Robert D. Stiehler, A. Allan Bates, and Myron G. Domsitz with the assistance of Richard O. Simpson, Allen V. Astin, and Donald L. Peyton], *NBS Special Publication 345-1,* December 1970, 145 pp.

and Donald L. Peyton, Managing Director of the American National Standards Institute. The report contained the conclusion that metric standards played an important, but not dominating, role in international trade. The process of product certification, they felt, would ultimately determine the significance of metrification for trade. Given the designation *Special Publication 345-1,* this report was issued in December 1970.

The views of the civilian agencies of the Federal government on metrification were described in a report written by Roy E. Clark, John M. Tascher, Joseph D. Crumlish, Joseph P. Alexa, Jeanine Murphy, and Sandra Wean.[111] The report highlighted the effects of metrification on some 15 areas of national responsibility of the civilian agencies, gleaned from questionnaires and/or from discussion with 55 such agencies. Many of the agencies queried already used the metric system to some extent. The general conclusion was that the metric system was the measurement scheme of the future, and that planned conversion to metric would be a preferred course of action over the policy of ignoring the measurement units problem altogether.

Stephen L. Hatos of the Office of Weights and Measures prepared a report on the effects of metrification on commercial weights and measures activities.[112] Hatos' study group received 15 detailed responses from manufacturers of devices used in weights and measures activities. Ten of those favored metrification, and they suggested that a mandatory program would probably be necessary in order to accomplish the task. Of 63 jurisdictions responding to the group's queries, forty favored increased use of metric measures. The National Conference on Weights and Measures, the professional organization that represented both sectors, was heavily involved in the study. The *Commercial Weights and Measures Report, NBS Special Publication 345-3,* recorded three recommendations: 1) If the United States should "go metric," a coordinated program, with target dates, should be established through the National Conference on Weights and Measures; 2) in the event of metric conversion, states should be encouraged to require metric packaging for various commodities; and 3) to achieve uniformity in packaging and labeling, Congress should first require dual labeling—metric and customary—and later require metric labeling with customary units optional. It was noted that some items—meats and cheeses, for example—are ordinarily packaged in random quantities, and that this practice should continue to be allowed.

The manufacturing sector was discussed in a report prepared by Louis Barbrow and Alvin McNish under the direction of Morris H. Hansen of Westat Research, Inc.[113] Hansen, a former Associate Director of the U.S. Bureau of the Census, was considered an expert on the use of statistical surveys. In a prefatory *"Critique on Metrication Cost Estimates in Manufacturing,"* McNish stated that the results of the group's cost

[111] "U.S. Metric Study Interim Report: Federal Government: Civilian Agencies," U.S. Metric Study, Daniel V. De Simone, Director, *NBS Special Publication 345-2,* July 1971, 317 pp.

[112] "U.S. Metric Study Interim Report: Commercial Weights and Measures," U.S. Metric Study, Daniel V. De Simone Director, *NBS Special Publication 345-3,* July 1971, 102 pp.

[113] "U.S. Metric Study Interim Report: The Manufacturing Industry," U.S. Metric Study, Daniel V. De Simone, Director, *NBS Special Publication 345-4,* July 1971, 141 pp.

In 1969, NBS Director Branscomb appointed Louis E. Barbrow (pictured here) and Alvin G. McNish to co-manage an especially critical component of the Metric Study which focused on the manufacturing sector.

questionnaires presented a "phantasmagoria" to the analysts. Estimated metrification costs ranged over a factor of 900, even excluding the pharmaceutical industry, which already made considerable use of metric measures. The report summary included the statement that larger manufacturers tended to use metric measures more intensively and to prefer it, whereas smaller ones were less likely to use the metric system and less likely to prefer it. Significantly, most manufacturers both large and small (70 % of all respondents) agreed with the statement that increased use of the metric system would be in the best interest of the United States.

The Non-manufacturing Business study was carried out by Elaine Bunten under the direction of June R. Cornog.[114] Information was obtained by telephone interviews with 2563 business firms chosen from Agriculture, Forestry, Fisheries, Mining, Construction, Transportation, Communication, Utilities, Wholesale and Retail Trade, Finance, Insurance, Real Estate, and Business and Personal Services. This group represented about 65 % of all U.S. employment. Remarkably, 90 % of the interviews

[114] "U.S. Metric Study Interim Report: Non-manufacturing Businesses," U.S. Metric Study, Daniel V. De Simone, Director, *NBS Special Publication 345-5*, by June R. Cornog and Elaine D. Bunten, July 1971, 184 pp.

yielded usable results. The interviews probed a number of areas: knowledge of the metric system; attitudes towards it; company "products"; company equipment and procedures; and hypothetical future use of metric measures and the problems and benefits thereof. About 75 % of the respondents had an "adequate" knowledge of the metric system. While a majority of respondents foresaw no particular difficulty in "going metric," about one in four expressed antipathy towards metric measure for their firm. Most firms saw employee retraining as the primary obstacle. Over 60 % of those queried expressed the view that increased use of metric measure was in the best interest of the U.S. and favored a mandatory (Congressionally legislated) change to metric measures.

The report on Education was prepared by the Education Development Center of Newton, Massachusetts under the direction of Berol L. Robinson.[115] In his Foreword, De Simone stated: "No other sector is so nearly unanimous in its endorsement of the metric system as is education." In fact, the text—written by a large group of distinguished educators—contained more discussion of the lack of effective instruction on measurement skills in the Nation's schools than it did on the desirability or problems of "going metric." The last two chapters of the Education report were entitled "A Program for Metric Conversion in Education" and "Education and a THINK METRIC Campaign."

Professor George Katona of the Survey Research Center at the University of Michigan was responsible for the preparation of the report on attitudes of the American consumer.[116] Katona and his staff addressed the questions: How much does the American consumer know about the metric system? What are their attitudes towards it? What are their opinions about metrification? Do they have preferences as to the methods that could be used to improve public knowledge of the system?

Many years of consumer research on a variety of topics had given Katona's group an advantage over other Study groups: he could simply append a questionnaire on metrification to a quarterly survey intended for about 1400 representative U.S. families. Knowledge of and experience with the system were probed, along with attitudes towards metrification for themselves and for the United States. He found that few consumers were familiar with metric measure and that most were loath to learn, although about half guessed that the metric system would be easier for students to master than the customary units. Only those respondents who were familiar with metric measures favored American conversion to the system.

A report prepared in the Bureau of Domestic Commerce of the Department of Commerce treated the impact of metrification on America's foreign trade. The report was drafted by Gerald F. Gordon under the supervision of Thomas E. Murphy.[117] Of the billions of dollars' worth of U.S. goods for export, only about 1 % were designed

[115] "U.S. Metric Study Interim Report: Education," U.S. Metric Study, Daniel V. De Simone, Director, *NBS Special Publication 345-6*, July 1971, 201 pp.

[116] "U.S. Metric Study Interim Report: The Consumer," U.S. Metric Study, Daniel V. De Simone, Director, *NBS Special Publication 345-7*, July 1971, 139 pp.

[117] "U.S. Metric Study Interim Report: International Trade," U.S. Metric Study, Daniel V. De Simone, Director, *NBS Special Publication 345-8*, July 1971, 173 pp.

and manufactured using metric measures, according to the survey of approximately 510 firms involved in international trade. On the other hand, about 19 % of imports were designed and built using customary units. The impact of the type of units used to make the goods was thought by the export/import firms to have little bearing on international trade in comparison with such factors as reputation of the trading firm for reliability, the level of technology built into the products, and their quality.

The report on metrification in the U.S. Defense Department was prepared under the leadership of the Air Force. Leighton Lomas, Chairman of the Department of Defense Metric Study, acknowledged the assistance of Vincent S. Roddy, his predecessor, and of two groups of DoD personnel in preparing the study: the DoD Steering Committee, composed of R. F. Dunbar, Jack L. Vogt, Winton E. Allen, Joseph L. Krieger, and James Brownell; and staff members H. J. Dickinson, H. G. Tinsley, A. P. Babbitt, and F. L. Ellison. [118] More than 125 groups from the Joint Chiefs of Staff, the Army, Navy, Air Force, Defense Supply Agency, National Security Agency, and other DoD agencies helped prepare the study under the supervision of the DoD Steering Committee. The report steadfastly refused to recommend either for or against metrification, but stated that the DoD could go metric only at considerable expense ($18 billion) and over a period of time. The DoD recommended that any program of metrification be a national one with a definite schedule, and that certain customary units with wide international acceptance be retained. Detailed discussions were presented of the advantages, disadvantages, and special problems—mostly connected with supply—during all phases of a metrification program.

An especially interesting report was written by Charles F. Treat of the NBS Director's Office. [119] Entitled "A History of the Metric System Controversy in the United States," the report provided a well-written account of the origins and development of both the customary and the metric system of measurement. The "battle of the standards" that flared periodically within the debates of Congress and through dedicated organizations—those favoring metrification for the United States as well as those opposed—was well documented; an extensive bibliography on the metric system and the controversy surrounding it was included. Treat closed with a synopsis of the arguments—some of them a century old—for and against the adoption of the metric system for America. We paraphrase the arguments here, since they retain their validity even today:

- The arguments "for":

1. Metric is a scientifically based decimal system.
2. Virtually the entire world excepting the United States uses metric measures.
3. Metrification is practical for the United States.

[118] "U.S. Metric Study Interim Report: Department of Defense," U.S. Metric Study, Daniel V. De Simone, Director, *NBS Special Publication 345-9,* June 1971, 118 pp.

[119] "U.S. Metric Study Interim Report: A History of the Metric System Controversy in the United States," U.S. Metric Study, Daniel V. De Simone, Director, Charles F. Treat, Historian, *NBS Special Publication 345-10,* August 1971, 298 pp.

4. Metrification for the United States is inevitable; planning for it is only sensible.
5. The U.S. Constitution gives the Congress the power—never used—of fixing the standards of weights and measures.

- The arguments "against":

1. There is no particular need for America to change from customary units.
2. The disadvantages of metrification outweigh the advantages.
3. Few countries use the metric system exclusively.
4. Metrification would be impractical and costly.
5. Compulsory metrification in the United States would be repugnant to American ideals.

A Metric Study task force on Engineering Standards, headed by Robert Stiehler and including Gustave Shapiro, Robert Klein, Harry Stoub, Arthur Strang and Theodore Young, prepared its report as *NBS Special Publication 345-11.*[120] The authors drew attention to the importance of the measurement system for engineering standards to be used in manufacturing products whose sizes were based upon simple progressions of units, such as is the case for screw manufacture. They also pointed out the irrelevance of the measurement system for items—such as the manufacture of electrical plugs—in which the problem is simply to replicate a pattern. They also noted that the great multitude of engineering standards in existence prompted them to limit the scope of their study to nine areas; steel and non-ferrous metals, plastics, rubber, pipe and tubing, anti-friction bearings, threaded fasteners, electrical and electronic components and equipment, and building construction and materials. In surveying the standards in these areas—less than 1 % of the 60,000 or more engineering standards issued as national standards by private and government organizations in the United States—they found that engineering standards could be harmonized internationally without the United States changing to the metric system. On the other hand, full standardization of manufacture would require most countries to modify their engineering practices. They foresaw the eventual use of metric units in all international standards.

As noted earlier, Jeffrey V. Odom coordinated a series of seven National Metric Study Conferences. A report was prepared which summarized the views given by the various participating groups.[121] Of the 700-odd groups invited to participate, about 230—representing 674,000 firms and more than 19 million individuals—did so. Of the groups expressing a preference for or against metrification, a strong majority found metrification to be inevitable and/or desirable. Most preferred a program of metrification on a national, coordinated basis over a 5-15-year span of time. Many industrial groups testified that the costs would be heaviest in inventory, new tools, re-training, and re-design. Consumers mostly agreed that metric conversion would be beneficial in the long run because of the simpler nature of the metric system, but that a long-term educational program would be required to make the transition successful.

[120] "U.S. Metric Study Interim Report: Engineering Standards," U.S. Metric Study, Daniel V. De Simone, Director, *NBS Special Publication 345-11*, July 1971, 250 pp.

[121] "U.S. Metric Study Interim Report: Testimony of Nationally Representative Groups," U.S. Metric Study, Daniel V. De Simone, Director, *NBS Special Publication 345-12*, July 1971, 165 pp.

Results of the Bureau's Metric Study

The viewpoint on metrification of the majority of participating individuals—both from within and outside NBS—came clear in the title of the Metric Study concluding report: "*A Metric America: A decision whose time has come.*"[122] Written by Metric Study Director De Simone, the summary contained a review of the metric debate, the implications of metrification for America, and a synopsis of the experience of Japan and the United Kingdom as they entered the metric world. De Simone stated the majority view forcefully:

> The U.S. Metric Study concludes that eventually the United States will join the rest of the world in the use of the metric system as the predominant common language of measurement. Rather than drifting to metric with no national plan to help the sectors of our society and guide our relationships abroad, a carefully planned transition in which all sectors participate voluntarily is preferable. The change will not come quickly, nor will it be without difficulty; but Americans working cooperatively can resolve this question once and for all.

In a one-page transmittal preface, Secretary Maurice H. Stans similarly urged the Congress to act. As requested by Congress, he offered his own recommendations. There were nine:

- That the United States adopt the metric system.
- That this step be accomplished through a coordinated national program.
- That Congress assign responsibility for guidance in metrification to a central body.
- That all sectors of the United States work out guidelines and timetables for metrification.
- That metric education of students be given high priority.
- That Congress immediately take steps to foster participation in international standards activities.
- That costs of metrification should "lie where they fall," to minimize costs of the program.
- That Congress should set a ten-year target date for effective completion of the metrification program.
- That there be a firm government commitment to this goal.

Because of the enthusiasm for metrification displayed by so many American organizations during the Metric Study, the Bureau staff was convinced that Congress would act quickly on Secretary Stans' recommendations. *The NBS Technical News Bulletin*

[122] "A Metric America: A decision whose time has come," Daniel V. De Simone, Director, U.S. Metric Study, *NBS Special Publication 345*, July 1971, 170 pp.

of September 1971 featured an eight-page summary of the reports in the *Special Publication 345* series. [123] A similarly extensive article appeared in the employee bulletin The NBS Standard. [124] Director Branscomb weighed in with supportive statements and articles. [125] Curiously, Secretary Stans' report was not buttressed by publicity from the White House—perhaps because the study revealed vocal, though minority, opposition to metrification among Americans who expressed themselves on the topic.

Controversy and Inaction

The ball was now clearly in Congress' court. It had to digest the thousands of pages of testimony contained in the reports and to make its own evaluation of the mood of its constituents with respect to metrification. Quickly the legislators learned that, as usual, those citizens who opposed the change were as vocal as those who favored it—sometimes more so.

To the surprise of many at NBS, some four years would pass before anything resembling a Congressional consensus would emerge. In the meantime, the Bureau opened a Metric Information Office to answer questions and to provide metric instruction to all comers. The office functioned for several years, distributing some 100,000 metric conversion kits by the end of 1975 and answering more than 20,000 letter requests for information during 1975 alone.

Despite all the evidence of public interest in metrification, the larger portion of the body politic held decidedly mixed views on the topic. Indeed, antipathy towards metric highway signs and metric weather reports was widespread. [126] And the efforts of labor and small businesses were mostly confined to assuring that any conversion costs for their constituents would be compensated by any metric legislation. Because of the divided opinion among its constituents, the 94th Congress passed a Metric Conversion Act of 1975 (PL 94-168) that contained encouraging words, but no substantial progress towards a metric America.

Following their fast-paced efforts, the Bureau members of the Metric Study team mostly returned to projects left undone. De Simone, the Study Director, could be found in January 1972 back at the Office of Invention and Innovation; the Metric Study section that had formerly been part of his office was disbanded.

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[123] "A Metric America," *NBS Technical News Bulletin*, September 1971, pp. 222-230.

[124] "Secretary Stans recommends metric conversion over 10-year period", *NBS Standard* Vol XVI, No. 8, August 1971, pp. 1, 12-15.

[125] One such, addressed to educators, a key sector in the anticipated program, was presented at the 1971 convention of the National Science Teachers Association. It was reprinted later as a handout: "The U.S. Metric Study," Lewis M. Branscomb, *The Science Teacher*, Vol. **38**, No. 8, November 1971, 5 pp.

[126] A well-written survey of post-metric-study responses was published by Edith F. Cooper, "The Metric Conversion Act of 1975; Legislative History and Implementation 1970-1980," *Report 10-203 SPR*, Congressional Research Service, Library of Congress, October 24, 1980.

As part of its continued effort to promote the use of the metric system in the United States, the National Bureau of Standards placed an interactive "Think Metric" exhibit in the lobby of its Administration Building in 1975. Groups of school children from Gaithersburg, Maryland, attended the exhibit.

Metrification—An Epilogue

Sent forth by Congress to gather data on the usefulness of the metric system to America and on the willingness of U.S. citizens to accept measurement units unfamiliar to them, the Bureau labored fiercely and delivered the requested information. The many conferences, interviews, and statements showed the rationality and value of the system, as well as the vocal feelings that existed on both sides of the question of the adoption of the metric system as a national policy. Little remained to be said. Daniel De Simone was honored as one of 10 top Federal employees by the National Civil Service League later during 1972. The National Conference of Standards Laboratories presented him with its Career Service Award. Soon, he was asked to join the office of the President's Science Advisor; he left NBS to do so. [127]

[127] *NBS Technical News Bulletin* May 1972, p. 116.

During the 1975 NBS "Think Metric" program, a student learned how much he weighed in kilograms.

Uncontrolled Fire, a Continuing Problem

As Lewis Branscomb assumed command of NBS, he, like his predecessors, was compelled to address the problem of loss of American life and property by the ravages of fire. Accidental fires in homes, offices, hotels, stores, factories, forests, and grasslands still claimed a disproportionate share of lives and goods. Fire had become a weapon of choice for rioters—the Watts area of Los Angeles had burned in 1965 and, two years later, rioters burned parts of Newark, New Jersey, and Detroit, Michigan, then attacked firemen who responded to the emergency calls. A Department of Labor occupational survey that year found fire-fighting to be the most hazardous of U.S. occupations. And one of the most visible fire tragedies ever seen had taken place on January 27, 1967, when a flash fire aboard the spacecraft Apollo killed astronauts Virgil I. Grissom, Edward H. White, II, and Roger B. Chaffee. The men were participating in routine testing prior to their anticipated first Apollo mission. Their deaths shocked the nation.

President Johnson addressed the growing menace of fire by requesting in 1967 that Congress consider fire safety legislation; bicameral responses took the form of extending the coverage of the *Flammable Fabrics Act* and hearings on a Fire Research and Safety Act. Both pieces of legislation assigned responsibilities to the National Bureau of Standards.

Flammable Fabrics, a Perennial Issue

NBS showed concern for flammable fabrics almost from its founding, no doubt in direct response to publicized fire disasters. [128] Fabric industry representatives, as might be expected, were of two minds on the topic: on the one hand, the magic of chemistry could produce cloth with wonderful properties such as colorfastness, strength, and warmth—though with an alarming tendency to flare at the touch of a match. On the other hand, it was clearly in their long-term interest to reduce the flammability of cloth. After World War II, the growing importation of foreign textiles without regard to flammability tipped the scales towards development of standards for burn-resistance.

Congress passed a Flammable Fabrics Act in 1953, in response to a growing number of tragic deaths of children and adults from burns incurred while wearing cowboy outfits, nightwear, scarves, and other items of clothing that easily caught fire. [129] This act gave particular responsibilities to NBS, including the development of a standard flammability test: any fabric that burned faster than a specified rate in the test could not be marketed in interstate commerce.

The 1953 act provided needed publicity to convince the clothing industry that flammability must be taken seriously. As such, it was a good start on the problem. But the one test method prescribed in the act was flawed. Further action was necessary if non-clothing types of fabrics were to be tested for fire safety.

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[128] G. M. Kline, "Fire-resistant doped fabric for aircraft," *J. Res. NBS* **14**, 575 (1935). See also Anonymous, "Flameproofing of textiles," *NBS Letter Circular LC467,* May 5, 1936, 9 pp. See also Marjorie W. Sandholzer, "Flameproofing of textiles," *NBS Circular C455,* August, 1946. The author notes loss of life in a Boston nightclub fire and a Hartford circus tent fire as reasons to pursue her study.

[129] Daniel Gross, "Fire research at NBS; the first 75 years," Invited lecture at the *Third International Symposium; Fire Safety Science,* pp. 119-133, 1989.

In the early 1970s, the fire research staff of the National Bureau of Standards developed test methods for the evaluation of flammability in children's sleepwear.

Flammable Fabrics Act, Amendment of 1967, (Public Law 90-189, 81 Stat. 568-574, December 1967)

In 1967, Congress extended the provisions of the 1953 Flammable Fabrics Act, directing the Secretary of Commerce, among other duties, to:

- Conduct research into the flammability of products, fabrics, and materials.
- Conduct feasibility studies on reduction of flammability of products, fabrics, and materials.
- Develop flammability test methods and testing devices.
- Offer appropriate training in the use of flammability test methods and testing devices.

Secretary Smith, as expected,[130] delegated these responsibilities to NBS. [131] However, Congressional funding for the program was not forthcoming until Fiscal 1969 (during October 1968), delaying implementation of the work for a full year. Even then, the funds amounted only to $304,000, barely enough to begin the new program. [132]

By the end of 1969, NBS had 17 staff members working full-time on the flammable-fabrics problems and several others working part-time. Three contracts had been let to outside research organizations to perform complementary tasks. The Bureau program was established in the Product Evaluation Division. James V. Ryan was named chief of the Flammable Fabrics Section, but soon he left NBS. Ryan was succeeded on a temporary basis by Sanford B. Newman. In 1969, new NBS Director Branscomb created within the Institute for Applied Technology an Office of Flammable Fabrics, temporarily headed by Elio Passaglia. In 1970, Joseph E. Clark was appointed permanent head of that Office.

Initial flammable-fabrics projects at NBS included determination of the products of fabric combustion, calorimetry of fabric combustion, laboratory burning of fabrics, analysis of burn cases, study of flame retardants, instrumented burning of full-scale household furnishings, and study of heat transfer from burning fabrics. Outside contractors studied the burning of carpets and rugs, and the preparation of sampling questionnaires. A symposium on the measurement of flammability was held in Washington, DC on June 5-6, 1969; more than 600 people attended the meeting to learn details of the new program. Further publicity came from notices placed in the *Federal Register.* [133]

During 1970, flammability standards were established for two types of carpets and rugs, and another was proposed for children's sleep-wear. Conflicting test methods and the uncertainty that was necessarily involved in developing sampling techniques complicated the NBS efforts. In the same year, testing was begun on mattresses and blankets, building on work accomplished during earlier years. [134]

Besides effort expended specifically on developing test methods to evaluate the flammability of carpets and rugs, children's sleep-wear, and blankets and mattresses, the Office of Flammable Fabrics sponsored a number of research projects. Some of

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[130] Allen Astin had held preparatory meetings with the Public Health Service. See Memo, AV Astin to Secretary, "Implementation of Amended Flammable Fabrics Act," May 27, 1968; RHA; Dir. Off. ; Box 386; Chron Folder May 1968.

[131] Department Organization Order 30-2A, October 1, 1968.

[132] AV Astin, "Chronology of Activities and Implementation of Revised Flammable Fabrics Act," February 8, 1969; RHA; Dir. Off. ; Box 388; Chron. Folder February 1969.

[133] Material from *NBS Technical Note 525*, "The Flammable Fabrics Program, 1968-1969," April 1970, 76 pp.

[134] Material from *NBS Technical Note 596*, "The Flammable Fabrics Program, 1970," September 1971, 56 pp.

these were accomplished within NBS and others were performed by outside groups under contract to the Bureau. Projects included:

- Identification of fabric combustion products.[135]
- Calorimetry—measurement of the heat produced by burning fabrics.
- Full-scale burn experiments, intended to identify all the hazards that accompanied fires involving carpets or upholstered furniture.
- Heat transfer between burning fabrics and the human body (performed at the Cornell University Aeronautical Laboratory).

NBS work on flammable fabrics decreased dramatically with passage of the *Consumer Product Safety Commission Act* (Public Law 92-573, October 27, 1972). Congress transferred to the CPSC all responsibility for continuing to implement the Flammable Fabrics Act. The Bureau role changed to providing technical support to CPSC within the context of its regular fire program.

Viewed in retrospect, participation in a program so near to regulatory responsibility was somewhat removed from the Bureau's most comfortable role. In fact, the responsibilities of the Secretary of Commerce were not entirely clear; the language of the *Flammable Fabrics Act* caused the Secretary to suggest that standards "might be needed," leaving any decision open to criticism. Nevertheless, the publicity attending the creation of the Act and the establishment of the CPSC—not to mention the standards that actually came to fruition—provided powerful incentives to the fabric industry to reduce the chances of death or economic loss from use of their products.

Fire Research and Safety Act of 1968 PL90-259

Responding to the call by President Johnson in 1967 for renewed legislative attack on the problem of uncontrolled fire, the 90th Congress amended the NBS Organic Act and authorized a new program in fire research through the *Fire Research and Safety Act of 1968.*

Governmental efforts to shore up the Nation's beleaguered fire-prevention and fire-fighting units had been mostly scattered and ineffectual up to that time. In 1961, a panel formed by the National Research Council of the National Academy of Sciences had recommended that a Federal center be created to focus on the problem of uncontrolled fire. NBS subsequently was designated a central agency for fire research, in recognition of its long-standing and effective work in the field, by the Federal Council for Science and Technology.

[135] One of these was undertaken by Robert J. McCarter, who developed an apparatus to be used in measuring the rate at which vapors were evolved during thermal degradation. See R. J. McCarter, "Apparatus for rate studies of vapor-producing reactions," *Proc. Symp. on Current Status on Thermal Analysis, NBS Gaithersburg, April 20-21, 1970*, SP 338, October 1970, pp. 137-150.

Seeking substantial funding to establish a new fire program in fiscal year 1964, the Bureau had found itself in the center of a controversy which never seemed to die out.[136]

The NBS fire plan was threefold: to begin an educational effort to better inform the American public about the dangers of fire and ways to reduce its likelihood; to assist in university-level training in fire studies; and to bolster and focus its own fire-research program. The International Association of Fire Chiefs was enthusiastic about the Bureau's plan, but the National Fire Protection Association, fire insurers, and other industrial representatives were critical. Predictably, no funds were forthcoming that year.

By 1965, accidental fires cost more than 12,000 lives each year in the United States, and more than $1.5 billion in property loss. Publicity surrounding the very visible fire losses in the period 1965-67 finally prompted both the President and the Congress to action.

PL90-259, enacted into law on March 3, 1968, assigned to the Secretary of Commerce in its Title I many features of the earlier NBS plan—"provide a national fire research and safety program, including the gathering of comprehensive fire data; a comprehensive fire research program; fire-safety education and training programs; and demonstrations of new approaches and improvements in fire prevention and control, and reduction of death, personal injury, and property damage." The secretary was directed to establish a fire center to focus these many activities.

Title II of the new act established a National Commission on Fire Prevention and Control. Its 20 members were to furnish in two years a report to Congress with recommendations on methods for the abatement of fire losses.

Given the extensive publicity surrounding the Nation's fire problems and the care with which assignments were given under its provisions, it is astounding that no funding was immediately provided by the Congress to implement the Fire Research and Safety Act of 1968. To understand its lack of support for its own creation, one must remember the dichotomy that is Congress; one committee authorizes work, another committee appropriates funds to implement it. The affected agency—in this case, the National Bureau of Standards—can be left holding the bag.

Lacking essential funding, Bureau management did what it could to satisfy the intent of the 1968 act; it created an Office of Fire Research and Safety in the Institute for Applied Technology, and assigned John A. Rockett as its head. This office was deliberately placed outside the Building Research Division, home to the Fire Research Section. The section was headed at that time by Irwin A. Benjamin. An example of useful work done during that time was a pilot study by James O. Bryson and Daniel Gross; they surveyed two large office buildings, evaluating live floor loads and fire loads. The results were utilized by the American Iron and Steel Institute as the basis for statistical sampling in other buildings.[137]

[136] Appropriation hearings, FY 1964, pp. 978-980.

[137] J. O. Bryson and D. Gross, "Techniques for the survey and evaluation of live floor loads and fire loads in modern office buildings," *Building Science Series*, No. 16, 312 pp. (1969).

With the collaboration of Alexander F. Robertson, Rockett planned the future of the NBS fire program, which now could include the investigation of accidental fires, the accumulation of fire statistics on a national basis, the development of fire-prevention and fire-control measures, and training and education activities to complement Benjamin's program.

And in 1972, the Bureau created an Office of Fire Programs under the leadership of G. King Walters; the Office of Flammable Fabrics, established in 1970, was placed under Walters as well. When Walters left NBS later that year, an NBS Fire Technology Division was created with Joseph E. Clark as Chief.

The 1968 act did not accomplish its major objectives, but it set a new and expanded course for the Bureau's fire program.

An Experiment in Technology Incentives Is Proposed

In August 1971 (see **The NBS Budget**, p. 182), President Richard Nixon responded to an increasingly sick U.S. economy by unveiling a *New Economic Policy*. Some of the provisions of the new policy—calling for reduced Federal expenditures and reduced Federal employment levels—were costly to the Bureau both in personnel and in funds. However, one feature that evolved early in 1972 from the plan was intended to establish at NBS a new multi-million-dollar project designed to boost the use of modern technology in American industry.

Because of the timing of the New Economic Policy, nearly a year would pass before Congressional funding would be requested for its execution.[138] By the time funds became available for the Bureau's part in the new proposal, NBS had a new director. We note here the birth of the new program because it foretells so clearly the movement towards direct NBS involvement in the problems of American industrial productivity, a movement that eventually would rename NBS.

The unusual circumstances under which the program originated were outlined earlier in this chapter. In essence, NBS was asked to explore various ways in which incentives could be placed before industry to encourage the use of newer technology, with the expected result that American industry would become more competitive in both domestic and international trade.[139] The name for the project, the *Experimental Technology Incentives Program* (ETIP), was selected more or less on the spur of the moment,[140] in order to meet a deadline for completion of a budget document early in 1972.

Although the ETIP name was chosen somewhat arbitrarily, the concept behind it rested solidly on work performed late in 1971 for the Office of the Assistant Secretary of Commerce for Science and Technology by a study team from the Bureau's Technical Analysis Division.

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[138] The first presentation on the president's experimental technology plan was made to the House Appropriations subcommittee by Lewis Branscomb at the Fiscal 1973 budget hearing, March 1972.

[139] Memo, L. Kushner to L. Branscomb, January 26, 1972; RHA; RG 167; Director's Office; Box 424; Folder January 1972.

[140] Lawrence Kushner, Oral History, June 7, 1988.

Under the guidance of John A. Birch, Advisor for International Affairs for the Department of Commerce, the NBS team reviewed efforts in five countries to stimulate invention and innovation and the development, transfer, and application of new technologies within their own industries. Behind the review was the hope that it could lead the U.S. government to policies that would reverse the decline in its balance of trade and enhance the development and export of high-technology products.

The study was directed by George C. Nichols, Senior Economist of NBS, who examined the principal technology enhancement programs, mechanisms, and incentives used in the civilian sector of Japan. The same pattern was followed by Suellen Halpin for Canada, Donald W. Corrigan for France, John C. Schleter for Germany, and Stephen S. Karp for the United Kingdom.

The Bureau team learned that the countries with well defined science and technology goals appeared to be more successful in stimulating technological advances within their industrial sectors. They also found:

- The most effective technology enhancement programs came from Science and Technology agencies placed at the highest levels of government.
- An atmosphere of trust and open communication between government and the private sector was essential.
- Successful technology enhancement involved continual modernization of equipment and facilities, spurred by government policies and incentives.
- Special attention to the needs of small- and medium-sized firms was beneficial.
- Extra funding accompanied by extra government interference and "red tape" was not especially helpful in technology enhancement.

Not until December 1972 was a report describing the results of the study made available to the public, and even then the release took the form of an internal Department of Commerce document rather than an NBS publication.[141] Nevertheless, the clarity of the study results moved the department to initiate multi-million-dollar funding for an NBS technology enhancement program in March 1972 so that work could begin in Fiscal 1973.

The Bureau scrambled to flesh out the basis for what would become—Congress willing—a substantial NBS undertaking.[142] Quickly, Director Branscomb assigned to Edwin J. Istvan, newly employed by the Center for Computer Science and Technology, leadership of a Bureau "ETIP team."[143] In preparing the ETIP concept, Istvan and his

[141] "Technology enhancement programs in five foreign countries", Walter G. Leight, editor, DoC Report COM-72-11412, December 1972, 328 pp. Section authors: Suellen Halpin, Donald W. Corrigan, John C. Schleter, George C. Nichols, Stephen S. Karp. Project Director: George C. Nichols. General Advisor: John A. Birch.

[142] Memo, L Branscomb to Larry Jobe, Asst. Sec. of Comm. for Administration, January 28, 1972; RHA; RG 167; Director's Office; Box 424; Folder January 1972.

[143] Memo, L Branscomb to NBS Executive Board, February 4, 1972; RHA; RG 167; Director's Office; Box 424; Folder February 1972.

team made a serious effort to involve private industry. Acting quickly and using methods reminiscent of the Metric Study, they contacted a large number of individuals and corporations:

- All of the members of NBS Evaluation Panels (300 individuals).
- The 20-member Inventors' Council.
- Thirty trade associations.
- Senior officials at more than 100 corporations, 8 universities, 7 professional societies, and 18 research institutes.
- Government officials in two states, 7 local government associations, and 11 departments.

The persons contacted were queried about their response to the ETIP idea, whether their organizations might by willing to participate, and the types of activities that seemed most attractive. The responses were uniformly positive.[144]

The results of Istvan's efforts quickly appeared in the March 1972 House hearings on the fiscal 1973 Bureau budget, where Branscomb described a $14.4 million program:[145]

> 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 the final NBS budget for fiscal 1973, the ETIP program was allocated $10 million. This handsome sum was immediately reduced to $6.2 million as an economy measure by President Nixon. However, the task of choosing a leader who would spend the money and produce results fell not to Lewis Branscomb, but to his successor. More about ETIP later.

A New Building for Fluid Mechanics Studies

During 1969 the twentieth major building for the Gaithersburg site was completed and occupied. It was dedicated to the study of fluid mechanics; several special facilities were included in the design to make the new laboratory one of the finest anywhere.

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[144] Memo from LMB to the Under Secretary of Commerce, March 10, 1972: "Activities Related to the Proposed NBS Experimental Technology Incentives Program." RHA; RG 167; Director's Office Box 424; Folder-Chrono, March 1-31, 1972.

[145] House Hearings for Fiscal 1973 (March 28, 1972), pp. 1085-86.

One large laboratory featured facilities for calibration and research in large air meters and water meters. It was designed to aid NBS in developing and applying improved flow-rate measurements, transfer standards and flow theory. Dried, filtered air was available at flow rates from 45 grams to 2 kilograms per second. Treated water could be pumped from a quarter-million-liter reservoir at a rate of 40,000 liters per minute. Low-level flows could be metered within a temperature-controlled environment, and special facilities were available for monitoring flow of hydrocarbons, including jet fuel.

Also included was an aerodynamics laboratory which permitted study of both laminar and turbulent air flow at speeds that ranged into the supersonic area. Wind-speed instruments could be calibrated in the range 2-150 mph. Boundary-layer studies were contemplated, as well as wakes and jets. A subsonic and a supersonic wind tunnel were both made part of this facility. A portion of the subsonic tunnel walls could be moved in order to vary the internal pressure distribution.

A water tunnel was built as part of the hydraulics section of the new building, as was a 1-meter square, 13-meter long wave tank.

The new building took NBS to the forefront of yet another technical field.

Science in Outer Space

Bureau scientists contributed in many ways to the successes of America's space program and to astronomy. In projects as varied as providing calibration of the mighty rockets used to lift spacecraft from their earthly bonds, measurement of the distance from earth to the moon, and the study of the sun's radiation, information and instruments from NBS lifted man a step closer to the stars.

In this section we summarize a few projects that illustrate Bureau contributions to space science during the directorship of Lewis Branscomb.

Lunar Ranging

On July 21, 1969, astronauts Neil A. Armstrong and Edwin W. "Buzz" Aldrin, Jr. carefully placed an aluminum panel the size of a generous birthday cake—46 cm square—on the surface of the moon, tilting it a bit so that it pointed towards the earth. In doing so, the astronauts initiated an experiment in lunar ranging, one in which NBS scientists played a pivotal role.

The aluminum panel, said the report, describing the experiment, contained an array of 100 "corner-cube" retro-reflectors:

> . . . made by cutting a nearly perfect cube of fused silica in half across a body diagonal, then polishing the resulting new face flat. Light entering the new face has the interesting and useful property that it is reflected from the three mutually perpendicular faces of the rear corner, returning along the same direction from which it came. [146]

[146] Slightly paraphrased quote from P. L. Bender, D. G. Currie, R. H. Dicke, D. H. Eckhardt, J. E. Faller, W. M. Kaula, J. D. Mulholland, H. H. Plotkin, S. K. Poultney, E. C. Silverberg, D. T. Wilkinson, J. G. Williams, and C. O. Alley, "The lunar ranging experiment," *Science* **182**, No. 4109, pp. 239-238, October 19, 1973.

Q-switched ruby lasers, installed at two earth-bound observatories, soon began sending pulses of light in the direction of the retro-reflectors in the hope of measuring several quantities, among them the distance between earth and the moon. If the experiment worked, it could substantially reduce the uncertainty in the earth-moon separation below previous estimates of ± 500 m.

The lunar-ranging project was the brainchild of a group of physicists from several institutions, allied with scientists working on the NASA Apollo missions. The project leader was C. O. Alley of the University of Maryland. Co-investigators included Peter L. Bender of the Bureau's Joint Institute for Laboratory Astrophysics (JILA); R. H. Dicke and D. T. Wilkinson of Princeton University; James E. Faller, then of Wesleyan University but by 1972 a JILA staff member; W. M. Kaula of the University of California at Los Angeles; G. J. F. MacDonald of the University of California at Santa Barbara; J. D. Mulholland of the Jet Propulsion Laboratory at the California Institute of Technology; and H. H. Plotkin of the NASA Goddard Space Flight Center. W. Carrion of NASA Goddard and R. F. Chang, D. G. Currie, and S. K. Poultney of the University of Maryland also participated in the work.[147]

The idea behind lunar ranging was simple: shine light on the moon for a moment and measure the time taken for the pulse of light to return.[148] But it took a decade of work for the idea, once undertaken by the group, to reach fruition. A key ingredient was the use of retro-reflectors. Attempts to perform the measurement using laser-light reflections from the lunar surface itself suffered from uncertainties created by the moon's curvature and its poor reflectivity, but use of the corner-cube array sharpened the return pulse and increased its intensity by 10 to 100 times.

Another major problem was placing the reflector unit on the moon. The unit as designed could be deployed automatically; by 1968, however, the NASA unmanned Surveyor program was complete. Furthermore, the Apollo Lunar Surface Experiments Packages for each of the manned lunar landings were already committed to other experiments. The ranging team got lucky, however, when the Apollo 11 managers decided to replace a heavier, more complex experiment with the lightweight, easily deployed, rugged, and scientifically important Lunar Ranging Experiment (LRE).

Telescopes at two astronomical observatories, the 3. 0 m (120 in) instrument at the Lick Observatory on Mount Hamilton in California and the 2. 7 m (107 in) telescope at the McDonald Observatory at Fort Davis in Texas, were equipped with ruby lasers,

[147] C. O. Alley, R. F. Chang, D. G. Currie, S. K. Poultney, P. L. Bender, R. H. Dicke, D. T. Wilkinson, James E. Faller, W. M. Kaula, G. J. F. MacDonald, J. D. Mulholland, H. H. Plotkin, W. Carrion, and E. J. Wampler, "Laser ranging retro-reflector: Continuing measurements and expected results," *Science* **167**, January 30, 1970, 458-460 (1970).

[148] Galileo had tried to perform the converse of this experiment centuries earlier—determining the speed of light by measuring the time that elapsed between his uncovering a lantern and his observation of light from the lantern of an assistant who was standing a measured distance away and who was instructed to uncover his lantern at the first glimpse of light from Galileo's lantern. The delay time involved in human response, of course, proved far longer than the travel time of light between the earth-bound lantern stations.

which could deliver pulses of light of about 3 ns half-width at a wavelength of 694 nm and an intensity of 7 joules per pulse. Since the round-trip travel time from earth to the moon was approximately 2.5 s, the laser firing rate could be set at 3 s, allowing for many pulses—and therefore good statistical averaging—in a relatively short time interval. The LRE team expected that measurements could be accomplished during the lunar day as well as the night, providing only that the moon was sufficiently high in earth's sky to permit good viewing.

The lunar ranging experiment had to be fitted into a full schedule of astronomical work in both observatories. Therefore a schedule was set of 50-200 pulses per attempt, with three attempts per day, permitting considerable improvement in results through signal-averaging without monopolizing the telescopes.

Despite considerable effort to collimate the laser beam as it passed through the observing telescope, it was expected that the laser light would diverge to cover an area on the moon 4-6 km in diameter, reducing the return signal to about 1 photon per laser pulse. However, careful screening of spurious light and electronic time-sorting of the return signals could make even such sparse results meaningful.

Excruciating delays—due to moon position in the sky, bad weather, and earthly equipment problems—followed the July 21st deployment of the reflectors by astronauts Aldrin and Armstrong. On the first of August, though, return signals were obtained by the Lick observatory telescope, then by the McDonald instrument as well.

Early results indicated a ranging uncertainty below 10 m, a substantial improvement over previous determinations. The imprecision of the measurements quickly dropped to ± 0.3 m, with further improvement expected. The Lunar Ranging Experiment was a success.

Encouraged by the quality of the Apollo 11 experiment, NASA happily scheduled the deployment of a similar retro-reflector array by Apollo 14. It was placed on the moon on February 5, 1971; return signals were obtained the same day. A larger package containing 300 reflectors was carried on the Apollo 15 flight and deployed on July 31, 1971. Besides the NASA units, retro-reflectors built in France were carried to the moon by the Soviet spacecraft Luna 17 in November 1970, and Luna 21 in January 1973; the McDonald Observatory obtained signals from the latter within days of its deployment.

By mid-1971, enough ranging data had been obtained to permit an evaluation and possible correction of the moon's orbit. It was expected that observations from more than one earth site would also permit the detection of tectonic motion on the earth's surface.

In 1976, James Faller completed construction of a telescope that was designed specifically for the lunar-ranging studies. [149] Composed of 80 lenses, each with its own system of mirrors to focus light on a single point on the telescope axis, the instrument—with its large aperture and tiny field of view—made optimum use of the tenuous beam returned from the moon's retro-reflectors.

[149] This part of the lunar-ranging story was summarized well by Bragaw and Snyder, op. cit., pp. 638-670. The telescope was described in clear terms in articles by Frederick P. McGehan, "The fly's eye telescope," *NBS Dimensions* **62**, pp. 3-6 (1978), and David Orr, "A technical look at the telescope," *NBS Dimensions* **62**, pp. 6-7 (1978).

The telescope was built with a light but extremely rigid body, so that it could be pointed automatically in any celestial direction, using computed lunar ephemeris data. Its output signal was handled in a manner similar to that of its larger astronomical cousins at the Lick and McDonald observatories. During August 1976, the telescope was placed on Mount Haleakala in Hawaii, which rides on the Pacific tectonic plate. From this installation arose the possibility of utilizing lunar ranging to directly detect movement between the Pacific plate and the continental United States plate.

In a later paper written for the journal Science, Faller, Bender, and their colleagues summarized the many contributions to man's knowledge of the earth-moon system brought by the Lunar Ranging program:[150]

> Lunar laser ranging turns the earth-moon system into a laboratory for a broad range of investigations, including astronomy, lunar science, gravitational physics, geodesy, and geodynamics.
>
> Contributions from lunar laser ranging include a three-orders-of-magnitude improvement in accuracy [to ± 3 cm] in the lunar ephemeris, a several-orders-of-magnitude improvement in the measurement of the variations in the moon's rotation, and the verification of the principle of equivalence for massive bodies with unprecedented accuracy. Lunar laser ranging analysis has provided measurements of the earth's precession, the moon's tidal acceleration, and lunar rotational dissipation.

Coupled with other studies such as Very Long Baseline Interferometry, lunar ranging helped to refine the picture of the earth and the moon as liquid-filled, undulating plastic spheroids, eternally coupled by gravitational forces as they whirl in their orbits about the sun. The sets of retro-reflectors installed on the surface of the moon by the Apollo astronauts still operated normally after 25 years. Returning to earth only 10^{-21} of the light sent their way from 385,000 kilometers distance, the simple devices greatly enriched man's understanding of his nearby universe.

Stellar Atmospheres

Bureau scientists at the Joint Institute for Laboratory Astrophysics, in collaboration with colleagues at several universities, made substantial contributions to the understanding of stellar atmospheres during this period:

- J. P. Cassinelli and David G. Hummer discussed stellar radiative transfer in terms applicable especially to spherically symmetric systems.[151]

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[150] J. O. Dickey, P. L. Bender, J. E. Faller, X. X. Newhall, R. L. Ricklefs, J. G. Ries, P. J. Shelus, C. Veillet, A. L. Whipple, J. R. Wiant, J. G. Williams, and C. F. Yoder, "Lunar laser ranging: A continuing legacy of the Apollo program," *Science* **265**, pp. 482-490 July 22, 1994.

[151] J. P. Cassinelli and D. G. Hummer, "Radiative transfer in spherically symmetric systems: II. The non-conservative case and linearly polarized radiation," *Monthly Notices of the Royal Astron. Soc.* **154**, No. 1, 9-21 (1971).

- A discussion of spectrum formation in stars with extended atmospheres, held during a colloquium of the International Astronomical Union, featured a paper by Richard N. Thomas that focused attention on the significance of the ideas behind the "extended stellar atmosphere."[152]

- Katharine B. Gebbie edited the proceedings of a symposium, held to honor the 70th birthday of astronomer Donald H. Menzel, on the topics of solar physics, atomic spectra, and gaseous nebulae. Professor Menzel contributed much to the success of the astrophysics program at the Bureau.[153]

- A strong disagreement between theory and experiment was resolved in favor of experiment at the Joint Institute for Laboratory Astrophysics. New experimental cross-sections for the photodissociation of the positive ions of hydrogen and deuterium, species important to astrophysics, were determined at wavelengths from 247 nm to 1.3 μm by Friedrich von Busch and Gordon H. Dunn of JILA.[154] Marked disagreement with earlier theoretical calculations, including some by Dunn himself, stimulated the project. The theory involved normalized Franck-Condon factors for the vibrational populations of the ions. Finding persistent disagreement between the theory and results obtained with the use of improved experimental conditions, the authors were led to the conclusion that the Franck-Condon approximation was not valid for the conditions they were studying.

Cryogenics in Space

Projects undertaken by the Cryogenics Division in Boulder had a significant impact on the U.S. space program. Division scientists and engineers provided data on the properties of cryogenic materials, they performed engineering calculations, and they served as consultants both to the National Aeronautics and Space Administration and to its contractors.

Among these projects were:

- Thermodynamic properties—equation-of-state, specific heat, sonic velocity, thermal conductivity, and viscosity—of hydrogen and oxygen used for propulsion, fuel cells, and breathing-oxygen systems.

- Measurements, engineering, and consultation for CENTAUR, the first hydrogen/oxygen-propelled vehicle, and for subsequent programs.

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[152] R. N. Thomas, "Definition of the physical problems connected with extended atmospheres," *NBS Special Publication 332*, pp. 38-54 August 1970.

[153] "The Menzel symposium on solar physics, atomic spectra, and gaseous nebulae in honor of the contributions made by Donald H. Menzel," K. B. Gebbie, Editor, *NBS Special Publication 353*, 213 pp., August 1971.

[154] F. von Busch and G. H. Dunn, "Photodissociation of H_2^+ and D_2^+; Experiment," *Phys Rev*. **A 5**, No. 4, 1726-1743 (1972).

Another project involved study of partially frozen "slush" samples of hydrogen, methane and natural gas, and mixtures of the latter two substances. These materials possessed very high heats of combustion—higher than either gasoline or kerosene—and they burned "clean," making them prime candidates for fuels for high-performance aircraft, rockets, and other vehicles. Use of the cryogens in partially frozen form was certain to reduce evaporative losses during storage and transfer, provided that suitable techniques could be developed for handling and utilizing the mixed-phase materials.

D. H. Weitzel, Jose E. Cruz, L. T. Lowe, R. J. Richards, and Douglas B. Mann developed instrumentation to store and transfer hydrogen in both liquid and slush form. They also measured the densities of the materials and developed devices to measure flow of the cryogens. [155] Charles F. Sindt and Paul R. Ludtke performed similar work with respect to liquid and slush methane, natural gas, and various mixtures of the two.[156]

Aerospace Calibrations

The U.S. space program utilized many instruments at the limits of their capabilities. Communications, optical systems, thermometry, and mechanical measurements were examples of areas requiring careful calibration to ensure adequate performance.

The projects were accomplished mostly by "unsung heroes"—Bureau staff members whose work did not result in publications, but whose services were recognized by their customers as vital to reaching national goals. Evaluation and calibration services involved antenna standards; the quality of shielding for electromagnetic radiation; microwave and radar performance and noise measurements; load cells to measure the thrust of the huge rocket engines (see the discussion in the next section); aircraft fatigue measurements; mechanical properties of composites; high-temperature thermocouple thermometers; radiometers; vacuum ultraviolet radiation standards; and x-ray standards.[157]

Mentioned in Chapter 1 was the Interagency Transducer Project, which contributed heavily to the space program. During the period covered by this chapter, Electronic Technology Division personnel were asked to adapt the calibration of static pressure transducers to the measurement of pressure under non-static conditions. In some cases—particularly those involving large rocket engines—telemetry

[155] D. H. Weitzel, J. E. Cruz, L. T. Lowe, R. J. Richards, and D. B. Mann, "Instrumentation for storage and transfer of hydrogen slush," *Advances in Cryogenic Engineering* **16**, pp. 230-240 (1971). The work of these scientists and a colleague, Robert Arnett, was credited with materially assisting in the design of the Pratt and Whitney RL-10 "Centaur" spacecraft engine; see *NBS Standard*, Vol XV, No. 2, February, 1970, p. 7.

[156] C. F. Sindt and P. R. Ludtke, "Characteristics of slush and boiling methane and methane mixtures," *Proc. XIIIth Int. Congress of the International Institute of Refrigeration, Washington, DC, Aug. 27 - Sept. 3*, 1971, pp. 1-6.

[157] Much of the material in this section was suggested in a letter from Robert S. Walleigh to Donald C. Winner, NOAA, dated November 16, 1971; RHA; RG 167; Director's Office; Box 391; chron folder November 1971.

repeatedly showed pronounced spikes in the pressure signals during ignition of the enormous engines. Careful study by the Bureau group, including Paul S. Lederer, John S. Hilten, and Leon Horn, showed that the apparent pressure spikes were spurious. They arose as a result of severe temperature gradients across the transducer as the igniting fuel rapidly heated only one end of it.[158]

Force Testing on a Large Scale

The need for calibration of the large forces encountered in rocketry increased dramatically as America entered the space race. Knowledge of the weight of "big birds" and measurement of the thrust of huge rocket engines were vital to the success of NASA's extraterrestrial missions.

As late as 1961, the Bureau capability for such services, maintained within the Mechanics Division, was far behind NASA's needs. During the previous two decades, the demand for large-force calibrations from NBS had increased by more than a factor of twenty, and many of these requests could not be met at all by the Bureau's outmoded equipment.[159] NASA needed to determine the actual forces exerted by rocket engines designed to deliver more than one million pounds of thrust. The Bureau's biggest dead-weight tester, with a capacity of but 0.5 meganewtons (SI symbol MN; about 112,500 pounds of force), was no help for such a task.

To comprehend the concept of the forces involved in aerospace projects, it was important for the layman to understand the distinction between mass measurement and force measurement and the relation of these mechanical terms to the common noun "weight." Mass, one of the base units of measure in the International System of Units, was defined in terms of an artifact—a physical object. The unit of mass, one kilogram, was defined by a cylinder of platinum-iridium alloy retained by the International Bureau of Weights and Measures as the international prototype. In the study of elementary mechanics one found that force was equal to the product of mass times acceleration. "Weight," as the term was commonly used in America, actually referred to a force, not to a mass. Space travel, with its essentially zero-gravity environment, provided a vivid reminder of this difference. For example, the *weight* of a one-kilogram *mass* on the moon, where the magnitude of gravitational attraction was about one-sixth of its value on earth, would be only one-sixth of its weight on earth. And measured in the near-zero gravity of outer space, the same one-kilogram mass would become weightless (as the first astronauts quickly discovered), even though the mass of the object clearly would remain equal to one kilogram.

Another useful distinction relative to force measurement was the difference between calibration using sets of weights of various sizes to provide the reference force and calibration in which the magnitude of an unknown force was evaluated by the use of a force transducer—a proving ring or a load cell. The uncertainty of the former (more basic) calibration typically was smaller by a factor of ten than the latter.

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[158] John Franklin Mayo-Wells kindly supplied this information.

[159] Testimony of Allen Astin, House hearings May 3, 1961, p. 821.

The reason for the smaller uncertainty in calibrations involving weights sets lay in the tighter uncertainty budget. Uncertainties of only about 10^{-6} each were contributed for calibration of the masses used, for the correction for air buoyancy, and for the acceleration due to gravity at the site of the calibration.

Calibration by the use of weight sets was restricted to vertical tension or compression, whereas the force axis of hydraulic or other force-generating machines—often called Universal Testing Machines—could be placed in any direction.

In 1965, six new "deadweight" calibration installations were put in operation at NBS. Their capacity ratings in newtons (or pounds of force) were 2.2×10^3 (495), 2.7×10^4 (6,078), 1.13×10^5 (25,438), 5×10^5 (112, 559), 1.33×10^6 (300,000) and 4.45×10^6 (1,000,000). The largest of these provided a calibration uncertainty limited to 0.002 %—80 newtons or 20 pounds—in either tension or compression. More efficient design shortened by half the time required for testing, an important advance considering that some 1000 devices per year—including direct measurements for certain NASA space flights—were calibrated at that time. Temperature was controlled in the facility to minimize uncertainties from this source. Arnold J. Mallinger and Raymond Russell were among the staff members involved in the force calibrations.[160]

In 1970, the Bureau provided calibration services for three types of devices used to measure force:

- "Load cells"—devices for converting a force to a magnetic, frequency or electrical-resistance output.
- "Proving rings"—actual ring-shaped devices invented at NBS in 1926 by S. N. Petrenko, in which the deformation of the ring could be evaluated in terms of the applied force.
- "Elastic force measuring devices"—similar in principle to proving rings.

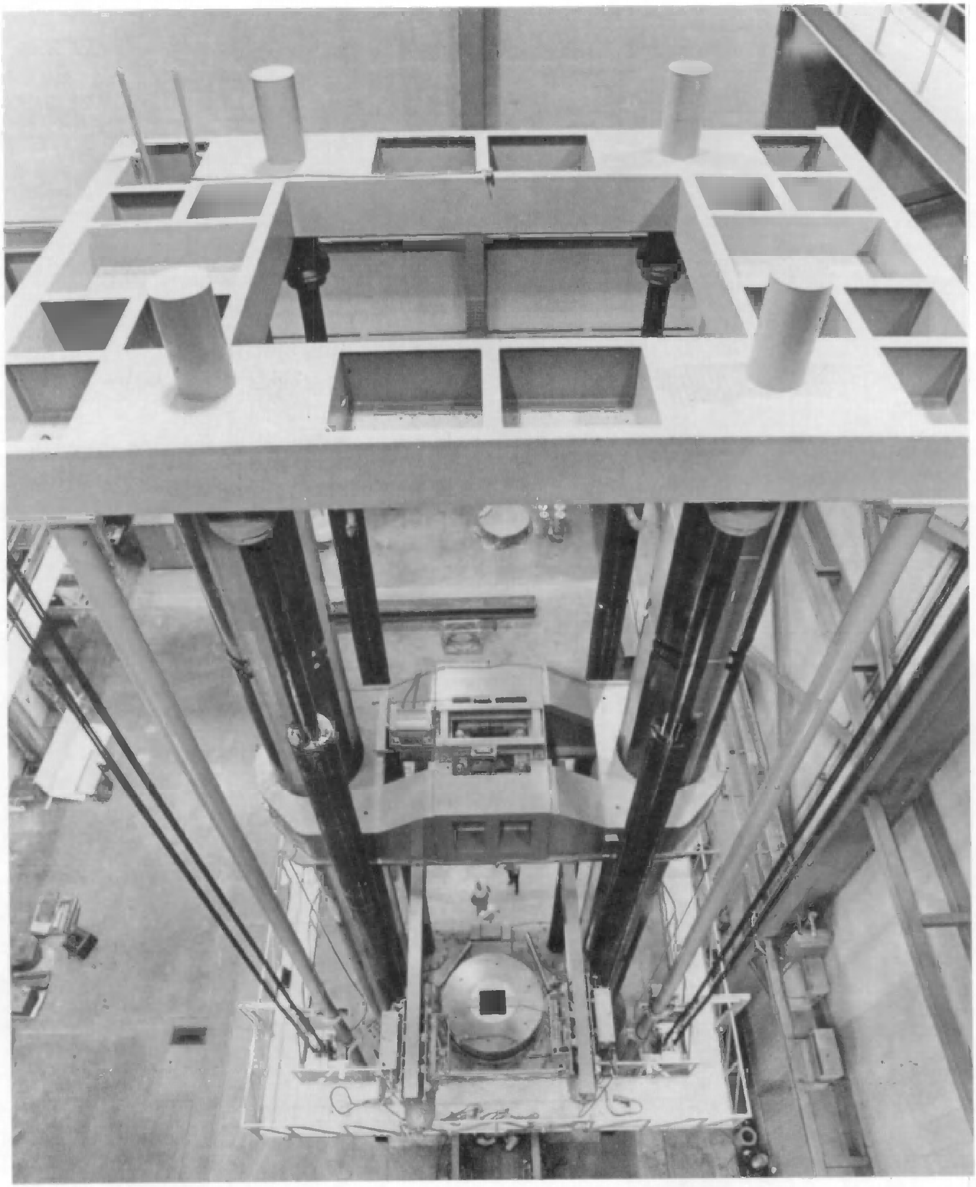
These devices could be calibrated in terms of compression, tension or both for forces ranging as high as 4.5 MN.[161]

In 1971, a new Universal Testing Machine was installed in the Engineering Mechanics building, replacing an older ten-million-pound-force compression tester. The new machine, using hydraulic force-generation, was capable of applying compression forces as large as 54 MN (about 12 million pounds). Three firms participated in its realization. It was designed by the Wiedemann Machine Company of Grove City, Pennsylvania; the E. W. Bliss Company of Salem, Ohio, manufactured the components; and assembly was accomplished by the McDowell-Wellman Company of Cleveland. The tester immediately became the largest such apparatus in the world.[162] Simply installing the machine was a challenge—it topped 33 meters in height including a 7-meter length underground. Tension tests up to 27 MN could be applied to specimens as long as 18 m, and 30 m long structural members could be tested for flexure using forces up to 16 MN.

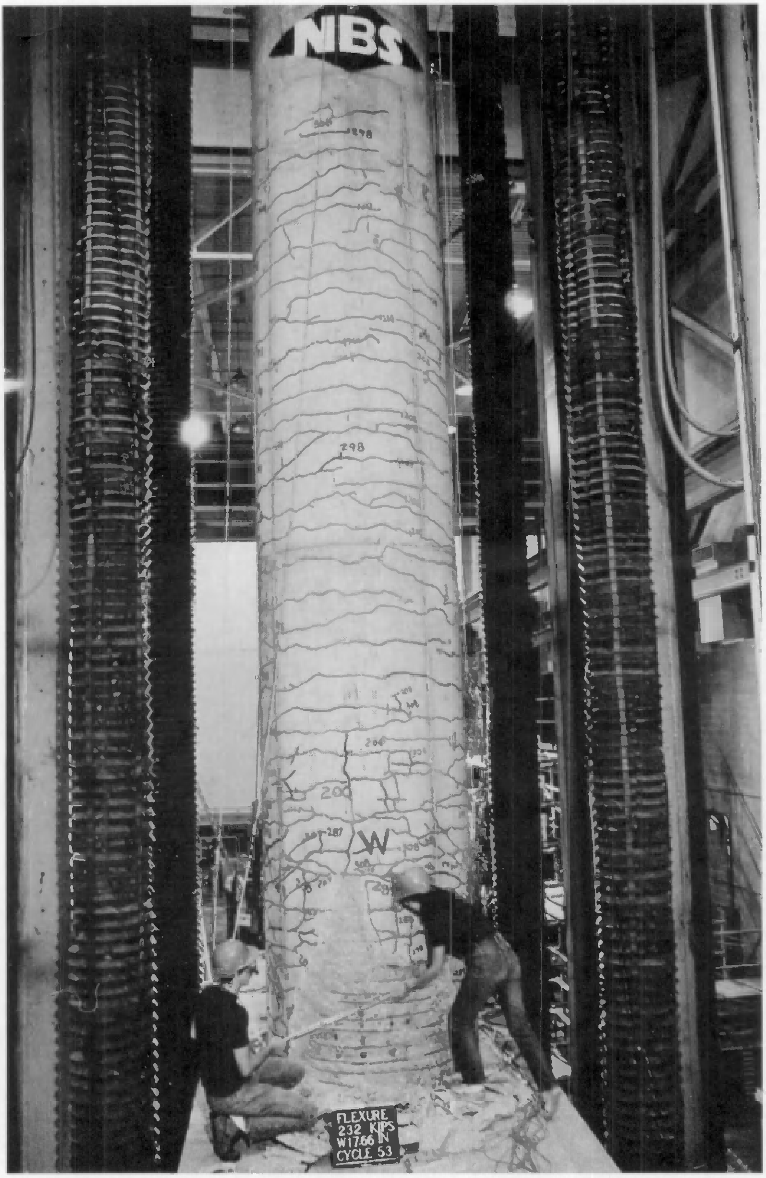
[160] "New NBS Force-Calibration Facilities," *NBS Technical News Bulletin*, November 1965, p. 186-188.

[161] "Calibration and Test Services of the National Bureau of Standards," *NBS Special Publication 250*, December 1970, pp. 4.5–4.8.

[162] "World's Largest Testing Machine Goes Into Operation," NBS Technical News Bulletin, November 1971, p. 274. See also "A gentle giant is dedicated," *NBS Standard* Vol XVI, No. 10, November 1971, p. 3.



Seen from above, the 12-million-pound-force Universal Testing Machine, installed in the Engineering Mechanics Building in 1971, dwarfed its operators.



Technicians examined a concrete column which was flexed to destruction by the Bureau's 12-million-pound-force Universal Testing Machine.

Mechanical Engineer Samuel R. Low stood on the platform of the NIST 12-million-pound-force Universal Testing Machine circa 1988. Behind him was the then-record fracture test specimen, a 35 ft long test specimen with a 6 in thick, 40 in wide insert. It took 5.94 million pounds of force in tension to fracture the insert.

Estimates of the force applied by the UTM were provided by several transducers. The load applied to the specimen was evaluated within about 0. 5 % by pressure transducers yielding an electrical signal. Special protective devices guarded against damage caused by catastrophic specimen failure.

The new universal tester found extensive use not only for calibrating NASA's rocket engines and other aerospace components but also for calibrating commercial and manufacturing weighing equipment.

Pieces of the Moon

Three Apollo missions brought back to earth samples taken from the moon. The samples were obtained by astronauts Neil A. Armstrong and Edwin W. Aldrin, Jr. (Apollo 11); Charles Conrad, Jr. and Alan L. Bean (Apollo 12); and Alan B. Shepard, Jr. and Edgar D. Mitchell (Apollo 14). Portions of the "moon rocks" were brought to NBS for examination. At the Bureau, the samples were analyzed and compared with terrestrial materials of similar composition. Materials from a meteorite crater in Arizona were included in the comparisons as well, yielding interesting and useful information on the age and sources of materials on the lunar surface.

Several groups of scientists, both from NBS and collaborating laboratories, participated in the studies. Kurt F. J. Heinrich and his colleagues used an electron microprobe in their work. They found and analyzed minerals in the lunar samples that were common on the earth's surface. The form of some of the Apollo 11 samples indicated the occurrence of meteorite impacts on the moon.[163]

Harvey Yakowitz and his collaborators found a great variety of minerals in an Apollo 11 sample, using three types of microanalysis. They concentrated their efforts on metallic particles that contained iron and nickel. Like Heinrich's group, they found evidence of meteor impact on the moon—certain of the samples resembled minerals found in meteor craters in the American west. [164] Similar results were obtained by David B. Ballard, Yakowitz and J. I. Goldstein in a study of Apollo 11 and 12 soils.[165]

Apollo 12 soil samples were examined by Yakowitz and Goldstein, who found nickel and cobalt in igneous rock. Some 80 % of the metallic regions studied showed compositions different from those expected even for meteorites; they appeared to have undergone "cooking" for a year or more at temperatures in the range 500 °C to 600 °C.[166]

[163] I. Adler, L. S. Walter, P. D. Lowman, B. P. Glass, B. M. French, J. A. Philpotts, K. F. J. Heinrich, and J. I. Goldstein, "Electron microprobe analysis of Apollo 11 lunar samples," *Geochim. Cosmochim.* **34**, Suppl. 1, pp. 87-92, January 30, 1970.

[164] J. I. Goldstein, E. P. Henderson, and H. Yakowitz, "Investigation of lunar metal particles," *Geochim. Cosmochim. Acta* **1**, pp. 499-512 (1970).

[165] D. B. Ballard, H. Yakowitz and J. I. Goldstein, "Study of metals in the lunar soil," *Proc. 4th Annual Scanning Electron Microscope Symposium, ITT Research Institute, Chicago, April 29, 1971,* Part 1, pp. 169-176 (1971).

[166] J. I. Goldstein and H. Yakowitz, "Metallic inclusions and metal particles in the Apollo 12 lunar soil," Chapter in *Proc. 2nd Lunar Science Conf., Houston, January, 1971,* **1**, pp. 177-191 (1971).

Heinrich also collaborated in a study of five Apollo 12 rocks. Again, the investigators found ready comparisons with earthly minerals.[167]

Isotopic abundance ratios on Apollo 14 samples were obtained by a group that included I. Lynus Barnes, B. Stephen Carpenter, Ernest L. Garner, John W. Gramlich, Edwin C. Kuehner, Lawrence A. Machlan, E. June Maienthal, John R. Moody, Larry J. Moore, Thomas J. Murphy, Paul J. Paulsen, Keith M. Sappenfield, and William R. Shields. Probing for the elements U, Pb, Rb, Sr, Ca, and Cu, they found little variation from terrestrial minerals. Dating by isotopic lead ratios indicated ages for the samples of more than 4×10^9 years.[168]

Other Bureau activities impinging on space and astronomy during this time period are mentioned under different headings.

Precision Measurement Grants

During August 3-7, 1970, the International Conference On Precision Measurements and Fundamental Constants was held at NBS.[169] The General Chairman of the conference was Bureau Director Lewis Branscomb. In his remarks, he announced the establishment of a new program to encourage work in all specialties of precision measurement. The new program would be known as Precision Measurement Grants (PMG), said Branscomb. Each grantee would receive from NBS the sum of $15,000.

Recipients of the first three grants were Prof. James E. Faller of Wesleyan University, Prof. Daniel A. Kleppner of MIT, and Prof. Hugh G. Robinson of Duke University. Initial grant applications were judged by a committee composed of members of the Joint Institute for Laboratory Astrophysics with the assistance of an advisory board of distinguished metrologists.

This program of grants to facilitate and encourage work at U.S. colleges and universities in precision measurement—though not a large enterprise—led to significant advances over the years in many different areas of physics and metrology. In some cases—such as that of James Faller, whose work we saw in the section on lunar ranging—the grants helped bring to NBS scientists already familiar with the nature of research in precise measurement.

By the summer of the year 2000, the program was in its 30th year. Awards had been made to 66 scientists, two of whom—Steven Chu of Stanford University and Daniel C. Tsui of Princeton University—had won Nobel prizes in physics for work

[167] B. M. French, L. S. Walter, K. F. J. Heinrich, P. D. Loman, Jr. , A. S. Doan, Jr. , and I. Adler, "Compositions of major and minor minerals in five Apollo 12 crystalline rocks," *NASA Special Publication 306,* 142 pp., 1972.

[168] I. L. Barnes, B. S. Carpenter, E. L. Garner, J. W. Gramlich, E. C. Kuehner, L. A. Machlan, E. J. Maienthal, J. R. Moody, L. J. Moore, T. J. Murphy, P. J. Paulsen, K. M. Sappenfield, and W. R. Shields, "Isotopic abundance ratios and concentrations of selected elements in Apollo 14 samples," *Geochim. Cosmochim. Acta* **2**, pp. 1465-1472 (1972).

[169] *NBS Technical News Bulletin* **54**, pp. 268-270, November 1970.

accomplished subsequent to their participation in the PMG program. The amounts of the grants had increased by then to $50,000 annually, and they were renewable for two additional years.

From 1975 to the present year, the PMG program was administered by Barry N. Taylor of NBS.

NBS Nuclear Reactor Completes Its First Year At Full Power

The Bureau's nuclear reactor, which first "went critical" in December of 1967, completed its first year at full power during October 1970. Taking stock of the year's progress, Reactor Radiation Division Chief Robert S. Carter expressed satisfaction both with the flawless operation of the reactor and with the quality and number of the technical projects accomplished there.[170]

The reactor was first licensed to operate at 10 MW. Its nuclear fuel, uranium enriched in the isotope ^{235}U, was contained in a set of 30 cylindrical rods arranged in three hexagonal rings. During reactor operation, the ^{235}U content in replacement fuel elements was gradually increased, allowing longer operation between refueling events. As operating experience grew, an ever larger ^{235}U content—as much as 250 g—was incorporated into replacement fuel elements, in the hope of achieving 9-10 days of operating life.

NBS scientists and administrators clasped hands in anticipation of the moment when its new nuclear reactor would go critical. Standing from left to right were Allen Astin, Harry H. Landon, Carl Muehlhause, Robert S. Carter, and Irl C. Schoonover. Seated behind them on the right was Ivy M. Collier.

[170] Robert S. Carter, "Reactor Radiation Division: Annual Progress Report for the Period Ending October 31, 1970," *NBS Technical Note 567*, March 1971, 58 pp.

An optimal fuel-rotation scheme was studied, along with careful monitoring of the shape of the nuclear flux pattern within the reactor. Generally speaking, best results seemed to involve removal of elements from the inner ring and the moving of partially consumed elements from the outer rings toward the center. Efficient replacement was important from a cost point of view; the percentage burnup of the ^{235}U fuel increased from 19 % at startup to nearly 40 % with the use of higher-density fuel elements and improved replacement pattern.

The reactor was built to serve a large variety of users from within NBS and from other government agencies, universities and industry. This pattern of use was followed from the start.

The Reactor Radiation Division consisted of three sections—Reactor Operations, Engineering Services, and Neutron Physics. Knowledgeable reactor physicists from outside the division planned and conducted their own irradiation sequences. The division staff assisted other scientists and technical workers in planning and carrying out irradiations so as to provide needed information or samples.

Four neutron diffractometers were available for crystal-structure analysis. A time-of-flight instrument permitted the study of inelastic neutron scattering. Thermalized neutrons were available for experiments in yet another facility. Further facilities were still in the developmental stage in 1970.

During the fueling process prior to criticality tests, Harry H. Landon, Chief of the NBS Neutron Nuclear Physics Section, checked the nuclear reactor core configuration through a periscope while Robert S. Carter, Chief of the Neutron Solid State Physics Section, observed.

Change in the neutron flux in the NBS Reactor was monitored in the control room by (from left to right) Larry Smith, Arthur Chapman, and Albert W. Crebs as control rods were withdrawn to achieve criticality.

A time-shared computer was used to control all the experimental devices, with stations available for all users. Use of the time-shared computer permitted coordination of the various irradiation experiments and quick evaluation of results.[171]

During the first full year of operation, more than 1,500 in-core irradiations were undertaken on a total of nearly 10,000 samples for purposes as diverse as biology, medicine, activation analysis, isotope production, and study of radiation effects. Some of the agencies involved in these irradiations included the U.S. Geological Survey (identification of trace constituents in geological materials); Food and Drug Administration (halogen and mercury concentrations in various commercial products, including foods); U.S. Post Office, Internal Revenue Service, and Federal Bureau of Investigation (activation analysis in crime-detection studies); Army Institute of Dental Research (role of trace metals—for example, zinc—in bone healing); Teledyne Isotopes, Inc. (study of fission products from transuranium isotopes); and the University of Maryland (mercury levels in oysters from the Chesapeake Bay).

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

Among other technical projects performed at the reactor, many involved NBS scientists both within the Reactor Radiation Division and from other divisions. Although it is not possible to mention all of these first-year projects, their variety gave a strong indication of the enormous power of the nuclear reactor as a research tool.

Antonio Santoro joined NBS as a member of the Reactor Radiation Division in November of 1964, while the reactor was still under construction. He and his Bureau colleagues Marcello Ziocchi, Curt W. Reimann and Alan D. Mighell utilized single-crystal x-ray diffraction techniques elsewhere to analyze the crystal structures of several transition-metal complexes with particular emphasis on understanding the interactions between metal ions and ligand molecules.[172] However, once the neutron-diffraction facilities at the reactor became available, the team could utilize that capability to obtain unambiguous assignment of atoms such as the carbon and nitrogen in the pyrazole group and to obtain more reliable information regarding the presence or absence of hydrogen-bonding in these molecules.[173]

Other crystal-structure analysis work done using the reactor's neutron-diffractometer facilities included the following:

- Observations on potassium silicotungstate, undertaken by Edward Prince and his colleagues from Georgetown University, P. M. Smith and J. V. Silverton, to determine the configuration of the silicotungstate ion and to elucidate the role of water of hydration in the crystal.
- Dimethyl sulfone diimine, a relative of synthetic detergents, studied by Prince and J. Bevan of the Proctor & Gamble Co. to ascertain the positions of the hydrogen bonds.
- Apophyllite, examined by Prince, A. A. Colville of California State College, and G. Donnay of the Carnegie Institution of Washington in order to work out the unusual sheet structure of this crystal.
- Durene, a tetramethylbenzene, studied by Prince, John J. Rush and Leroy W. Schroeder, a Postdoctoral Research Associate, to obtain insight into the conformation of the methyl groups in this crystal as well as the origin of their hindered rotation.[174]

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[172] A. Santoro, A. D. Mighell, M. Ziocchi and C. W. Reimann, "The crystal and molecular structure of hexakis (imidazole) nickel(II) nitrate, $(C_3H_4N_2)_6Ni(NO_3)_2$," *Acta Cryst.* **B25**, pp. 842-847 (1969). See also A. D. Mighell, C. W. Reimann and A. Santoro, "The crystal structure of dibromotetrapyrazolenickel(II), $Ni(C_3H_4N_2)_4Br_2$," *Acta Cryst.* **B25**, pp. 595-599 (1969).

[173] A. Mighell, A. Santoro, E. Prince and C. Reimann, "Neutron diffraction structure determination of dichlorotetrapyrazolecopper(II), $Cu(C_3H_4N_2)_4Cl_2$," *Acta Cryst.* **B31**, pp. 2479-2482 (1975).

[174] E. Prince, L. W. Schroeder and J. J. Rush, "A constrained refinement of the structure of durene," *Acta Cryst.* **B29**, pp. 184-191 (1973).

- Potassium cyanide and sodium cyanide, examined by John J. Rush and his colleagues from Argonne National Laboratory, J. Michael Rowe, D. G. Hinks, D. L. Price, and S. Susman, in order to understand how the linear cyanide groups were able to display cubic symmetry at temperatures near the melting point of the crystal.[175] Soon after this work was accomplished, Rowe joined the NBS staff.

Rush, Schroeder, and their colleague A. J. Melveger of the Allied Chemical Corp. performed a detailed study of the crystal and molecular dynamics of sodium bifluoride, using the techniques of infrared and Raman spectroscopy as well as inelastic neutron scattering. In this way they were able to gain information on the acoustic and optical translational lattice modes of vibration and to assign approximate values to the vibrational frequency distribution.

Bert Mozer and his collaborator L. A. de Graaf of Argonne National Laboratory utilized the neutron diffraction method to measure the structure factors of liquid neon at 35 K as functions of liquid density. Radial distribution functions, direct correlation functions, and effective interatomic potentials were calculated from the data.[176] Mozer also participated in preparing for use a two-axis spectrometer with a neutron-energy analyzer facility. The equipment could be used as a time-of-flight spectrometer or for three-axis crystal spectrometry. In the time-of-flight mode, the system utilized a 4 m evacuated flight tube with a group of eight detectors, producing an energy resolution as fine as 2 %.

In its schedule of projects focusing on collaboration with other government agencies, the division staff worked with members of the Naval Ordnance Laboratory on crystal structures, magnetic structures, the time-shared computer system, and a superconducting magnet for high-magnetic-field studies. With members of the Naval Research Laboratory (including Jerome Karle, awarded the Nobel Prize for chemistry in 1985 for his work with Herbert A. Hauptmann on the development of direct methods for the determination of crystal structures), they studied the properties of amorphous solids. With C. S. Schneider of the U.S. Naval Academy, they performed precise measurements of thermal-neutron scattering amplitudes. And with the staff of the Picatinny Arsenal, they characterized metastable materials; the Picatinny Arsenal group was pleased to find a replacement for the experimental facilities denied them when the Army nuclear reactor at Watertown, Massachusetts was decommissioned.

Beginning in its first year, the nuclear reactor also provided experimental facilities for Bureau employees from other divisions, often in collaboration with colleagues from other organizations. Philip D. LaFleur of the Analytical Chemistry Division, for example, collaborated with W. F. Marlow and Donald A. Becker of the Reactor Research

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[175] D. L. Price, J. M. Rowe, J. J. Rush, E. Prince, D. G. Hinks and S. Susman, "Single crystal neutron diffraction study of potassium cyanide," *J. Chem. Phys.* **56**, pp. 3697-3702 (1972). See also J. M. Rowe, D. G. Hinks, D. L. Price, S. Susman and J. J. Rush, "Single crystal neutron diffraction study of sodium cyanide," *J. Chem. Phys.* **58**, pp. 2039-2042 (1973).

[176] L. A. de Graaf and B. Mozer, "Structure study of liquid neon by neutron diffraction," *J. Chem. Phys.* **55**, pp. 4967-4973 (1971).

Division in a long-term program of neutron-activation analysis.[177] Another group, from the Optical Physics Division—Richard D. Deslattes, William C. Sauder, James A. Hammond and Albert Henins—initiated a program of measurement of atomic constants.

Several groups from the Nuclear Radiation Division commenced experimental programs:

- James A. Grundl, in collaboration with colleagues at the Los Alamos Scientific Laboratory, began preparing an intense ^{235}U fast neutron source, using the thermal neutron column.
- Ivan G. Schroder and his colleagues from Harvard University (J. L. Alberi and R. Wilson) and from Brookhaven National Laboratory (G. Scharff Goldhaber) set up a Cd target for the study of parity-conservation in strong interactions.[178]
- Frank J. Schima began a study of the decay characteristics of krypton isotopes.
- Alan T. Hirshfeld, Dale D. Hoppes, Wilfrid B. Mann and Frank Schima prepared samples of the isotope ^{82}Br for use in nuclear orientation studies.[179]

Water and Polywater

Water is thought by the layman to be the most ordinary of substances. "H-2-O," he will say if asked, proud that he knows a chemical formula, "two protons stuck to an oxygen atom. So what?" But water is so common and its properties so well-known that one often forgets that its properties are not what one would expect from its atomic makeup. Its unusual properties include the following:[180]

- A surprisingly high boiling point (100 °C or 212 °F) considering its small molecular size.
- A peculiar density-*vs*-temperature pattern. Most—though not all—substances become progressively denser as their temperature is reduced, with the frozen solid more dense than the liquid. It is very important to life on earth that ice is *less* dense than water. Ice forms on the surface of lakes and rivers, insulating

[177] W. F. Marlow and P. D. LaFleur, "Standard reference materials for the analysis of environmental samples," in *Proc. Symp. Nuclear Techniques in Measurement and Control of Environmental Pollution, Salzburg, Austria, Oct 26-30, 1970,* International Atomic Energy Agency, Vienna Austria, March 1971, pp. 91-94.

[178] J. L. Alberi, R. Wilson and I. G. Schroder, "Parity violation in neutron-capture gamma rays," *Phys. Rev. Lett.* **29**, No. 8, 518-521 (1972).

[179] A. T. Hirshfeld, D. D. Hoppes, W. B. Mann and F. J. Schima, "Nuclear orientation of ^{82}Br in iron," *Proc. Intl. Conf. on Hyperfine Interactions in Excited Nuclei, Rehovot, Israel, Sept 6-11, 1970*, Chapter in *Hyperfine Interactions in Excited Nuclei* **1**, 335-338 (Gordon & Breach Sci. Publ., New York, NY, 1971).

[180] Felix Franks, "Polywater," (Cambridge, MA: The MIT Press, 1981) 208 pp.

living plants and animals in those waters from freezing weather above and—in temperate climates—melting completely during the summer season. The mechanism by which water at 0 °C becomes more dense as it is heated is not entirely clear, but it is a fortunate fact that water reaches a maximum density above 0 °C (actually at 4 °C).

- An unusually large heat capacity. For a small molecule, water exhibits an anomalously large heat capacity, allowing it to serve nature as an enormous energy-storage reservoir.
- An increase in the vapor pressure when dispersed in small droplets. Lord Kelvin noticed nearly a century ago that the vapor pressure of water is unusually large in micrometer-sized droplets. He composed an equation to relate the vapor pressure to the droplet curvature. Is it unusual to find water in such small spaces in nature? Not at all, it turns out: many minerals and many biological materials contain confined spaces of magnitudes that are small enough to warrant use of the Kelvin relations. Among these substances are the human blood system, water droplets in clouds, and interstices in certain rocks.

It is such unusual properties of water as these, as well as the absolute importance of water to biological life, that has always impelled scientists to experiment with water. Any new understanding of the humble liquid that they could achieve would potentially affect all humanity.

In the case that follows, hard-working scientists thought they had found an unusual new property of water—until the use of newly developed, sharper tools showed them otherwise.

"Anomalous Water"

Given the importance of water to mankind, it was not surprising that a Russian scientist—one Nikolai N. Fedyakin, working in relative obscurity in the Technological Institute in Kostroma a few hundred kilometers northeast of Moscow—devoted himself to a study of water sealed in fine capillaries of diameter 2-4 μm. Careful and methodical, Fedyakin purified his water samples, encapsulated them and watched them. When he found in 1962 that certain of the samples seemed very slowly (over periods of many days) to separate into two fractions, one above the other in the capillary, his interest picked up considerably. Why should the water separate? Were there two components in his purified water samples? What properties would the new fraction exhibit?

Although further experiments were difficult—only a few micrograms of material was available for test—he nevertheless found that the new fraction showed a density that was clearly larger than that of ordinary water. When he was confident of his results, he published a paper describing them. In this first paper, Fedyakin expressed no knowledge of the composition of the separated fraction in his capillaries; he only noted that he had seen "anomalous water."[181]

[181] N. N. Fedyakin, "Change in the structure of water during condensation in capillaries," *Kolloid Zhurnal* **24**, 497 (1962); (translation: *Colloid Journal USSR* **24**, 425 (1962).

Fedyakin's report—available for some time only in Russian—attracted no immediate attention outside Russia. It was considered very interesting, however, by the group headed by Boris V. Deryagin at the Institute of Physical Chemistry in Moscow. Recognizing potential importance in Fedyakin's work, they immediately formed a collaborative project with him. Subsequent publication and discussion of new separation experiments with "anomalous water" came from Deryagin's laboratory. The first such paper, containing startling information on the properties of the condensed fraction, was published (again in Russian) in 1967.[182]

Gradually the news reached Western scientists that ordinary water, when allowed to re-condense in fine capillaries, might be exhibiting strange long-range-order properties. The new fraction showed anomalously high viscosity, large thermal expansion, increased boiling-point temperature and reduced freezing-point temperature, as well as the higher density found by Fedyakin. In talks at scientific meetings, Deryagin began to speculate that ordinary tap water might really be a metastable state, changing to a stabler form in contact with certain solid surfaces. Heady stuff for such a prosaic liquid!

The Russian results were corroborated by a group from the Unilever Research Laboratories in Cheshire, England.[183] They mentioned Deryagin's interesting speculation as their primary motivation. Placing numerous Pyrex capillaries of 10-100 μm diameter in a desiccator at room temperature and reduced pressure, they found condensed columns in "about 5 %" of the capillaries after a few days. They sealed the capillaries containing the condensate and found some of them to contain a gel-like residue. Mass-spectrometric analysis showed only mass 17 and 18, typical of water.

NBS Experiments On "Polywater"

One of the first American groups to follow up on the Russian "anomalous water" results was formed by Robert Stromberg, Deputy Chief of the NBS Polymers Division, and Ellis Lippincott, professor of chemistry at the University of Maryland and Director of the Center for Materials Research there. Together with Warren H. Grant of the Polymers Division and Gerald L. Cessac, a predoctoral student at Maryland, they prepared many samples of "anomalous water" by condensing purified water in Pyrex and quartz capillaries of 5-20 μm interior diameter, either at reduced pressure or full saturation pressure. They noted that the sample yield was very small, causing severe problems in analysis of the material. Nevertheless, they analyzed their "anomalous water" using laser-probe excitation, finding only "small" quantities of sodium and silicate impurities. Their analytical method was only slightly sensitive to the light hydrogen and oxygen atoms that make up the water molecule.

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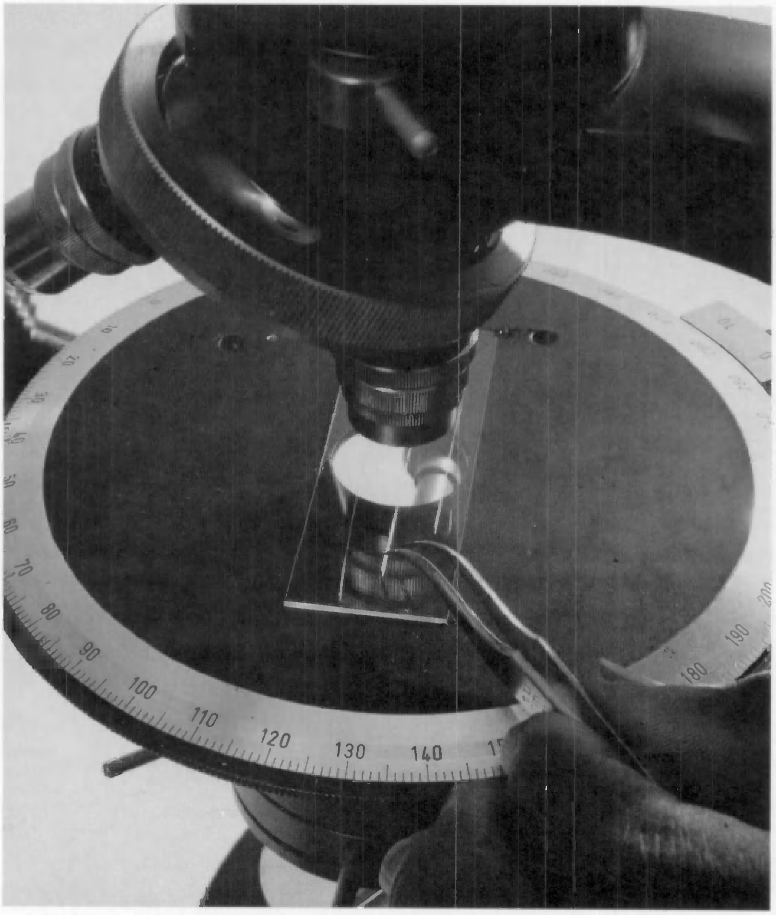
[182] B. V. Deryagin, N. V. Churaev, N. N. Fedyakin, M. V. Talayev, and I. G. Yershova, "The modified state of water and other liquids," *Bulletin of the Academy of Sciences of the USSR (Izv. Akad. Nauk SSSR, Ser. Khim.)*, No. 10, pp. 2178-2187, 1967.

[183] E. Willis, G. K. Rennie, C. Smart, and B. A. Pethica, "'Anomalous Water,'" Letter to the Editor, *Nature* **222**, 159, April 12, 1969.

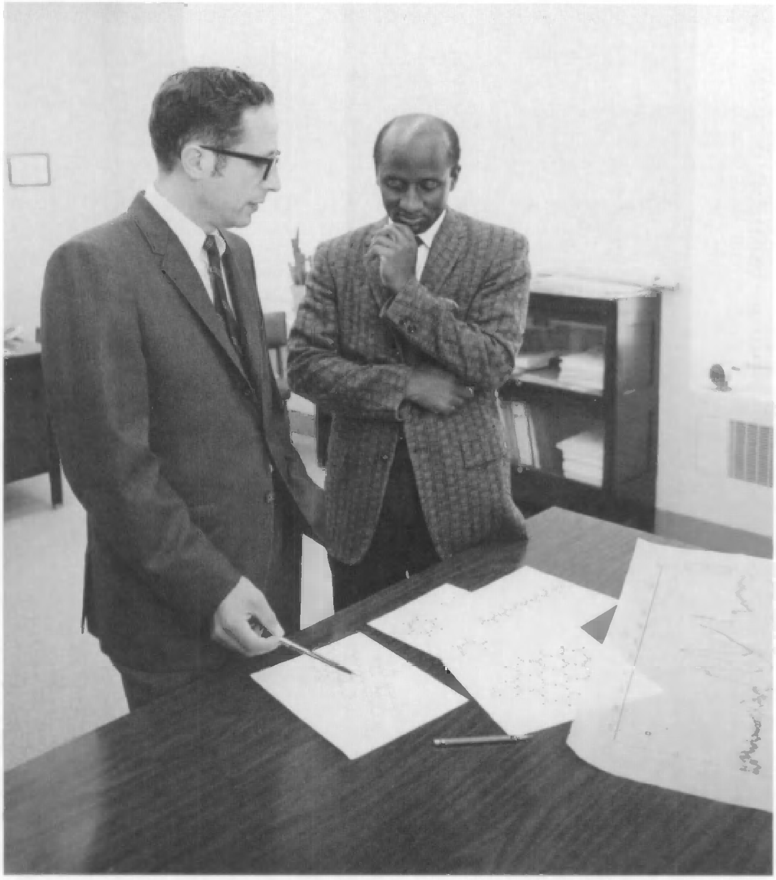


Quartz capillaries containing anomalous water samples were studied by microscopy as well as by spectroscopic techniques.

An exciting find by the NBS-Maryland group came when they analyzed infrared spectra of the samples. The spectra looked nothing like those of ordinary water! Instead, the results indicated the presence of a polymer. In publishing their results, they portrayed two polymeric forms of water that appeared possible, and they coined the term "polywater" to describe the sample material.[184]

Stromberg and Lippincott were not in a position to know that they had fallen into a trap. The analytical methods they used were not sensitive enough to give them a full picture of the microgram-sized contents of their capillaries. Hints there were in the identification of sodium ions and silicates in the condensate, but they had no way of knowing that such impurities in reality dominated the spectra given by their samples.

[184] E. R. Lippincott, R. R. Stromberg, W. H. Grant, and G. L. Cessac, "Polywater," *Science* **164,** 1482-1487, June 1969.



Polymers Division scientists Robert R. Stromberg and Warren H. Grant discussed possible polymeric structures of water.

The name "polywater" captivated both the group's scientific colleagues and the public at large. Considerable experimentation and more speculation emerged from many sources over the following three-year period. All together, about 450 references to "anomalous water" or "polywater" appeared over the next forty-odd months[185] despite unsettling results that began to appear early in 1970.

[185] Bruce C. Bennion and Laurence A. Neuton, "The epidemiology of research on 'Anomalous Water.'" *J. Amer. Soc. for Information Science* **27**, No. 1, pp. 53-56 (1976).

Questions About Impurities

In March 1970, the journal Science carried back-to-back articles that raised the question of impurities as the source of the unusual properties of the "anomalous water." The first, written by D.L. Rousseau of the Bell Telephone Laboratories at Murray Hill, NJ and S.P.S. Porto of the University of Southern California, discussed a special effort to prepare "pure polywater" and then to analyze it.[186] The two scientists boiled ordinary quartz tubing in aqua regia, a powerful cleaner composed of nitric and hydrochloric acids, and rinsed the tubing in distilled water prior to drawing the tubing into hundreds of capillaries. They washed all glassware sequentially in acetone, in water distilled several times, in chromic acid, and again in distilled water. They mounted the capillaries in two different ways in their desiccator—by leaving them in contact with the desiccator walls, and by suspending them from fine wires above a pool of distilled water. The suspended group of capillaries was included in order to minimize "creep" of stopcock grease or other impurities contained within the assembly.

"Anomalous water" condensed in 1 % to 5 % (more with higher chamber pressure) of the capillaries that Rousseau and Porto placed on the bottom of the desiccator, but no condensate formed in any of the suspended capillaries (an obvious clue to the possible role of impurities). The authors allowed the condensate to dry for about a week to evaporate all normal water prior to analyzing the residue.

Infrared and Raman spectroscopic analysis of the residue in the capillaries containing the dried condensate showed a substantial amount of sodium impurity—20 % to 60 % by weight. Also appearing were chloride and sulfate ions (each about 15 %) and smaller amounts of potassium and calcium.

The other March 1970 *Science* article was written by S. L. Kurtin and C. A. Mead of the California Institute of Technology in collaboration with W. A. Mueller and B. C. Kurtin of the Stanford Research Institute in South Pasadena, California and with E. D. Wolf of the Hughes Research Laboratories in Malibu, California.[187] This group prepared anomalous water samples in the "standard" manner, then centrifuged the condensate to obtain about 2 μg of material for examination. Mechanical and infrared studies showed the expected results, but further testing by dielectric methods indicated the presence of sols of particulates in ordinary water. Examining the samples with a scanning electron microscope showed "fluffy" particles, unlike control samples of ordinary distilled water.

Sharper Tools and a Discarded Idea

A January 1971 number of Science contained an extensive report discouraging the notion that there existed a high-polymer form of water. Written by collaborators R. E. Davis from Purdue University, D. L. Rousseau from the Bell Telephone

[186] D. L. Rousseau and S. P. S. Porto, "Polywater: polymer or artifact?" *Science* **167**, March 27, 1970, p. 1715.

[187] S. L. Kurtin, C. A. Mead, W. A. Mueller, B. C. Kurtin, and E. D. Wolf, "Polywater: a hydrosol?" *Science* **167**, March 27, 1970, p. 1720.

Laboratories, and R. D. Board from the Hewlett-Packard Corporation laboratory, the report offered spectroscopic results on samples prepared at the Bell Laboratories and at Purdue.[188] The ESCA (electron spectroscopy for chemical analysis) technique turned up a veritable soup of impurities; sodium and potassium salts of the sulfate, chloride, nitrate, borate and silicate ions, as well as compounds containing the C-O bond.

Davis and his group had used the usual techniques to prepare their samples, drying or sealing them before analysis. They emphasized that all their samples showed impurities and that all ESCA and infrared spectral lines were accounted for without need to invoke polymerization of water.

By the end of 1970, the NBS/University of Maryland group had come to question their own earlier speculations regarding anomalous water. Further experimentation had turned up evidence indicating the presence of impurities in their preparation techniques. They described this work in the *Journal of Colloid and Interface Science.*[189]

The debate over anomalous water and polywater continued for some time, but evidence that water vapor developed a remarkable reactivity with glass or quartz—especially when the silicate was subjected to the type of strain induced by drawing, as it was in the process of forming capillaries—continued to mount. Water, it seemed, was indeed an unusual substance—but it did not polymerize.

An epitaph of sorts for the polywater episode was written by Theodor Benfey of Guilford College, who wrote an editorial for the journal *Chemistry.*[190] He noted that remarks made during a 1971 symposium by the Russian scientist Deryagin had been revised by him prior to later publication of the symposium proceedings. The revised comments included the statement that "anomalous water" contained significant amounts of silicon, probably in the form of silicic acid gel or silica gel, and that quartz definitely dissolved more readily on exposure to water vapor than it did in liquid water. Even in Russia, water continued to be an unusual substance, but not a polymeric one.

The case of "polywater" served to remind scientists in the Soviet Union, at NBS, and elsewhere to move with caution into unknown areas. Unexpected results of experiments on the humblest of earthly substances—water—had been interpreted too quickly as indicators of an exciting possibility. Such things happen in science.

Advances in Microscopy

The Electron Microprobe in Color

The scanning electron microprobe was developed as an analytical tool during the 1950s. It was added to the NBS chemical-analysis arsenal chiefly by Kurt F. J. Heinrich when he joined the Bureau in 1964 as chief of the Microanalysis Section of

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[188] R. E. Davis, D. L. Rousseau, and R. D. Board, "Polywater: Evidence from electron spectroscopy for chemical analysis (ESCA) of a complex salt mixture," *Science* **171**, 167 (1971).

[189] Ellis R. Lippincott, Gerald L. Cessac, Robert R. Stromberg, and Warren H. Grant, "Polywater—a search for alternative explanations," *J. Colloid and Interface Sci.* **36**, No. 4, 443-460 (1971).

[190] T. Benfey, "Last word on polywater?" *Chemistry* **46**, No. 8, p. 4 (Editorial), September 1973.

the Analytical Chemistry Division.[191] Some of the capabilities of the device were evident in the note on "moon rock" analysis (in a previous section).

In principle, the technique was simple enough; a beam of energetic electrons was directed at a target, generating x rays whose energy depended upon the atomic number of the target constituents. By analyzing the energy and intensity of the x-ray spectrum as functions of the electron-beam location on the target, the operator could construct a map of the target that showed the identity and concentration of its constituent elements at each position. The map usually was rendered as one or more black-and-white microphotographs of the target area, with one picture for each impurity scan.

There were plenty of complications to the technique. The analytical methods were not especially simple and, typically, specimens were necessarily prepared with microscopically smooth surfaces to avoid distortion of the x-ray spectrum. Nevertheless, the electron microprobe developed into a powerful tool for chemical analysis.

The principal applications of electron microprobe analysis included metallurgy, mineralogy, ceramics, polymers and biology, with the last generally limited by the unresponsiveness of biological constituents (hydrogen, carbon, and oxygen), owing to their low atomic numbers.

Early in 1969, Heinrich and his colleague Harvey Yakowitz of the Metallurgy Division published a treatise on the conversion of the multiple black-and-white microprobe scans to single photographs in color, greatly simplifying the interpretation of the electron microprobe data.[192] Their technique, one of three methods initially proposed to introduce color into the analytic process, was to use the black-and-white scanning images as color-separation positives with different color filters for each scanned element.

In their paper, Yakowitz and Heinrich discussed the procedures required to prepare the composite color prints, including the use of fast color film, such as Polaroid, to quickly and inexpensively produce color images. By careful choice of the color filters, the operator could identify regions containing single elements as well as multiple-element areas of a particular sample.

New Scanning Electron Microscope Facility

During 1969 a new scanning electron microscope was installed in the laboratories of the Lattice Defects and Microstructures Section of the Metallurgy Division. A complement to the electron microprobe, it quickly became a favorite tool for an

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[191] For an introduction to this topic, see, for example, S. J. B. Reed, "Electron microprobe analysis," Second edition, Cambridge University Press, 1993, 326 pp. See also "The Electron Microprobe: Proceedings of the Symposium Sponsored by the Electrochemical Society, Washington, DC, October, 1964," T. D. McKinley, K. F. J. Heinrich, and D. B. Wittry, Editors, John Wiley & Sons, Inc., New York, 1966. The latter includes an extensive, indexed bibliography through 1964.

Use of the electron microprobe for quantitative analysis was the topic of "Quantitative electron probe microanalysis, Proceedings of a seminar held at NBS, Gaithersburg, MD, June 12-13, 1967," K. F. J. Heinrich, editor, *NBS Special Publication 298,* October 1968, 305 pp.

[192] Harvey Yakowitz and Kurt F. J. Heinrich, "Color Representation of Electron Microprobe Area-Scan Images by a Color Separation Process," *J. Res. NBS* **73A**, No. 2, 113-124, 1969.

interesting variety of studies, including lunar-rock samples, strained and fractured metals, dental surfaces, and tiny electronic devices. Its electron-beam probe produced images of 25 nm resolution that exhibited substantial depth of field. Unlike the earlier transmission electron microscope, thick samples with irregular surfaces could be observed with the SEM.

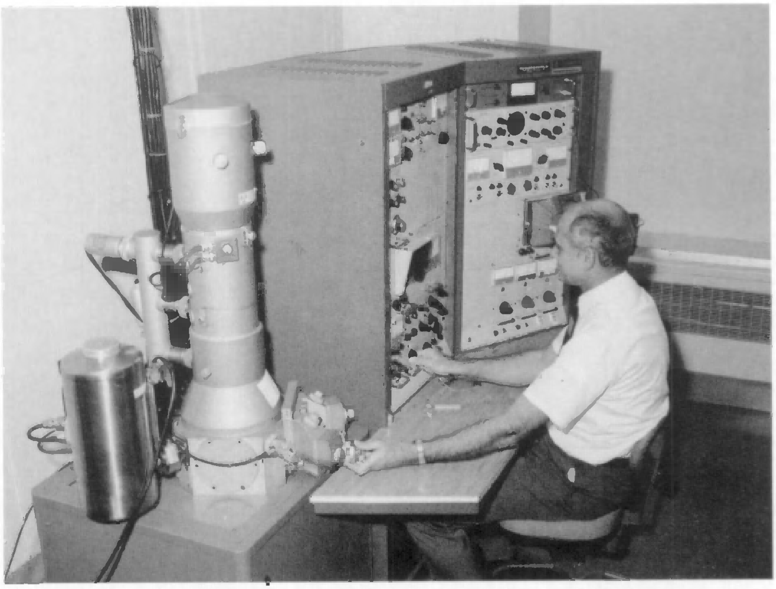
The first principal operator of the new device was David B. Ballard, an Indiana-bred metallurgist trained at the Virginia Polytechnic Institute. He found the microscope useful for his own work on the study of metallic fracture, and he also assisted colleagues in its use. Some thirty NBS scientists employed the new instrument within the first two years of its installation.

Chemistry Research

This section conveys some of the broad range of NBS studies during the early 1970s in the field of chemistry.

Chemical Impurities at Parts Per Billion

Combining the techniques of isotope dilution and spark-source mass spectrometry, an Analytical Chemistry Division group including Paul J. Paulsen, Robert Alvarez, and Daniel E. Kelleher found that they could detect impurity elements at concentrations as



David B. Ballard readied for operation the NBS scanning electron microscope and its associated electronics.

low as about 10^{-9}. In certain applications, for example in nuclear physics and electronics, the presence of impurities at that level could render a material useless for its intended purpose.

The method used by the group relied upon the use of enriched isotopes provided by external producers such as the Oak Ridge National Laboratory. Adding isotopes of a suspected impurity to a sample of the test material, then performing spark-source mass spectrometry, the group could evaluate the original concentration of the impurity at the extremely low levels desired. Initial tests of the method were successful in both platinum and zinc samples.[193]

Chemical Analysis With Flame Spectroscopy

The limit of detection for trace impurities receded noticeably as a result of a new method introduced by Analytical Chemistry Division researchers Oscar Menis, Theodore C. Rains, Kenneth W. Yee, and Herbert D. Cook, and W. Snelleman, their colleague from the Rijksuniversiteit in Utrecht, Netherlands. The group developed a flame-emission spectrometer which performed a rapid repetitive scan of a narrow wavelength region, minimizing spectral interference from the matrix in which the trace elements were held.

Key to the small, new device was a quartz plate vibrating at 145 Hz, and an amplifier tuned to twice that frequency. By providing a second-derivative signal, the new instrument gained substantially in sensitivity, eliminating the need for a monochromator of high resolving power. A second benefit was the ability of the device to identify trace elements in only 50 microliters (roughly a cube 3.6 mm on each side) of solution, extending the method to biochemical studies and monitoring of air pollution where sample sizes were necessarily tiny.[194]

Using Liquid Sodium Safely

During the late 1960s and early 1970s, liquid sodium was used as a heat-exchange fluid in certain nuclear power reactors. The application took advantage of the favorable thermodynamic and nuclear properties possessed by the liquid metal. However, sodium was inherently dangerous because of its extreme chemical reactivity. Some thought that the most corrosive properties of sodium arose from the presence of trace quantities of carbon or oxygen.

Detecting carbon and oxygen impurities in sodium and quantifying their amounts was not an easy problem, but it was one that George J. Lutz and Larry W. Masters could do. They used a combination of photon-activation analysis and rapid chemistry

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[193] R. Alvarez, P. J. Paulsen, and D. E. Kelleher, "Simultaneous determination of trace elements in platinum by isotope dilution and spark source mass spectrometry," *Anal. Chem.* **41**, No. 7, 955-958 (1969). See also P. J. Paulsen, R. Alvarez, and D. E. Kelleher, "Determination of trace elements in zinc by isotope dilution spark source mass spectrometry," *Spectrochim. Acta* **24B**, 535-544 (1969).

[194] W. Snelleman, O. Menis, T. C. Rains, K. W. Yee, and H. D. Cook, "Flame emission spectroscopy with repetitive optical scanning in the derivative mode," *Anal. Chem.* **42**, No. 3, 394-398 (1970).

to accomplish the job. They irradiated sodium samples with bremsstrahlung from the NBS electron linear accelerator, converting ^{16}O, the common isotope of oxygen, to ^{15}O; similarly, ^{12}C, the common isotope of carbon, was converted to ^{11}C. Rapid chemical separations were needed because the two light isotopes had half-lives of 2 min and 20 min, respectively.

For oxygen, Lutz found yields of about 50 % and a detection limit of about 2 ppm.[195] Lutz and Masters, using similar methods, could detect carbon as an impurity at levels below 1 ppm.[196]

Research on Reactive Molecules

In all probability, the parent of excitation chemistry at the Bureau was a 1954 discovery by Herbert P. Broida and John R. Pellam of strange glows and bright flashes from a dewar wall held at 4.2 K. Curious about the possibility of creating energetic new fuels for rocketry, they had diverted gases such as nitrogen, hydrogen, and oxygen through an electrical discharge, thus creating molecular fragments with unpaired electrons—free radicals.[197] It seemed possible that the highly energetic fragments could be stored at low temperatures for later use.

In 1956, the Department of Defense initiated a broad program of free-radicals research at NBS. It helped to support the work of more than 30 scientists, including Broida—head of the Bureau effort, Arnold M. Bass—his deputy and frequent collaborator, and many visitors from industry and academia. Among NBS employees associated with the program were James R. McNesby, Milton D. Scheer, Ralph Klein, Louis J. Schoen, Jerome Kruger, and Robert W. Zwanzig.

For three years, the group engaged in free-ranging studies of energetic materials and reactions. Although no "superfuel" for rockets materialized as a result of the program, nearly 100 scientific papers documented advances in materials and techniques brought forth during its existence.

The Free Radicals program was formally discontinued in July 1959 and its remaining staff members were integrated into a new Physical Chemistry Division in 1960, under the leadership of Merrill B. Wallenstein.

After the formal demise of the Free Radicals program, two Bureau scientists who continued studies of the chemistry of excited molecules were Dolphus E. Milligan and Marilyn E. Jacox. The two had met and collaborated on free-radicals research at the Mellon Institute of Industrial Research in Pittsburgh in 1958. Separately and more or less coincidentally, both joined the NBS staff.

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[195] G. J. Lutz, "Determination of oxygen in sodium by photon activation analysis," *Anal. Chem.* **42**, No. 4, 531-532 (1970).

[196] G. J. Lutz and L. W. Masters, "Determination of carbon in high purity metals by photon activation analysis," *Anal. Chem.* **42**, No. 8, (1970).

[197] H. P. Broida and J. R. Pellam, "Phosphorescence of Atoms and Molecules of Solid Nitrogen at 4.2 K," *Phys. Rev.* **95**, 845-846 (1954).

Milligan had learned of matrix-isolation spectroscopy as a student of George Pimentel at the University of California at Berkeley. Much of this work involved holding marginally stable, metastable, or unstable chemical species in a low-temperature matrix to stop the chemical reactions that ordinarily would prevent their observation.[198]

Jacox joined the Bureau staff in November 1962. When Milligan joined NBS in 1963, they renewed their collaboration on free radicals made from various small molecules, eventually using a Beckman IR9 spectrometer[199] to study the infrared spectra of a large variety of substances. Among these were: CF_2, CN_2, HNC, HCO, FCO, CF_3, ClCO, NCN, CH_3, SiF_3, $SiCl_2$, and $SiCl_3$.[200]

Vacuum-ultraviolet photolysis techniques used in the Photochemistry Section (see Ch. 4) made possible the study of the last four species in the list given in the previous paragraph. The same techniques permitted the study of molecular cations and anions. The first of these was C_2^-,[201] which was also the first molecular anion to yield a gas-phase electronic spectrum. Another important anion identified in this program was O_3^-.[202]

Jacox and Milligan also learned to make and identify other anions and cations produced by their matrix-isolation techniques.

In 1966, Milligan was awarded the prestigious Arturo Miolati Prize from the University of Padua, Italy. In 1970, Milligan and Jacox jointly received the Department of Commerce Gold Medal award for their work. In 1973, Jacox received the Federal Women's Award. In the same year, she and Milligan shared the NBS Stratton award for "their determination of the spectroscopic properties of charged radical ions in inert matrices at low temperatures, and the elucidation of their structures and chemical reactivities."

Radiation sources in the vacuum-ultraviolet range were the specialty of other groups that also were interested in chemically reactive species. One group was led by Pierre Ausloos. Hideo Okabe and James McNesby had similar interests. Their work is described in some detail in Ch. 4.

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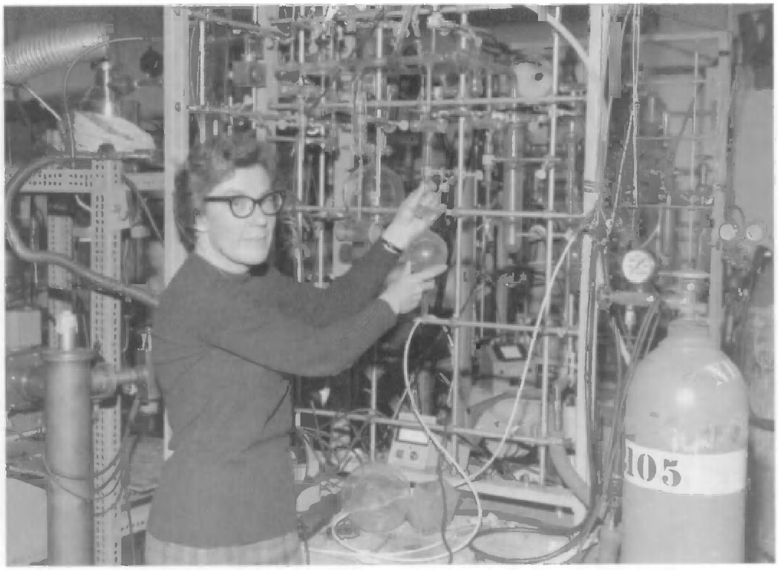
[198] Oral History, Marilyn Jacox, 11 February, 1998.

[199] According to Jacox (Oral History, February 11, 1998) a great advantage of this instrument was that its range extended from 4000 cm^{-1} to 400 cm^{-1}.

[200] D. E. Milligan and M. E. Jacox, "Infrared and ultraviolet spectroscopic studies of a number of small free radicals and molecular ions in a matrix environment," *Advances in High Temperature Chemistry* **4** (New York: Academic Press, 1971) Chapter 1, pp. 1-24. See also D. E. Milligan and M. E. Jacox, "Infrared and ultraviolet spectroscopic studies of free radicals and molecular ions isolated in inert solid matrices," *Molecular Spectroscopy;* Modern Research (New York: Academic Press, 1972) pp. 259-286.

[201] D. E. Milligan and M. E. Jacox, "Studies of the photoproduction of electrons in inert solid matrices. The electronic spectrum of the species C_2^-," *J. Chem. Phys.* **51**, No. 5, 1952-1955 (1969).

[202] M. E. Jacox and D. E. Milligan, "Vibrational and electronic spectra of the O_3^- anion isolated in an argon matrix," *J. Mol. Spectrosc.* **43**, No. 1, 148-167 (1972).



Marilyn Jacox adjusted the high-vacuum gas-handling system used in matrix isolation studies of reactive molecules.

During the same period, Henry M. Rosenstock, Vernon H. Dibeler, James A. Walker, and Kenneth E. McCulloh utilized photoionization and mass analysis to derive dissociation energies of excited species.[203]

Olefin Reactions at Low Temperatures

An olefin—also called an alkene—is an unsaturated hydrocarbon, i.e., it has one or more doubly-bonded carbon atom pairs. The simplest examples of this type of molecule are ethylene, whose formula can be written semi-graphically as $H_2C = CH_2$; propene, $H_3C–CH = CH_2$; 1-butene, $H_3C–CH_2-CH = CH_2$; 2-butene, $H_3C–CH = CH–CH_3$; and 1,3-butadiene, $H_2C = CH–CH = CH_2$. The olefins became interesting to chemists before World War II as the nature of free radicals became known.[204] It was hoped that, by studying the reactions of olefins, insight could be gathered into the mechanisms of chemical reactions and into the kinetic properties of the reactions.

[203] V. H. Dibeler, J. A. Walker, K. E. McCulloh, and Henry M. Rosenstock, "Effect of hot bands on the ionization threshold of some diatomic halogen molecules," *Intern. J. Mass Spectrom. Ion Phys.* **7**, 209-219 (1971). See also V. H. Dibeler, J. A. Walker, and K. E. McCulloh, "Dissociation energy of fluorine," Letter to the Editor, *J. Chem. Phys.* **50**, No. 10, 4592-4593 (1969).

[204] See, for example, Walter J. Moore, Jr. and Hugh S. Taylor, "The mercury photosensitized hydrogenation of ethylene, propylene, and n-butylene," *J. Chem. Phys.* **8**, 504 (1940).

In March 1966, Dolphus Milligan was presented the Arturo Miolati award by the Italian Ambassador to the United States at the Italian Embassy in Washington, while his children, his wife (left), Marilyn Jacox (second adult from left), Allen Astin (center), and others looked on.

Ralph Klein, Milton D. Scheer, and Richard D. Kelley of the Physical Chemistry Division, as part of the Bureau's Free Radical Program, began study of the hydrogenation of olefins at low temperatures during the early 1960s.[205] The use of low temperatures was commenced in order to slow or eliminate some of the many reactions which could so complicate the experiments as to defy analysis. Another tool used by Klein, Scheer and Kelley was a matrix of inert molecules (typically propane) to dilute the active olefin radicals.

[205] Ralph Klein and Milton D. Scheer, "Matrix effects in the gaseous hydrogen atom—olefin diffusion model," *J. Phys. Chem.* **66**, 2677 (1962). See also R. Klein, M. D. Scheer, and R. D. Kelley, "Disproportionation-combination reactions of alkyl radicals and hydrogen atoms at low temperatures," *J. Phys. Chem.* **68**, 598 (1964).

By 1970 the group began to understand some of the elementary reaction steps that occurred in this type of system and experimented with atomic oxygen and with deuterium as alternative reactants.[206] By analyzing the products that resulted from the various reactions, they could speculate on the reactive pathways followed by the olefin radicals. Mainly, these took the form of disproportionation reactions—such as the formation of normal butane and 2-butene from the hydrogenation of 1-butene—or of dimerization. Differences arising from the use of atomic deuterium as a reactant instead of atomic hydrogen occasionally were spectacular—changes in product concentrations by factors of as much as three, indicating the existence of a tunneling mode in these reactions. The oxygenation reactions showed direct relevance to air-pollution problems, such as the production of aldehydes and ketones, well-known as eye irritants in smog.

During this time period, Klein also studied chemisorption and decomposition of reactive species on metals. Ruthenium was a favorite target, field emission microscopy a favorite tool. Over the next decade, Klein teamed with John T. Yates, Jr., Allan J. Melmed, James W. Little, Theodore Madey, and Arnold Shih, a collaborator from the U.S. Naval Research Laboratory, to elucidate the activity of such molecules as nitric oxide. The scientists obtained information on physisorption *vs* chemisorption, chemical binding states, and work functions.[207]

Awards For Prominent Chemists

Two prominent Bureau chemists were recognized by outside organizations for the excellence of their work during Branscomb's tenure as director.

Robert S. Tipson, a member of the NBS staff since 1957, received the 1971 Hudson Award from the American Chemical Society's Division of Carbohydrate Chemistry. Tipson, a research chemist in the Analytical Chemistry Division, was recognized internationally for his studies in carbohydrate chemistry.

Then 65 years of age, the English-born Tipson was in the midst of collaborations with colleagues Barbara F. West, Robert F. Brady, Jr., and Alex Cohen on the reactions of sulfonic esters, on acid hydrolysis of acetals, on synthesis of pentuloses, and on the preparation of D-psicose.[208]

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[206] R. Klein and M. D. Scheer, "Reaction of O(^{3}P) with 2-methyl-2-pentene at low temperatures and its implication for the transition state," *J. Phys. Chem.* **73**, 1598 (1969). See also R. Klein and M. D. Scheer, "Addition of oxygen atoms to olefins at low temperatures. IV. Rearrangements." *J. Phys. Chem.* **74**, 613 (1970). For a brief summary of this work, see the *NBS Technical News Bulletin* **54**, No. 6, 119-120, June 1970.

[207] See, for example, Ralph Klein and Arnold Shih, "Chemisorption and decomposition of nitric oxide on ruthenium," *Surface Science* **69**, pp. 403-427 (1977).

[208] R. S. Tipson and A. Cohen, "Reaction of some sulfonic esters of D-mannitol with methoxide: synthesis of 2,3:4,5-dianhydro-D-iditol," *Carbohydrate Res.* **7**, 232-243 (1968). See also R. S. Tipson, B. F. West, and R. F. Brady, Jr., "Acid-catalyzed hydrolysis of isopropylidene acetals of some 2-pentuloses and 2-hexuloses," *Carbohydrate Res.* **10**, 181-183 (1969). See also R. S. Tipson and R. F. Brady, Jr., "Synthesis of the two D-2-pentuloses. New derivatives of D-erythro-pentulose," *Carbohydrate Res.* **10**, 549-563 (1969). See also R. S. Tipson, R. F. Brady, Jr., and B. F. West, "Cyclic acetals of ketoses, Part IV. Re-investigation of the oxidation of 1,2:4,5-Di-O-isopropylidene-β-D-fructopyranose with methyl sulfoxide-acetic anhydride," *Carbohydrate Res.* **16**, 383-393 (1971).

Ralph Klein (seated) and Arnold Shih made observations on the desorption and decomposition of nitric oxide on a ruthenium surface.

John K. Taylor, a member of the Analytical Chemistry Division, continued to receive the plaudits of his professional peers. He was presented the 1972 Professional Service Award of Alpha Chi Sigma for his long, continuous service to chemistry.

Taylor was a Washington, DC, native who had joined NBS as a laboratory assistant upon graduation from high school in 1929. While a Bureau employee, Taylor earned a B.S. degree in chemistry from George Washington University and M.S. and Ph.D. degrees in chemistry from the University of Maryland. In the meantime, he undertook ever more ambitious and meaningful laboratory investigations in the fields of analytical and electrochemistry. He wrote more than 200 scientific articles and wrote or edited seven books on chemistry or quality assurance—a field of work that felt his impact during his later years.

By the time he retired in 1986, Taylor's excellent work and longevity had been recognized by President Ronald Reagan. Taylor received many awards. Among them were the DC Education Association Award in 1965; the Joint Board of Science Education Award in 1966; the Department of Commerce Gold Medal in 1967; the Honor Scroll of the American Institute of Chemists in 1968; and the Service Award of the Chemical Society of Washington in 1969.

Cryogenic Liquids, Then and Now

We noted in Chapter 1 that the Cryogenics Laboratory at NBS/Boulder came into being to supply liquid hydrogen and liquid deuterium for testing and production of thermonuclear weapons. With the successful tests of the thermonuclear-explosion concept in 1951 and 1952, the value of the Cryogenics Laboratory was clear. In 1953, the Department of Commerce Gold Medal award for "The design, construction, and operation of large and unique hydrogen and nitrogen liquefiers" was given jointly to Paul G. Baird, Bascom W. Birmingham, Ferdinand G. Brickwedde, Dudley B. Chelton, George A. Freeman, William F. Goddard, Victor J. Johnson, Richard Kropschot, Robert L. Powell, Russell B. Scott, and Peter C. Van der Arend.

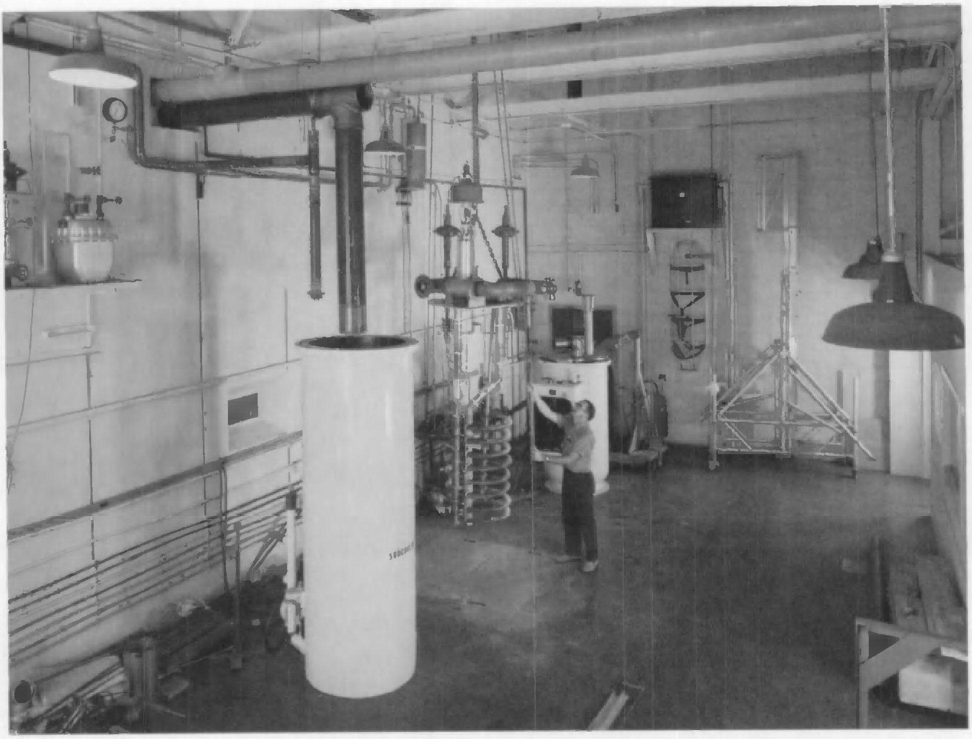
The special-weapons work did not spell the end of the laboratory's work with large quantities of liquid cryogens, however—far from it. During the 1950s the staff also was asked to assist scientists at the University of California Radiation Laboratory (UCRL) in the design and construction of an unusually large hydrogen bubble chamber for use in tracking sub-atomic particles emanating from experiments in the accelerators there. In the process, the Boulder group—Bascom W. Birmingham, Dudley B. Chelton, and Douglas B. Mann—spent considerable time in teaching the UC scientists how to handle the explosive liquid.

The effort spent at UCRL paid off in a big way during the winter of 1968–1969, when Luis W. Alvarez was awarded the 1968 Nobel Prize in physics in recognition of his discoveries in the field of elementary particles. His work depended heavily upon the use of the hydrogen bubble chamber that Birmingham, Chelton, and Mann had helped bring to reality. Alvarez gave full credit to the Bureau scientists for their contributions to his work.

One of the outstanding problems in the cryogenics industry was that of accurately metering the transfer of cryogenic liquids. Cryogens constituted a valuable component of U.S. industrial production—about $500 million in 1970, expected to triple by 1975. So it was with great enthusiasm that the Compressed Gas Association and officials of the California Weights and Measures Department teamed with members of the Boulder Cryogenic Engineering Division to establish a flowmetering and flow research facility at the Boulder laboratory of NBS.

It might have seemed a simple problem to meter the flow of, say, liquid nitrogen. After all, one could readily ascertain the amount of gasoline pumped into an automobile tank to two decimal places, using pumps certified by the weights and measures officials of any of the United States. However, the extreme cold generated in the metering equipment and the significant changes in density of the cryogens with substantial changes in temperature or pressure interfered considerably with the accuracy of cryogen deliveries.

The state of California sought in 1967 to create a code for cryogenic flowmetering, with an accuracy goal no worse than ± 3 %. NBS efforts to participate in the technical aspects of the project foundered on the shoals of insufficient funding at that time, but the vocal support of the industry gradually raised the priority of the task for the Bureau. Careful plans were prepared for the eventual creation of an NBS cryogenic flowmetering facility. Douglas B. Mann was placed in charge of the project.



James Brennan assembled a liquid nitrogen heat exchanger at the NBS cryogenic flowmetering and flow research facility in Boulder, Colorado.

In 1970 the facility completed its first year of operation.[209] A closed flow loop permitted the continuous operation of flowmeters under test, to monitor both accuracy and wear. The system could be operated isothermally at any temperature from 63 K to 115 K, at any pressure from 7 kPa to 2000 kPa, and at flow rates from 76 L/min to 760 L/min.

One of the unique features of the loop was a flow diverter valve. It proved necessary for the NBS staff to design and manufacture a suitable valve, since none available commercially could promise the leak-proof service needed to ensure accuracy. Another component unique to the project was a weigh tank used to monitor the amount of cryogen delivered within a given time through the test meter.

As the facility began its service, Mann contemplated needed improvements, including the ability to directly measure quantities of liquid oxygen and the development of a transfer standard for use in the field. But the basic capability, a cryogenic flowmetering facility, was a reality.

[209] "Cryogenic flowmetering at NBS," *NBS Technical News Bulletin* 54, No. 8, pp. 167-169, August 1970.

Protecting the Consumer

Among the many consumer-oriented programs at NBS, two of the most visible ones were in law enforcement and vehicle safety. We note in this section the progress in each of these during the Branscomb years.

Standards For Law Enforcement

In 1967, the President's Commission on Law Enforcement and Administration of Justice took notice of the growing trend towards lawlessness and disorder on American streets in a report entitled *The Challenge of Crime in a Free Society.* The Commission urged that a Federal agency be assigned to "coordinate the establishment of standards for equipment to be used by criminal-justice agencies, and to provide those agencies with technical assistance." Perhaps remembering the work of Wilmer Souder, an NBS physicist who long ago had served as an expert analyst of ransom notes, inks, bullet fragments, and other forensic evidence, the writers named the Bureau as a suitable place for the job. Their faith was justified.

On June 19, 1968, the 90th Congress passed the *Omnibus Crime Control and Safe Streets Act of 1968 (Public Law 90-351).* Its preamble stated:

> Congress finds that the high incidence of crime in the United States threatens the peace, security, and general welfare of the Nation and its citizens. To prevent crime and to ensure the greater safety of the people, law enforcement efforts must be better coordinated, intensified, and made more effective at all levels of government.

The text of the Act made clear its aim to strengthen state and local law-enforcement capabilities. This goal would be accomplished by a team centered in the Department of Justice, where a Law Enforcement Assistance Administration (LEAA) would be created. As part of the LEAA, there would be a National Institute for Law Enforcement and Criminal Justice (NILECJ); its job would be to activate a program of research and development to give state and local police the tools they needed to fight crime more effectively.

During its first year of existence, NILECJ—at the suggestion of the Law Enforcement Commission—turned to NBS for help. Once ground rules for funding, personnel, and relationships were worked out, a memorandum of understanding was signed by the two organizations. Irving Slott, Acting Director of the LEAA, transferred $400,000 to the Bureau to fund a new entity for NBS, the Law Enforcement Standards Laboratory.[210]

Paul J. Brown, experienced in the creation of interdepartmental entities,[211] was named the first Director of LESL. Within a year, Richard B. Morrison succeeded him at that position.

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[210] Letter from Irving Slott to Lewis Branscomb, December 22, 1970; RHA; Director's Office; Box 390; Folder January 1-31, 1971.

[211] Brown had earlier helped organize the Office of Vehicle Systems Research to work with the Department of Transportation.

LESL quickly found flaws in the way that state and local police armed and equipped themselves. In the absence of national standards for equipment, police groups tended to copy equipment specifications from other departments or to make use of sales literature in their purchases. Accordingly, LESL assigned its staff to develop standards programs in several areas:

- Vehicle standards, led by Richard Morrison, to consider type of terrain, climate, type of use, steering, brakes, suspension, tires, engines, equipment-carrying capability, stability, durability, safety, and comfort.
- Communications equipment, led by Marshall J. Treado, to consider portable radios and power supplies, voice scramblers, digital systems, and automatic vehicle locators.
- Security systems, led by Marshall Isler, to consider false-alarm rates (estimated by some departments to be as high as 90 %), alarm sensors (sound, vibration, heat, motion), surveillance, locks, protective room equipment, safes, and night-vision devices.
- Concealed-object detectors, led by Robert Mills, to consider detection methods for metallic weapons, narcotics, and explosives.
- Protective equipment and clothing, led by Jacob J. Diamond, to consider guarding against injury from bullets, bombs, fire, thrown missiles, tear gas, carbon monoxide, vehicles, rain, and snow. Items specific to certain conditions were investigated, including body armor, helmets, face shields, breathing masks, ear-muffs, seat belts, and apparel to resist damage from radiation, heat, flame, chemicals, rain, and cold, while permitting needed range of motion.
- Emergency equipment, led by Avery T. Horton, to consider first aid equipment, emergency procedures, and the standardization of emergency-identifying flashing lights.
- Police weapons, led by Jacob Diamond, with virtually all preliminary developments—for both lethal and non-lethal weapons—to be performed by outside contractors.
- Building systems, led by Avery T. Horton, to consider the design and evaluation of all law-enforcement buildings, construction materials, furnishings, and other building equipment and supplies.[212]

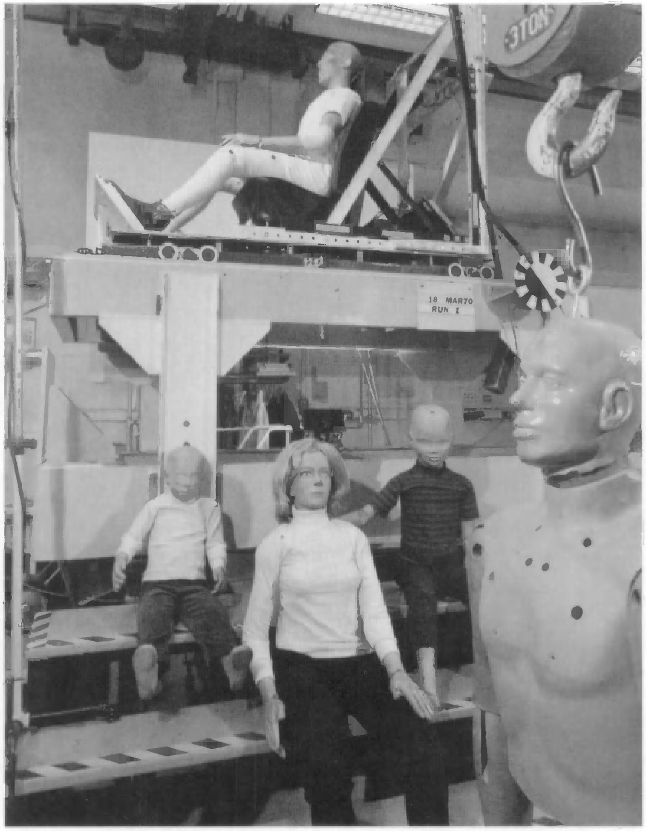
The new-born LESL did not build its own laboratory at the Bureau, but purchased research and development from existing NBS groups or from outside contractors. Thus the LESL staff became "matrix"-type program managers. NBS divisions involved in the work included electromagnetics, analytic chemistry, applied radiation, mechanics, heat, building research, technical analysis, measurement engineering, and electronic technology.

[212] "NBS Works with Justice Department on Modern Law Enforcement Standards," *NBS Technical News Bulletin* **56**, June 1972, pp. 139-141, 149.

Automobile Crash Testing

In 1969, the program of the Bureau's Office of Vehicle Systems Research was continued by agreement between the Department of Commerce and the Department of Transportation. The National Highway Safety Bureau was glad to have access to the objectivity and expertise of NBS in the field of auto safety.

One project, reported by OVSR's Richard F. Chandler and Robert A. Christian, detailed problems inherent in simulating the effects of automobile crashes on human occupants.[213] They noted that, unlike standard auto design—which relies heavily on anthropomorphic data obtained from live subjects—crash testing utilized dummies or cadavers.



A family of dummies—a 217-pound male, a 105-pound female, and their children weighing 31 and 49 pounds—awaited a sled ride at the NBS that would subject them to the same force as a crashing car. This research on occupant restraint systems was sponsored by the Department of Transportation.

[213] R. F. Chandler and R. A. Christian, "Crash testing of humans in automobile seats," pp. 112-132 in *Proc. Society of Automotive Engineers Safety Conf., May 13-15, 1970, Detroit* (New York: SAE, June 1970).

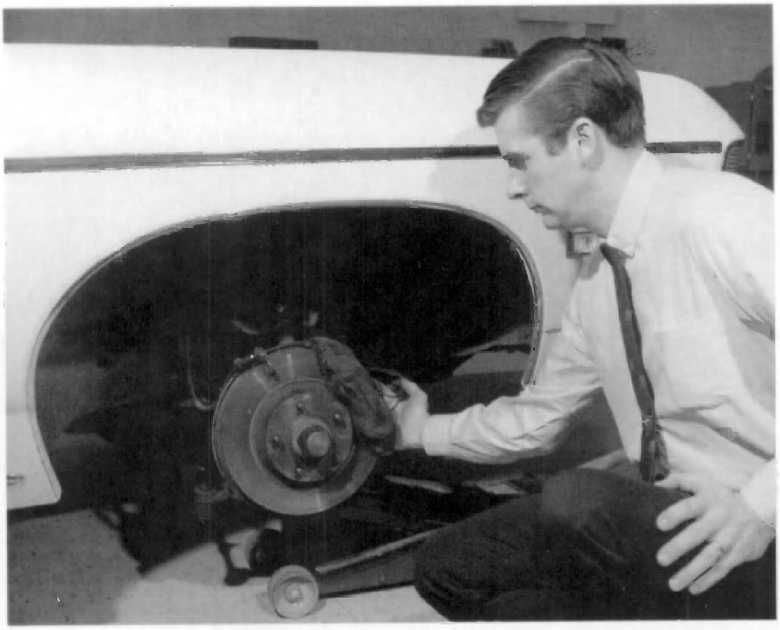
To augment the meager store of data on human response to automobile crashes, the Bureau scientists initiated a "crash" program with colleagues operating the Daisy Decelerator at Holloman Air Force Base. The testing included 32 trials in which human subjects participated in simulated crash decelerations while sitting in production-model auto seats and wearing restraints of various types. By repeating the tests with dummies, they were able to relate the more extensive data obtained with the use of dummies to actual human responses.

A critical part of automobile-crash safety was the effectiveness of seat belts. Personnel of the OVSR used a variety of test equipment to evaluate the breaking strength of manufacturer-installed belts, as well as their resistance to abrasive wear in use.

Dorian Sanders of the NBS Office of Vehicle Systems Research positioned seatbelt webbing in a tensile test machine. The resulting data was used to update Federal automotive standards in the early 1970s.

Pushing on the Brakes

The then-current *Federal Motor Vehicle Safety Standard* for braking force by a driver called for the exertion of 200 pounds on the automobile brake pedal. Curious about the difference in strength between men and women, Richard W. Radlinski and James I. Price tested 105 women, using actual automobiles as the test stations. They found that fewer than half of the women could actually meet the force standard, clearly demonstrating a need for re-evaluation of the Federal code.[214]

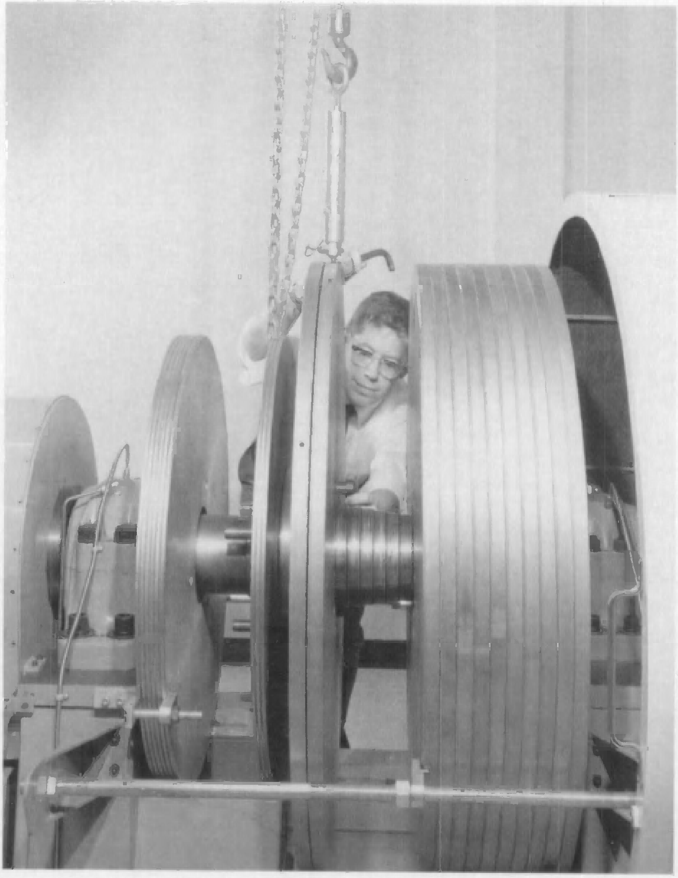


Richard Radlinski of the NBS Office of Vehicle Systems Research checked the leads to a temperature sensor placed on automobile disc brakes.

With Robert J. Forthofer and Jack L. Harvey, Radlinski evaluated the effect of water on the performance of brake fluids.[215] They found that most brake systems took on road water through connecting hoses, causing a reduction in the temperature at which vapor lock took place and increasing the fluid density at temperatures near the water freezing point. They obtained data on water-contaminated brake fluids under various conditions.

[214] R. W. Radlinski and J. I. Price, "The brake pedal force capability of adult females," *NBS Tech. Note 557*, 25 pp., October 1970. See also "Panic stops: are women strong enough?" *NBS Technical News Bulletin*, January 1971, pp. 15-16.

[215] R. W. Radlinski, R. J. Forthofer and J. L. Harvey, "Operating performance of motor vehicle braking systems as affected by fluid water content," *Proc. Society of Automotive Engineering Conf.*, pp. 1-11, Jan. 11-15, 1971.



John Preston adjusted weights on the NBS dual-end inertia dynamometer, used to study automotive braking systems in the laboratory. The machine could be set to simulate vehicles weighing from 900 to 14,000 pounds. Data obtained with the device compared well with actual road-test results.

Slippery when Wet!

Disturbed by reports of numerous wet-weather accidents occurring along the interstate highway closest to NBS,[216] the Office of Vehicle Systems Research developed a test for pavement skid resistance. Under the direction of F. Cecil Brenner, chief of the OVSR tire systems section, OVSR staff members fitted a truck to tow a test rig that was mounted on a two-wheeled trailer. Tires with known braking properties could be individually locked as the rig was driven along the "interstate" while water was sprayed on the roadway. Recording equipment provided data on the frictional force exerted on the axle of the skidding wheel.

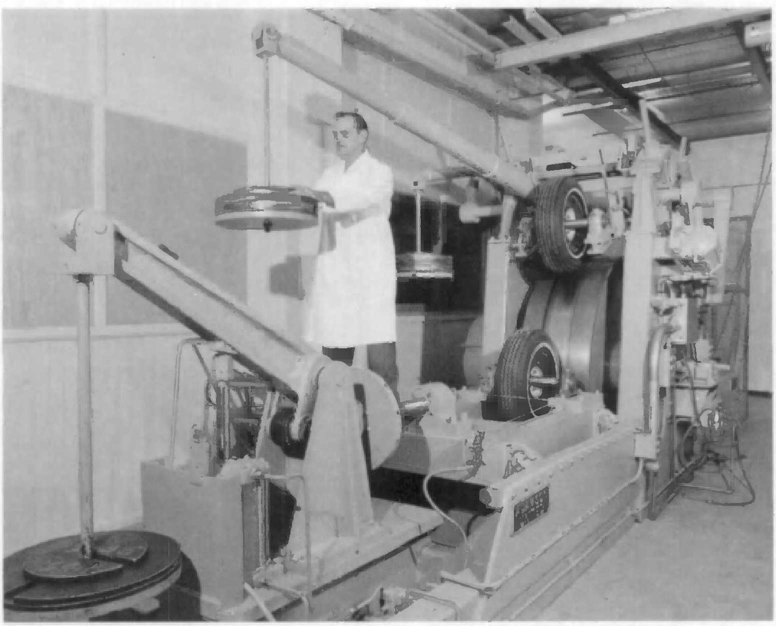
[216] More than 100 wet-weather crashes took place on Interstate 70S (later designated I-270) during 1968-69. Details of the Bureau skid program are given in "Warning—Slippery when Wet," *NBS Standard*, Vol XV, No. 1, January 1970, pp. 1, 4.

The road tests showed that the interstate road surface became unsafe in wet weather. At seven of eight test locations, the wet-highway skid resistance was below the norm even for low-speed, rural roads; at one location, the wet surface reacted as if it had been coated with ice!

Brenner ascribed the dangerous condition to the tendency of the surface—initially prepared from rough aggregates—to become smoother with use because of the "polishing" effect of traffic. In addition to its official reports on the testing, OVSR provided Bureau employees with appropriate hints to avoid commuting accidents in wet weather.

A Grading System for Tires

Systematic research on tire wear was performed by OVSR staff in order to develop a uniform and reliable grading guide. F. Cecil Brenner and Akira Kondo participated in testing tires on two road courses built in Texas. Results were obtained for some 18 different brands of commercially available passenger-car tires.[217]



Tire endurance and heat sensitivity were tested on the "NBS Wheel," a large wheel 1/300 of a mile in circumference. Dallas Rhodes positioned weights to simulate the weight of a vehicle. A similar wheel was used at the Bureau as early as 1920.

[217] F. C. Brenner and A. Kondo, "Research for a uniform quality grading system for tires. IV. Tread wear," *Rubber Chem. Technol.* **44**, No. 1, pp. 106-121, March 1971.

In a separate series of tests, Brenner and Kondo compared the mileage expectancy for front-wheel-drive automobiles and those using rear-wheel drive. They found that tires wore twice as fast if they were on the front wheels of a front-wheel-drive car as they did on the rear wheels of the same vehicle, whereas tire wear was nearly the same on both axles of rear-wheel drives. However, frequent rotation of the tires on the front-wheel-drive vehicles made them last nearly as long as tires on rear-wheel-drive cars.[218]

Teaching Computers to Serve

The first fully operational, automatic, electronic computer in the United States was the Standards Electronic Automatic Computer (SEAC), built at NBS.[219] The useful life of SEAC began in May 1950 and extended into 1964, despite its designation as an "interim" development. Because of this early experience, NBS staff members who worked on the SEAC were asked by the Bureau of the Census, the U.S. Army, and the U.S. Air Force to monitor progress on a fully automatic computer—the UNIVAC machine.[220]

As a result of assignments given to NBS by the Brooks Act (Public Law 89-306, 1965), the Bureau provided a broad range of services on the use of computers—from guidance on hardware and software standards to performing research involving computers in all sorts of projects.[221]

The work was focused in the Center for Computer Science and Technology. As we noted earlier, Director Branscomb placed Ruth M. Davis in charge of the CCST program and its staff of about 150 people. The program, already strong, continued its tradition of service under Davis until her departure from the Bureau in 1977.

Managing the UNIVAC 1108

The NBS main-frame computer, a UNIVAC 1108/418, provided workhorse service—three shifts of operators a day—to Bureau employees and to outsiders who were connected to it by telephone hookups. A typical remote-site customer, the Economic Development Administration, utilized the UNIVAC to develop a data base and data-handling procedures for several years before its own computer system became available.

[218] A. Kondo and F. C. Brenner, "Research for a uniform quality grading system for tires. VI. Comparison of the effect of front and rear wheel drive vehicles on projected tread wear of a tire," *Rubber Chem. Technol.* No. 4, pp. 960-961, September 1971.

[219] Russell A. Kirsch kindly furnished the references for this paragraph.

[220] "Computer development (SEAC and DYSEAC) at the National Bureau of Standards," *NBS Circular 551*, 1955.

[221] A useful discussion of the work of the Center for Computer Sciences and Technology during this period appears in "NBS Technical Highlights, 1970," *NBS Special Publication 340*, February 1971, pp. 174-185.

An Office of Computer Information was set up within the Center to provide a magnetic-tape-based information-retrieval service, along with a database involving NBS reports, useful computer programs, and guidelines for Automatic Data Processing systems.

FIPS Publications

Federal Information Processing Standards (FIPS) were created for the benefit of the user community. These standards provided official information on computer use. They were published by the Bureau as a non-periodical series. The titles of the first ten FIPS publications give an idea of the topics treated by the standards:

- FIPS PUB 0: General Description of the Federal Information Processing Standards Register;
- FIPS PUB 1: Code for Information Exchange.
- FIPS PUB 2: Perforated Tape Code for Information Exchange.
- FIPS PUB 3: Recorded Magnetic Tape for Information Exchange.
- FIPS PUB 4: Calendar Date.
- FIPS PUB 5: States of the United States.
- FIPS PUB 6: Counties of the States of the United States.
- FIPS PUB 7: Implementation of the Code for Information Interchange and Related Media Standards.
- FIPS PUB 8: Metropolitan Statistical Areas.
- FIPS PUB 9: Congressional Districts of the United States.

As of early 1971, another half-dozen standards—on bit sequencing, character structure, and other details of computing practice—were awaiting approval at the Office of Management and Budget. Most of these were written by Harry S. White, Jr.

Computer Hardware and Software

A new Standard Reference Material, SRM 3200, provided magnetic tape for use in evaluating the performance of magnetic tape produced by various industrial organizations. The standard was developed by Sidney B. Geller of the CCST along with a tape-evaluation system that could be used in calibration.[222] An updated version of the system was presented by NBS to the Magnetic Surfaces Laboratory of the General Services Administration to be used in governmental acceptance testing.

[222] S. B. Geller, "Calibration of NBS secondary standard magnetic tape (computer amplitude reference) SRM 3200 using the reference tape amplitude measurement 'Process A' Model II," *NBS Special Publication 260-29*, 57 pp., June 1971.

Consultations

Several CCST staff members were involved essentially full-time in providing consulting services to NBS and to other government agencies. Some of the assistance took the form of responses to telephoned requests for help; much of it, however, involved long-range projects intended to develop specialized computer systems. Automation of data acquisition in Bureau scientific laboratories was a prime need, both to save valuable time for the scientists and their assistants and to make possible the acquisition of data beyond the capability of manual dexterity. As smaller, more powerful individual computers became available to Bureau staff members, automatic data acquisition became both spectacular in its sophistication and routine in its ubiquity.

An example of the marriage of computers to laboratory equipment was given in 1969 by Philip G. Stein of the Information Processing Division. Collaborating with Lewis Lipkin and Howard Shapiro, both staff members of the National Institutes of Health, Stein linked an optical microscope with an image-plane scanner, a motor-driven stage and a general-purpose computer. Stein "taught" the computer to move the microscope stage in such a way as to scan an image in the *x-y* plane, then repetitively at successive values in the vertical, or *z*, direction. This process produced a three-dimensional image of the subject material, allowing a whole variety of computer-controlled operations.[223]

Phillip Stein of the NBS Center for Computer Science and Technology viewed a slide through a computer-controlled microscope that he developed in collaboration with the National Institutes of Health in 1969.

[223] P. G. Stein, L. E. Lipkin, and H. M. Shapiro, "Spectre II: General-purpose microscope input for a computer," *Science* **166**, pp. 328-333 (1969).

In exploratory efforts to expand the capabilities of computers in the laboratory, the CCST initiated measurements of the performance of remote-access systems, first in a time-sharing mode with a large central unit, then with smaller, personal systems. Center employees also designed data-acquisition and filing systems, interactive programs, and graphics displays for the use of computer-illiterate personnel.

Superconductivity, a Versatile Property

Superconductivity, a state of matter that was unknown at the time of the Bureau's founding (the property was discovered in the laboratory of H. Kamerlingh Onnes in Leiden, The Netherlands, in 1911), began to enter into the language of NBS standards and instrumentation during this period. A few examples illustrate the usefulness of this phenomenon in Bureau projects.

Superconductors, Josephson Junctions, and the Volt Standard

Two-layer junctions formed of two superconducting films separated by a thin insulating layer behave according to equations put forward by Brian Josephson in 1962.[224] Shortly after Josephson's predictions, "Josephson effects" were found experimentally; in the course of studying the sometimes complicated current-voltage characteristics of Josephson junctions, properties of distinct utility to NBS goals appeared.[225]

One of the properties of Josephson junctions that interested the Bureau's Electricity Division was their ability to provide voltage references that appeared to be extremely stable. In 1967, Barry N. Taylor, then at the RCA Laboratories, and his colleagues W. H. Parker, D. N. Langenberg, and A. Denenstein of the University of Pennsylvania called attention to the limited accuracy of the chemical cell used to maintain the standard of electromagnetic force, and postulated a new voltage standard based upon the ac Josephson effect.[226] A tendency of the cell voltage to change slowly with time made the maintenance of a standard of emf into a challenging task indeed—it required careful storage and handling and frequent intercomparisons among a group of cells.

The authors tested the idea of a new voltage standard with Josephson junctions composed of crossed strips of tin, separated by a thin tin oxide layer; crossed strips of lead, separated by a thin lead oxide layer; combinations of lead and tin strips, again separated by oxide layers; and various types of "point contacts," similar in configuration to a pencil-point pressed against a solid block. All of the junctions obeyed one Josephson relation involving microwave radiation and voltage—the ratio of the microwave frequency to the voltage was always equal to the constant quantity $2e/h$, where e is the elementary charge (the absolute value of the charge on the electron)

[224] B. Josephson, *Phys Lett.* **1**, 251 (1962).

[225] See, for example, Vladimir Z. Kresin and Stuart A. Wolf, *Fundamentals of Superconductivity,* (New York: Plenum Press, 1990), Ch. 12.

[226] B. N. Taylor, W. H. Parker, D. N. Langenberg, and A. Denenstein, "On the use of the ac Josephson effect to maintain standards of electromotive force," *Metrologia* **3**, No. 4, 89-98 (1967).

and h is Planck's constant. They found results that were consistent within the 4 ppm uncertainty limitation imposed by the reference voltage cells. Better accuracy was not possible at that time because of the uncertainty (about 30 ppm) with which the ratio e/h was known.

By 1970, Taylor was an NBS employee—Chief of the Absolute Electrical Measurements Section of the Bureau's Electricity Division. He was beginning a robust Bureau career in the study of precision measurement and fundamental constants. In the same year, Forest K. Harris, the former section chief, Howland A. Fowler, and P. Thomas Olsen unveiled a new type of potentiometer built especially to compare voltages obtained from standard chemical cells (about 1 V) with voltage signals generated by Josephson junctions (a few millivolts).[227] The new instrument was capable of comparing dc voltage signals in the range 2 mV to 10 mV against standard-cell voltages with uncertainties of only 0.1 ppm.[228]

Comparatively ordinary superconducting tunnel junctions, prepared in a manner similar to Josephson junctions, were shown to provide reproducible voltage signals when maintained at a fixed temperature, although the magnitude of the voltage signals could not be calculated by the Josephson relations. Thomas F. Finnegan, a Bureau postdoctoral research associate, and A. Denenstein suggested that the inconveniently small voltages (about 2 Mv) generated by Josephson junctions could be overcome by the use of multiple, series-connected junctions.[229] Their ideas were later improved at NBS by the use of multiple Josephson junctions.

By the end of 1972, the uncertainty in values of $2e/h$, measured in terms of the laboratory unit of voltage at NBS, at the National Standards Laboratory in Australia, at the National Physical Laboratory in England, and at other national laboratories, reached a low of 0.1 ppm.[230]

Thermometry with Superconductors

Random noise in electrical circuits, known as Johnson noise, arose because the electrons in the circuit were thermally excited in a random way. For this reason, many scientists used measurements of Johnson noise to determine temperature. In principle, the noise voltage depended directly upon the resistance of a circuit element and upon its temperature. Success in such experiments usually depended upon the expenditure of great effort to exclude from the measurements all sources of electrical noise of the non-Johnson variety; these were many and pervasive.

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[227] F. K. Harris, H. A. Fowler, and P. T. Olsen, "Accurate Hamon-pair potentiometer for Josephson frequency-to-voltage measurements," *Metrologia* **6**, No. 4, 134-142 (1970).

[228] "Accurate measurements of Josephson junction voltage," *NBS Tech. News Bull.*, January 1971, p. 3.

[229] T. F. Finnegan and A. Denenstein, "A new transfer and maintenance voltage standard using superconducting tunnel junctions," *Metrologia* **7**, No. 4, p. 167 (1971).

[230] I. K. Harvey, J. C. Macfarlane, and R. B. Frenkel, "Monitoring the NSL standard of emf using the ac Josephson effect," *Metrologia* **8**, No. 3, 114-124 (1972). See also J. C. Gallop and B. W. Petley, "A new NPL determination of $2e/h$," *Metrologia* **8**, 129-132 (1972).

It occurred to Robert A. Kamper of the NBS/Boulder Cryogenics Division that Josephson junctions might be employed as voltage-to-frequency converters to detect the Johnson noise in a resistor held at temperatures within a few thousandths of a kelvin of absolute zero.[231] The determination of temperatures in that range was a chancy undertaking. Thermal equilibrium among the various parts of an experiment could not be guaranteed, and few indeed were thermometers that could be classified as reliable in that range. Thus Kamper's idea was welcomed in the special world of ultra-low-temperature thermometry.

The Johnson noise voltage in a cold resistor could be made to appear as "jitter" in the voltage observed across the resistor when a particular current was passed through it. If a Josephson junction were to be connected across the resistor, reasoned Kamper, the voltage jitter could appear as a linewidth of the radiation emanating from the junction. Determinations of thermal-noise voltage could then be made in terms of the scatter of frequency observations, measurements capable of relatively high precision.

Recruiting his Bureau colleagues James D. Siegwarth, Raymond Radebaugh, and James E. Zimmerman, Kamper formed a group that quickly demonstrated the usefulness of the idea. They assembled an experiment involving the use of a special refrigerator that could reach temperatures below 0.02 K, a Josephson junction formed by an adjustable niobium point contact and protected from non-Johnson noise by a superconducting niobium shield, a 10^{-5} Ω resistor, and a signal-amplifying circuit that was carefully shielded against non-Johnson noise.

The group evaluated its success by comparing the temperature values determined from their Johnson noise thermometer against temperature values derived from measurements of the susceptibility of a paramagnetic salt. As the experiment was refined, the values came more nearly into agreement, eventually differing by 0.003 K at 0.020 K.[232] It was a formidable achievement.

The noise thermometry experiments of Kamper and his colleagues in Boulder were extended and perfected over a 20-year period by Robert J. Soulen, Jr. and his colleagues in Gaithersburg. This part of the story is summarized in Ch. 6.

A quite different approach to the use of superconductors for thermometry was taken by James F. Schooley, Robert J. Soulen, Jr., and George Evans. Realizing the difficulty of performing temperature measurements below 10 K—a regime in which new cryogenic technology was increasing vastly the pace of research—these Heat Division staff members prepared wire samples of purified elemental superconductors to test the sharpness and reproducibility of the transitions between the normal and the superconductive states. They found that groups of carefully prepared and annealed lead,

[231] R. A. Kamper, "Millidegree noise thermometry," *Symp. on the Physics of Superconducting Devices, Charlottesville, Virginia, 1967.*

[232] R. A. Kamper and J. E. Zimmerman, "Noise thermometry with the Josephson effect," *J. Appl. Phys.* **42**, pp. 132-136 January 1971. See also R. A. Kamper, J. D. Siegwarth, R. Radebaugh, and J. E. Zimmerman, "Observation of noise temperature in the millikelvin range," *Proc. IEEE* **59**, 1368-1369 (1971).

indium, aluminum, zinc, and cadmium samples exhibited transitions that were both sharp and reproducible at the one-millikelvin level. Furthermore, the transitions were easy to detect using readily available mutual inductance measurement techniques.[233]

Many low-temperature-laboratory scientists expressed interest in making use of the superconductors as reference points at temperatures of 7.2 K (Pb), 3.4 K (In), 1.2 K (Al), 0.85 K (Zn), and 0.5 K (Cd). The authors were thus encouraged to prepare devices that incorporated all of the elements tested.[234] When the devices proved reliable, they were incorporated into the Standard Reference Materials program as SRM 767.[235] Later on, the element niobium (superconducting transition temperature about 9.3 K) was added to the SRM 767 group.

A second device of the same type was prepared by Soulen and R. Bruce Dove to provide reference points below 0.5 K.[236] Incorporated into the devices—designated SRM 768—were the following materials: $AuAl_2$, $AuIn_2$, Be, Ir, and W. Their superconducting transitions occurred in the range 0.21 K to 0.015 K.

During the lifetime of the program, more than 100 laboratories made use of the reference devices. An interim low-temperature scale, designated by the international Consultative Committee for Thermometry as the 1976 Provisional 0.5 K to 30 K Temperature Scale, incorporated the NBS SRM 767 devices to define five of the eleven scale reference temperatures.

Fishing for Low-Level Electromagnetic Measurements with SQUID

The idea of using Josephson junctions to detect and measure very small electrical currents and magnetic fields was an attractive one. Development of such new instruments was inevitable once it was discovered that the critical current in a superconducting ring closed by a Josephson junction behaved in a periodic way as a magnetic field threading the ring was increased or decreased.

While he was still working at the Ford Motor Company Scientific Laboratory with A. H. Silver, James E. Zimmerman participated in experiments which demonstrated some of the features of such devices.[237] With colleagues David Cohen of MIT and

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[233] J. F. Schooley and R. J. Soulen, Jr., "Superconductive transitions suitable as thermometric fixed points," *Proc. XII Conf. on Low Temperature Physics, Kyoto, Japan, September 3-10, 1970*, E. Kanda, Editor, (Tokyo: Keigaku Publishing Co., 1971) pp. 833-834. See also "Superconductive transitions suitable for thermometric fixed points," *NBS Technical News Bulletin*, February 1971, pp. 39, 58.

[234] J. F. Schooley and R. J. Soulen, Jr., "Thermometric fixed points using superconductivity," *Advan. in Cryog. Eng.* **17**, 192-198 (1972).

[235] J. F. Schooley, R. J. Soulen, Jr., and G. A. Evans, Jr., "Standard reference materials: preparation and use of superconductive fixed point devices, SRM 767," *NBS Special Publication 260-44*, 35 pp., December 1972.

[236] R. J. Soulen, Jr. and R. B. Dove, "Standard reference materials: SRM 768: Temperature reference standard for use below 0.5 K," *NBS Special Publication 260-62*, 47 pp., April 1979.

[237] A. H. Silver and J. E. Zimmerman, "Quantum states and transitions in weakly connected superconducting rings," *Phys. Rev.* **157**, No. 2, pp. 317-341 (1967).

Edgar Edelsack of the Office of Naval Research, Zimmerman developed a magneto-cardiographic instrument using these principles.[238] Recorded heartbeats (in one case, Zimmerman's own) were obtained in a shielded room by placing the subject's torso near the tip of the cryostat containing the detector circuitry. The recordings were clear and readily interpretable. The device portended a wholly new medical application for superconducting detectors.[239]

By mid-1970, Zimmerman was constructing weakly connected superconducting rings and investigating their properties as an employee of the Bureau's Cryogenics Division in Boulder. In these experiments he participated with a group that included Robert Kamper, L.O. Mullen, Donald B. Sullivan, Nolan V. Frederick, and Michael B. Simmonds.[240]

Detecting High-Frequency Radiation with the Josephson Effect

How high in frequency could a Josephson junction respond to radiation? This was more than an academic exercise for a group of scientists in the Time and Frequency Division in Boulder. The group included Donald G. McDonald, Kenneth M. Evenson, Joseph S. Wells and J. D. Cupp. They were interested in the possibility of measuring the output of lasers. They found that a point-contact Josephson junction would respond to radiation of frequency 2.5 THz, a factor of three higher than previously observed by direct irradiation. By using harmonic generation, the upper limit could be extended at least to 8 THz.[241]

Building Research

The Bureau's building research program addressed a diverse range of problems, many of them involving travel to the scenes of disasters. The following accounts provide a sampling of these projects.

Buildings Versus Mother Nature

On February 9, 1971, a medium-strength earthquake struck the San Fernando valley in California. At 6.6 on the Richter scale, it was strong, though nowhere near the record. Yet there was severe damage: 64 people killed, buildings and highway

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[238] D. Cohen, E. A. Edelsack, and J. E. Zimmerman, *Appl. Phys. Lett.* **16**, 278 (1970).

[239] J. E. Zimmerman, "Recent developments in superconducting devices," *J. Appl. Phys.* **42**, No. 1, pp. 30-37 (1971). This paper was part of the *1970 Applied Superconductivity Conference, June 15-17, 1970, Boulder;* Richard H. Kropschot of NBS Boulder was Conference Chair. See also "Superconducting device measures heartbeat magnetically," *NBS Technical News Bulletin,* April 1971, pp. 100-101. The author is grateful to Harold Weinstock of the *Air Force Office of Scientific Research* for pointing out that SQUID arrays in helmet-shaped Dewar systems were (in 1999) used to monitor brain activity, both in cognitive studies and in pathology.

[240] See D. B. Sullivan, "Superconducting Quantum Interference Devices: An operational guide for rf-biased systems," *NBS Tech. Note 629,* 40 pp., November 1972, and R. A. Kamper and D. B. Sullivan, "Developments in cryoelectronics," *NBS Tech. Note 630,* 68 pp., November 1972.

[241] D. G. McDonald, K. M. Evenson, J. S. Wells and J. D. Cupp, "High-frequency limit of the Josephson effect," *J. Appl. Phys.* **42**, No. 1, pp. 179-181, January 1971.

structures destroyed, and property loss estimated at $500 million. The White House Office of Emergency Preparedness requested that NBS send a team to evaluate the damage from the point of view of improving building codes so as to minimize losses from future quakes.

Four members of the Bureau's Building Research division, including Hai S. Lew, Edgar V. Leyendecker, and Robert D. Dikkers, reached the scene within 24 hours. They made photographic recordings of damaged homes, schools, hospitals, roadways, bridges, and other public facilities.

In some cases, the team found that local buildings had been constructed according to outdated codes, with the result that they failed under stresses that newer codes would probably have accommodated. Other buildings, such as the Veterans Hospital, had been built prior to the existence of earthquake codes. Its collapse might have been prevented had there been a mechanism to utilize existing information to reinforce it in critical areas. The team noted that important public facilities such as hospitals—four in the area were damaged so severely that they could no longer function—could be given special strengthening to reduce the chance that they would fail in future quakes. Water, sewage, gas and electric lines could similarly receive special attention.[242]

The Building Research Division was asked by the Environmental Sciences Services Administration to inspect an area near Lubbock, Texas, that was devastated by a tornado on May 11, 1970. Twenty-six people were killed by the twister; 1500 were injured and 3500 became homeless in moments. Total property damage was estimated at $200 million.

A Bureau team led by Norman F. Somes and including Robert D. Dikkers and Thomas H. Boone spent three days at the site. In June they issued a report on their findings. The highlights of the report[243] included the following:

- Most damage to the interiors of homes resulted from initial loss of the roof structures.
- Much of the damage and personal injury resulted from flying glass, wood, and masonry.
- Many mobile homes without over-the-top tiedowns were rolled, producing near-total destruction of their contents.
- Structures that stiffened building walls generally helped to preserve them in spite of the wind.

The Bureau work contributed to improved design of buildings against the forces exerted by the high winds accompanying tornadoes and hurricanes.

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[242] H. S. Lew, E. V. Leyendecker, and R. D. Dikkers, "Engineering aspects of the 1971 San Fernando earthquake," *NBS Building Science Series* **40**, 419 pp., December, 1971.

[243] "Tornado Havoc Linked to Building Elements," *NBS Standard,* Vol XV, No. 7, July 1970, pp. 4-5. See also N. F. Somes, R. D. Dikkers, and T. H. Boone, "Lubbock tornado; a survey of building damage in an urban area," *NBS Tech. Note 558,* March 1971.

A new organization concerned with wind damage was created by the U.S.-Japan Cooperative Program in Natural Resources in 1969. Edward O. Pfrang, chief of the BRD Structures Section, helped to form the U.S.-Japan Panel on Wind and Seismic Effects and served as the United States chair of the panel until 1984. Over the years, more than 1000 scientific papers were published as a result of panel meetings, data was shared on earthquakes, storm surges, and tsunamis in both countries, and co-operative testing was performed to advance the development of building-design criteria.[244]

Applying Performance Standards

The Bureau's efforts on behalf of *Project Breakthrough* took on a more substantial form early in 1971, as the first of 22 housing systems was delivered to the Building Research Division for testing and evaluation.[245] *Project Breakthrough* was a major Housing and Urban Development operation intended to create and demonstrate efficient methods using performance standards for the construction and erection of manufactured housing to alleviate a nationwide shortage of modestly priced homes.

The first module, a 20 m by 4 m by 5 m prototype built by Levitt Technology, Inc. of Kalamazoo, Michigan, was shipped by rail to the NBS Gaithersburg site. Initial tests were designed to verify that the units could be shipped by rail without damage.

The Building Research Division staff emphasized that performance criteria—a departure from the material specifications previously used in the housing industry—would be employed to decide the suitability for service of the housing units. Tests applied by the BRD group included rail-car-coupling bumps at speeds up to 8 mph and monitoring responses to various wind forces, floor loadings, impacts to walls and floors, and earthquake-type tremors.

The division staff assisted the Public Building Service of the General Services Administration (GSA) by applying the performance concept to new government office buildings. Procurement by the GSA of Social Security Administration payment centers in San Francisco, Philadelphia, and Chicago followed evaluation by David B. Hattis and Thomas E. Ware.[246]

Whether designing by the performance approach or by traditional methods, the designer needed reliable estimates of the loads to be expected during the service life of any building. To update estimates of live loadings—weights of occupants, stored materials, and furnishings—and fire loadings in office buildings from values developed during the 1920s, James O. Bryson and Daniel Gross created new techniques for surveying and evaluating these parameters in 1968.[247] Based on their work, a national survey of loadings was conducted. The results formed the basis for national and international standards that are still in use for building design. [248]

[244] Richard N. Wright kindly furnished the information on which much of this section was based.

[245] "'Breakthrough' module here for testing by BRD," *NBS Standard,* Vol XVI, No. 3, March 1971, pp. 1, 16.

[246] David B. Hattis and Thomas E. Ware, "The Public Building Service performance specifications for office buildings," *NBS Report 10527,* January 1971.

[247] James Bryson and Daniel Gross, "Techniques for the survey and evaluation of live floor loads and fire loads in modern office buildings," *NBS BSS* **16**, 1968.

[248] Charles G. Culver and Jill S. Kushner, "A program for survey of fire loads and live loads in office buildings," *NBS Tech. Note 858,* 1975.

In 1967, NBS was asked to help improve efficiency and consistency in the writing and administration of building regulations. A group of concerned state governors collaborated with the Bureau Building Research Division (BRD) staff to create in 1969 the National Conference of States on Building Codes as a non-profit corporation. The Bureau provided the secretariat for the new organization under the guidance of Gene A. Rowland, former leader of the Wisconsin Building Code Section and in 1967 chief of the BRD Codes and Standards Section.[249]

Shortly after the new corporation was established, its member-delegates began to develop new, more uniform building regulations for states. These were later adopted by the Council of State Governments as model legislation.

Blest Be the Ties that Bind

A humble but essential service to the construction industry was provided by a Building Research Division team of Thomas W. Reichard, E. F. Carpenter, and Edgar V. Leyendecker when they completed an evaluation of the holding strength of inserts embedded in concrete. The information generated during the project was expected to materially aid the design of systems for the suspension of structural members or equipment from ceilings.

The team studied three different types of inserts, all intended to secure 3 inch bolts to a concrete ceiling. Commercially available concrete mixes were used with reinforcement in the test, with the inserts cast in place. In one test, a tensile load applied to each insert was increased until the insert was pulled from the concrete. Several other flexural and fatigue tests were also performed on the assemblies. The team found that the pull-out load could be approximated from material parameters, leading to the possibility for improved design recommendations.[250]

And the Walls Came Tumbling Down

Hollow walls, solid walls, brick walls, block walls, cavity walls. They all came tumbling down, in tests performed by Felix Y. Yokel, Robert G. Mathey, and Robert D. Dikkers. The object of the testing to destruction of more than 100 masonry walls was to establish their strength under axial, transverse, and "raking" (diagonal) loads in order to derive analytical procedures for the prediction of strength in service, and to aid in the design of masonry structures. Special assemblies for the application of directed, measured forces provided the basis for the experiments.

The project was successful in deriving predictive methods for the strength of masonry construction. It was expected that the results would lead to improved construction practices.[251]

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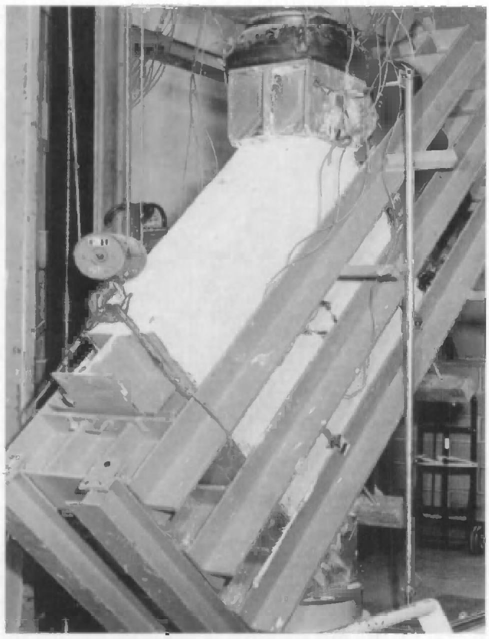
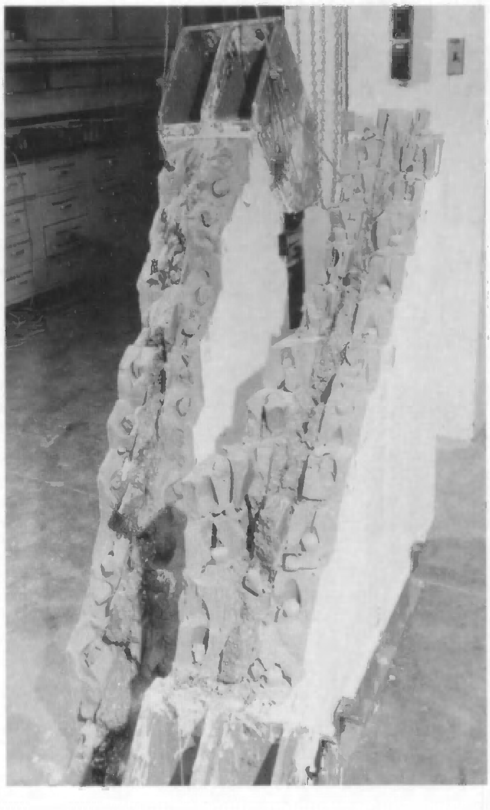
[249] Gene A. Rowland, "The increasing role of states in building codes and standards," *Proc. 26th Annual Conf. on Reinforced Plastics, Composites Division, Section 5B, February 10, 1971, Washington, DC,* pp. 1-3.

[250] T. W. Reichard, E. F. Carpenter, and E. V. Leyendecker, "Design loads for inserts embedded in concrete," *NBS Building Science Series* **42**, 28 pp., May 1972.

[251] "Transverse strength of masonry walls," *NBS Technical News Bulletin,* November 1970, p. 259.



A section of masonry wall, readied for strength testing under raking (diagonal) loads by personnel of the NBS Building Research Division.



The section of mansonry wall shown in the previous illustration, after testing to destruction under raking loads, exhibited the damage typically caused by such forces.

Applied Mathematics

100,000 "Handbooks"

We have seen in previous sections the fruits of the NBS applied mathematics effort mostly in terms of the program that gave statistical support to the Bureau's data-gathering scientists. A prime example of this support appeared in August 1969, when the *Handbook of Mathematical Functions* was reprinted for the seventh time. First published in 1964 under the careful editing of Irene A. Stegun, who finished the task begun years earlier in collaboration with the late Milton Abramowitz, the handbook was a best-seller.[252] In one of his final acts as retiring director of NBS, Allen V. Astin presented the 100,000th copy of the handbook to W. Reeves Tilley in recognition of his role in printing and publicizing the volume. An additional copy was presented to Lee A. DuBridge, Science Advisor to President Nixon.

Besides its data-analysis support of Bureau scientists, many other projects were undertaken by the Applied Mathematics Division staff. In the following, we present a small sampling of these projects.

NBS Deputy Director Lawrence M. Kushner (far right, above) served as a witness at the July 1, 1970 draft lottery.

[252] "Handbook of Mathematical Functions with Formulas, Graphs, and Mathematical Tables," Milton Abramowitz and Irene Stegun, editors, *NBS Applied Math. Series* 55, June, 1964.

Making the Draft Fair

The Selective Service System (SSS) needed a dose of impartiality in 1970, so it paid a call on the NBS Applied Mathematics Division. The SSS called potential draftees for military service according to the date on which they turned 19 in a given year; the fateful birthdates were chosen in a random fashion. NBS was asked to provide 25 calendars with 25 random permutations of the numbers from 1 to 365 for use in selecting the order of drafting 1970's nineteen-year-olds for service in 1971.

Joan Rosenblatt, chief of the Statistical Engineering Laboratory (SEL), and James Filliben consulted with Churchill Eisenhart and Joseph Cameron, both former heads of the SEL, then selected the requested lists and checked them for randomness. The NBS work was examined by a panel of well-known statisticians outside the Bureau, then the lists were placed in 50 envelopes and carried to the SSS draft proceedings by NBS Deputy Director Lawrence Kushner and Rosenblatt.[253]

For this work and for other tasks performed in the course of her leadership of the SEL, Rosenblatt was selected to receive the 1971 Federal Woman's Award.[254]

Modeling the Flow of Truck Traffic

Judith Gilsinn of the Applied Mathematics Division and Richard Ku of the Technical Analysis Division collaborated to develop a mathematical model for truck traffic in the more congested parts of New York City. The work was performed on behalf of the Department of Housing and Urban Development. Utilizing traffic counts of four different types of trucks, the two researchers derived a model that answered questions about the usefulness of banning automobile traffic in certain areas and the principal reasons for congestion in the affected area.

More important than the immediate results of the study—that too few commercial establishments offered off-street loading and unloading—was the realization by HUD officials that mathematical modeling could substantially improve decisions reached by urban planners.[255]

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[253] "NBS helps insure fairness of draft lottery," *NBS Standard,* Vol XV, no. 7, July 1970, p. 8.

[254] "Dr. Joan Rosenblatt to receive 1971 Federal Woman's Award," *NBS Standard,* Vol XVI, No. 2, February 1971, pp. 1, 4.

[255] "Computer roams downtown," *NBS Technical News Bulletin,* June 1971, pp. 139, 152.

Modeling Air Traffic

Robert Elbourn of the Center for Computer Sciences and Judith Gilsinn undertook a project with the objective of optimizing the assignment of transponder codes to aircraft as they entered an Air Traffic Control Center. Expecting a tripling of the number of aircraft operating under instrument flight rules by 1990, the Federal Aviation Administration asked NBS to help in the design of future identification systems.

Gilsinn and Elbourn considered a variety of options available to the Nation's nearly two dozen Control Centers, some of which would entail assigning a code number to each flight and others that would assign codes to each center. Evaluations were based upon comparisons of the efficiency of the models on the basis of actual air-control experience with nearly 28,000 flights connecting more than 1000 U.S. airports. Results of the modeling compelled FAA officials to consider trade-offs in the planning of future control systems.[256]

Research in Solid State Physics

In the following accounts, we highlight some of the varied projects undertaken at NBS in the area of solid state physics.

Crystal Structures at High Pressures

Study of crystal structures at high pressures fascinated certain members of the Crystallography Section of the Inorganic Materials Division. Charles E. Weir, Gasper J. Piermarini, and Stanley Block became especially adept at squeezing various materials between diamonds that had been shaped so as to exert pressures as high as 4 GPa (about 40,000 times atmospheric pressure) while still allowing an x-ray beam to pass through the sample.

In 1969 the trio published an account of their work, with details of construction of a high-pressure cell composed entirely of beryllium and diamond, both materials nearly transparent to x rays. The apparatus also incorporated a goniometer head and a modified Buergers-type camera. A flood of data followed, with structures of many high-pressure phases.[257]

The one problem most difficult to solve with the diamond-anvil cell was the determination of the actual pressure encountered by the squeezed sample. Only approximate methods, sometimes with uncertainties as high as 30 %, had been successful. John B. Wachtman, Jr., chief of the Inorganic Materials Division, brought forward a new idea—why not use as a standard the pressure shift in the luminescence spectrum of

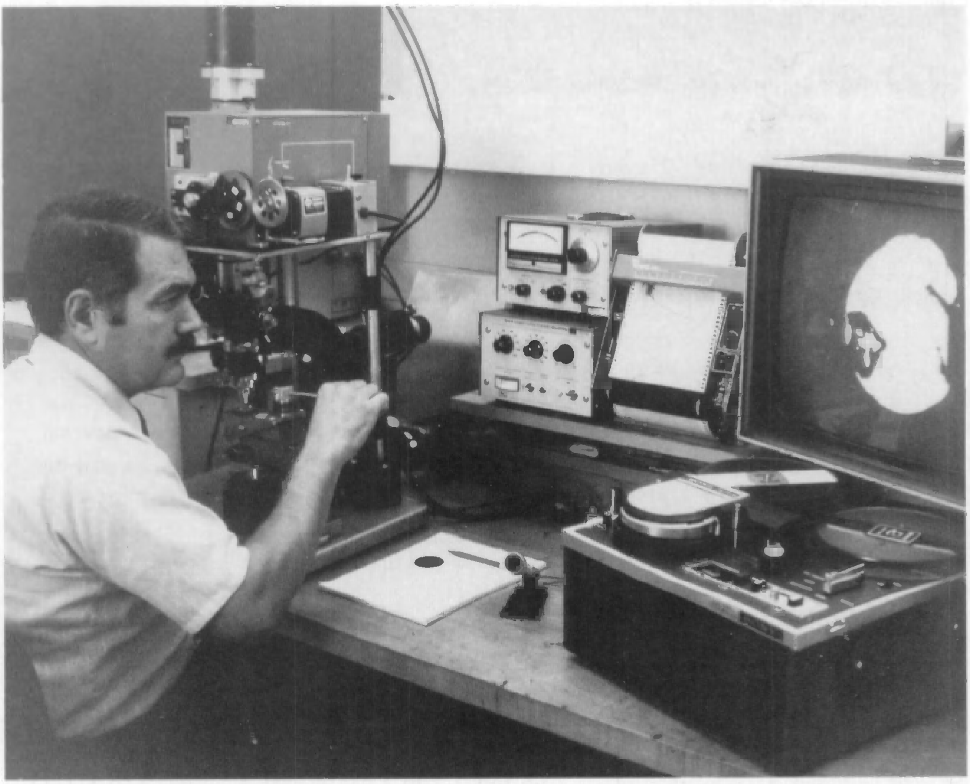
[256] R. D. Elbourn and Judith F. Gilsinn, "Simulation of air traffic control radar beacon code assignment plans," *NBS Technical Note 568,* March 1971.

[257] C. E. Weir, G. J. Piermarini, and S. Block, "Instrumentation for single-crystal x-ray diffraction at high pressures," *Rev. of Sci. Instrum.* **40**, 1133 (1969). See also C. E. Weir, G. J. Piermarini, and S. Block, "Crystallography of some high-pressure forms of C_6H_6, CS_2, CCl_4, and KNO_3," *J. Chem. Phys.* **50**, 2089-2093 (1969). See also G. J. Piermarini, A. D. Mighell, C. E. Weir, and S. Block, "Crystal structure of benzene II at 25 kilobars," *Science* **165**, 1250-1255 (1969). See also S. Block, C. E. Weir, and G. J. Piermarini, "Polymorphism in benzene, naphthalene, and anthracene at high pressure," *Science* **169**, 586 (1970).

ruby? Well, why not? thought Piermarini, Richard A. Forman, a young physicist in the neighboring Solid State Physics Section, and J. Dean Barnett, a colleague on sabbatical leave from Brigham Young University. So they tried Wachtman's suggestion.

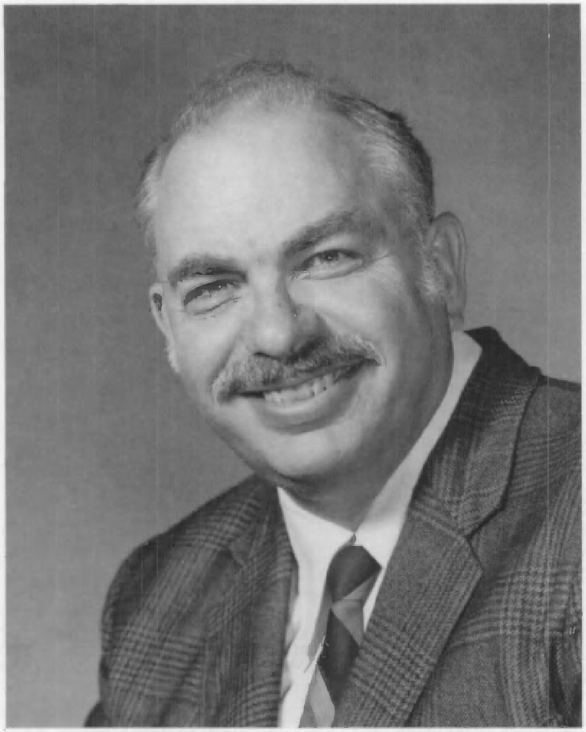
A small fragment of pink ruby containing less than 0.1 % Cr^{3+} ions, placed into the diamond anvil with the sample under study, provided an excellent pressure gage. Nearly linear with pressure up to 2000 MPa or so, the shifts in the R_1 and R_2 lines were easily observed.[258] The technique quickly became standard procedure for that type of experiment.

In 1974 Block and Piermarini were honored with the Department of Commerce Gold Medal for their work. The citation emphasized that the two had been able to make the new technology available to other laboratories where it had been applied to a wide variety of materials.



Using an activating rod, Gasper J. Piermarini raised the pressure in a diamond-anvil cell containing a zinc sulfide sample, which at about 7 GPa became metallic. The change to the metallic structure was recorded in photo sequence and displayed on the video monitor (right).

[258] Richard A. Forman, Gasper J. Piermarini, and J. Dean Barnett, "Pressure measurement made by the utilization of ruby sharp-line luminescence," *Science* **176**, 284 (1972).



Solid state physicist Stanley Block of the NBS Crystallography Section. With his colleagues Gasper Piermarini and Charles E. Weir, Block developed the diamond-anvil pressure cell.

High-Speed Measurements for High-Temperature Materials

Just as Lewis Branscomb was taking office as the Bureau's sixth director, several Bureau scientists were polishing the draft of a fairly long (27-page) paper describing a new technique in thermophysical-properties research on conductive refractory materials. The principles of the method were described by Charles W. Beckett and Ared Cezairliyan in Vol. I of the archival series, *Experimental Thermodynamics.*[259] In essence, they used very rapid measurements to obtain heat-capacity and radiative-property data at temperatures so high as to be out of reach by normal techniques.

Acknowledging support from the U.S. Air Force Office of Scientific Research program in high-temperature materials, Cezairliyan, Malcolm S. Morse, Horace A. Berman, and Beckett soon presented the first results obtained by the use of the new technique.[260] The scientists pointed out that they could obtain thermodynamic data on certain samples without the lengthy exposure to high temperatures required by earlier techniques. That long exposure frequently led to unwanted chemical reactions,

[259] C. W. Beckett and A. Cezairliyan, "High-Speed Thermodynamic Measurements and Related Techniques," in *Experimental Thermodynamics*, Vol I Calorimetry of Non-Reacting Systems, J. P. McCullough and D. W. Scott, Editors, Butterworths, London, 1968, p. 551.

[260] A. Cezairliyan, M. S. Morse, H. A. Berman, and C. W. Beckett, "High-Speed (Subsecond) Measurement of Heat Capacity, Electrical Resistivity, and Thermal Radiation Properties of Molybdenum in the Range 1900 to 2800 K," *J. Res. NBS* **74A,** No. 1, 1970, pp. 65-92.

Physicist Ared Cezairliyan operated this apparatus to obtain high-temperature thermodynamic data in sub-second time intervals.

excessive heat transfer, evaporation, diffusion, or loss of mechanical strength. Various workers throughout the world had attempted to obtain such information, but they had lacked the experimental resources needed to obtain useful and accurate values.

In the first detailed publication on the new technique, the group reported studies of the element molybdenum, a transition metal with a high melting temperature (~2610 °C). The new technique required that a subsecond pulse of resistive heating be applied to the sample, which was shaped in the form of a tube 10 cm long, 0.6 cm outside diameter, and 0.05 cm wall thickness. A tiny rectangular hole (0.1 cm × 0.05 cm) in the sample wall permitted the observation—by a newly-acquired, high-speed photoelectric radiometer—of thermal radiation from inside the sample. Potential probes in the form of Mo knife-edges defined the limits of an isothermal section of the sample and were used to obtain time-dependent voltage data. Thermocouple thermometers connected to the ends of the sample yielded pre-pulse sample temperatures. The sample environment could be regulated to approximate a vacuum or a selected gaseous environment.

A 28 V heavy-duty battery bank supplied the pulse power to the sample through a variable series resistor and a standard 0.001 Ω current-measuring resistor. From the standard resistor the current through the sample could be determined; combining this information with the time-dependent voltage data allowed evaluation of the time-dependent resistivity of the sample.

Cezairliyan and his co-workers obtained results on the heat capacity of molybdenum that agreed within 1 % to 8 % with values obtained by other experiments over the range 2000 K to 2800 K. Electrical-resistivity results agreed somewhat better, within 2 % over the same range of temperature. The largest source of error in the sample thermometry was caused by non-uniformity of the sample temperature—from approximately 3 K at 2000 K to about 4 K at 2800 K. At the higher temperatures, the uncertainty of calibration of the standard lamp used as a reference source contributed significantly to the overall uncertainty of the measurement.

In assessing the quality of their work, the authors pondered the question of internal thermodynamic equilibrium in the sample during such rapid experiments: they concluded that the electron-phonon interaction rate was sufficiently fast that no disequilibrium need be expected from this source. The relaxation rate for lattice vacancies was slower; along with changes in impurity content and grain growth, this source of variation in heat capacity was thought to account for the 1.3 % to 2.2 % variation in heat-capacity determinations found among the several series of measurements in the experiment. The authors were encouraged by the level of agreement of their results with those expected for molybdenum in the temperature range studied. Although they would spend some years in evaluating and reducing the uncertainties of the new method, they expected it to produce useful high-temperature results that could be obtained in no other way. Subsequent experience would prove them correct.

Getting in Touch with Semiconductors

Defective bonding of wire leads to metallized semiconductor surfaces caused many failures in the early days of microcircuit manufacture. An effort to pinpoint causes of the defects occupied scientists from the Electronic Technology Division for several years. Early in the project, George G. Harman and Herbert K. Kessler adapted various types of capacitive and magnetic pickup devices to detect motion of the bonded elements.[261]

William R. Hosler developed an improved method of preparing low-resistance contacts on semiconductors during this period, providing assistance to researchers using devices such as thermistors, diodes, and photodetectors. In making certain measurements—for example magnetoresistance, piezoresistance, or Hall effect—high-resistance contacts prevented the acquisition of accurate data; not infrequently, such contacts failed during testing.

For materials such as potassium tantalate, strontium or barium titanate, and titanium dioxide, the secret, according to Hosler, was the use of a special flux, TiH_2. Hosler pressed the solid flux and the metal button used to make the contact into a slight depression on the surface of the sample and heated the assembly in a furnace with an inert atmosphere. Whereas conventional methods might yield a contact resistance of several tenths of an ohm at 4.2 K, Hosler's technique provided contacts with resistances in the milliohm range.[262]

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[261] G. G. Harman and H. K. Kessler, "Application of capacitor microphones and magnetic pickups to the tuning and trouble shooting of microelectronic ultrasonic bonding equipment," *NBS Tech. Note 573,* April 1971.

[262] W. R. Hosler, "Low resistance contacts on semiconducting oxides," *Solid-State Electron.* **13**, 517-519 (1970).

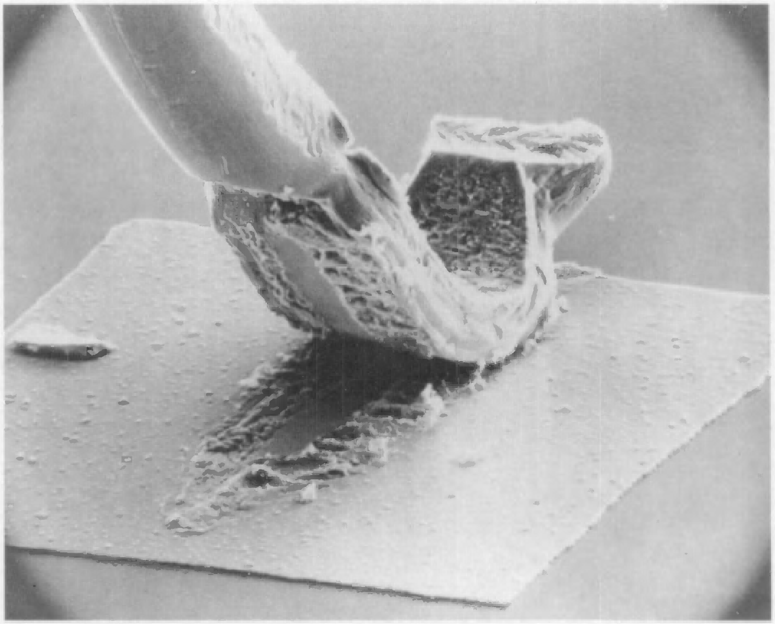
In research to determine the cause of failures in microelectronic wire bonds, Herbert Kessler positioned a magnetic pickup beside the end of an ultrasonic tool used to bond aluminum wire leads to metallized pads on semiconductor wafers. Using an oscilloscopic display of the pickup signal, he could adjust the transducer driver to the desired frequency and amplitude at the tool tip.

Tuning a Radiation Detector

Lithium-compensated germanium gamma ray detectors had been in use for some time when a "glitch" developed; certain of the devices were found to be defective for no apparent reason. Because of the usefulness of the detectors in measuring the energy of nuclear radiation, any problem was considered serious by the Atomic Energy Commission. The AEC contacted Alvin H. Sher of the Electronic Technology Division to see what could be done.

At NBS, William Croll and Howard Dyson were able to duplicate the vacuum deposition of lithium on the surface of p-type germanium and heat-diffuse the lithium to create the detector material. William Keery and Sher determined the energy-resolving characteristics of the completed detectors, while J. Robert Thurber measured the oxygen content in the germanium base material. The Bureau work was of great benefit in reducing the number of defective detectors. The results of the NBS work appeared in new preparation standards issued by the American Society for Testing and Materials.[263]

[263] "Evaluating nuclear radiation detectors," *NBS Tech. News Bull.*, April 1972, pp. 85-86.



The scanning electron microscope was used in NBS semiconductor technology research to evaluate the bond between wire leads and semiconductor surfaces. This scan showed an area of good adhesion surrounding an unbonded area.

Applications of Paramagnetism

During 1972, Ralph P. Hudson, Chief of the Heat Division, completed a monograph on the use of paramagnetic materials in low-temperature physics research. Using paramagnetic salts with the technique of adiabatic demagnetization, scientists could cool samples of many types to temperatures as low as 0.001 K. Using carefully prepared paramagnetic thermometers, they could measure temperatures in the range 0.001 K to perhaps 90 K.

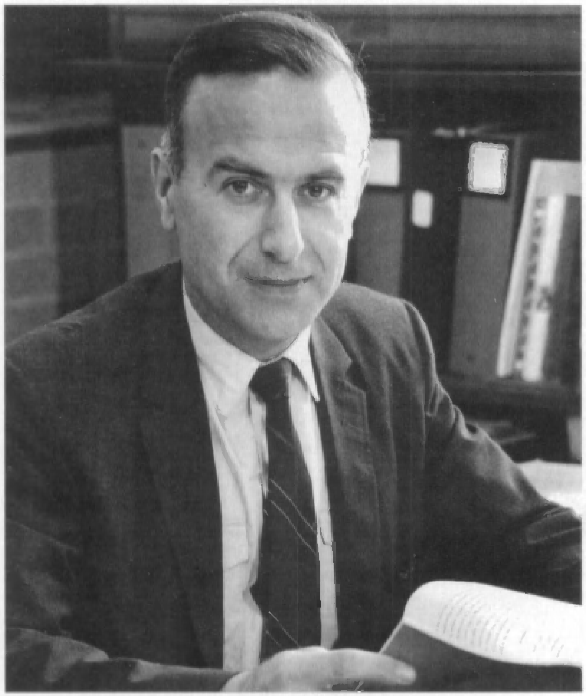
One of the most notable uses of paramagnetic materials at NBS, the demonstration in 1956 of parity non-conservation in weak nuclear interactions, involved both these methods. Along with Ernest Ambler, Raymond W. Hayward, and Dale D. Hoppes, Hudson had received the Department of Commerce Gold Medal award for that work.[264]

After the ^{3}He-^{4}He dilution refrigerator (see Ch. 1) was introduced in the late 1960s, paramagnetic thermometry was used for many years to provide reliable system temperatures.

In his monograph, Hudson discussed the thermodynamic principles involved in paramagnetic cooling and in paramagnetic thermometry. He also reviewed current experimental techniques, similar to those mentioned earlier in this chapter.[265]

[264] See, for example, Elio Passaglia, *AUI*, pp. 207-213.

[265] R. P. Hudson, "Principles and application of magnetic cooling," *Series in Low Temperature Physics* **2**, 1-230 (Amsterdam: North-Holland Publishing Co., 1972).



Ralph P. Hudson was chief of the NBS Heat Division from 1960 to 1978. He maintained an active interest in the fields of low-temperature thermometry and magnetism throughout that time.

New Drive for Soft X-Ray Spectrometers

In order to improve the constancy of resolution of the soft x-ray spectrometer during changes in wavelength, John R. Cuthill developed a new detector drive for the instrument. There were many applications for soft x-ray spectrometry at that time—spectrographic analysis for light elements and evaluating the density of electronic states in the valence bands of conductors, to name two. Often home-made, the instruments were consistently under improvement.

Cuthill's modification involved the use of a lead screw that moved the detector along a curved track. In his arrangement, it also aimed the detector at the grating, holding the effective slit width constant throughout the wavelength range. The device thus controlled the spectrometer resolution at a fixed value. An added benefit was an improvement in rigidity of the spectrometer.[266]

Prize-Winning Research in Solid State Science

Recognition came to several other Bureau staff members in recognition of the high quality of their work in the solid state sciences during Branscomb's tenure as Director:

[266] J. R. Cuthill, "A soft x-ray spectrometer with improved drive," *Rev. Sci. Instrum.* **41**, pp. 422-423 (1970).

A digital printout of an emission spectrum from a soft-x-ray spectrometer was examined by its designer, John Cuthill. All optical and some mechanical components of the spectrometer were housed in the large cylinder (center). Data were recorded on a stripchart (left), on paper (foreground), and on magnetic tape (right) for input into a computer.

- Alan D. Franklin received the 1970 Department of Commerce Gold Medal for his work on point defects in solids.[267] During this period, Franklin calculated the energies required to form point defects in ionic crystals, using a general formulation of the Born model; he also calculated specific values for CaF_2. He found that the calculations of the energy to form anion Frenkel pairs (2.7 eV per pair), to form cation Frenkel pairs (7.5 eV per pair), and to form Schottky trios (5.1 eV per trio), agreed reasonably well with recent experimental results, justifying the use of the Born model.[268]
- Herbert S. Bennett was named the Outstanding Young Scientist of 1970 by the Maryland Academy of Sciences, for:

> Extensive theoretical work on ferromagnetism near the Curie temperature; analysis of temperatures and stresses induced in laser glasses in high radiation fields; and especially for his development of the calculation of F centers in oxides.[269]

[267] "22nd annual Commerce honor awards presented," *NBS Standard,* Vol XV, No. 11, November 1970, pp. 1, 13.

[268] A. D. Franklin, "Born model calculation of defect energies in CaF_2," *J. Phys. Chem. Solids* **29**, 823-841 (1968).

[269] "Dr. Bennett honored by Md. Academy of Sciences," *NBS Standard,* Vol XVI, No. 2, February, 1971, pp. 6, 8.

During the same period, Bennett continued two series of theoretical investigations. One, attempting to elucidate the nature of F centers in ionic crystals, considered models that invoked a self-consistent treatment of the movement of the nearest neighbors to the F center. A second contribution treated the propagation of sound waves in ferromagnetic and antiferromagnetic insulators. In both cases, Bennett evaluated his efforts by comparing calculated results with those obtained experimentally.[270]

Bennett and Franklin, both members of the Inorganic Materials Division, shared the editorial tasks involved in summarizing the Bureau program of research, accomplished with the sponsorship of the Advanced Research Projects Agency, on materials for use in high-temperature work and in lasers.[271]

- Lawrence H. Bennett, a physicist in the Metallurgy Division (no relation to Herbert), was honored with the award of the Department of Commerce Gold Medal in 1971 for his work in metal physics.[272] Bennett was a prolific experimenter, the author or co-author of a dozen papers from 1966 to 1970. Either alone or with one or more of his colleagues Lyden J. Swartzendruber, Russell W. Mebs, Gesina C. Carter, Irwin D. Weisman, and J. C. Swartz of NBS and the team of Richard E. Watson and A. J. Freeman—both employed by Brookhaven National Laboratory—Bennett investigated a variety of solid state physics topics. These included nuclear resonance, ferromagnetic materials, the Mössbauer effect, the Knight shift, and magnetic clusters. Bennett also wrote a review of nuclear magnetism.[273]

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[270] H. S. Bennett, "F center in ionic crystals II. Polarizable-ion models," *Phys. Rev.* **184**, No. 3, 918-935 (1969). H. S. Bennett, "Frequency shifts of acoustic phonons in Heisenberg Paramagnets III," *Phys. Rev.* **185**, No. 2. 801-804 (1970).

[271] "ARPA-NBS program of research on high temperature materials and laser materials, January 1-June 30, 1969," *NBS Technical Note 514*, A. D. Franklin and H. S. Bennett, editors, January 1970, 98 pp. See also "ARPA-NBS program of research on high temperature materials and laser materials, July 1 -December 31, 1969," *NBS Technical Note 531*, A. D. Franklin and H. S. Bennett, editors, June 1970, 75 pp.

[272] See p. 1, *NBS Standard* Vol XVI, No. 10, November 1971.

[273] L. H. Bennett, "Influence of an external magnetic field on nuclear resonance in ferromagnetic materials," *J. Appl. Phys.* **37**, No. 3, 1242-1243 (1966). See also L. H. Bennett and L. J. Swartzendruber, "Ferromagnetic iron alloys lacking a hyperfine field at the iron site," *Phys. Lett.* **24A**, No. 7, 359-360 (1967). See also R. E. Watson, L. H. Bennett, and A. J. Freeman, "Origin of solvent Knight shift in alloys," *Phys. Rev. Lett.* **20**, No. 13, 653-656 (1968). See also L. H. Bennett, L. J. Swartzendruber, and R. E. Watson, "Magnetic clusters associated with isolated Fe atoms in paramagnetic Cu-Ni alloys," *Phys. Rev. Lett.* **23**, No. 20, 1171-1174 (1969). See also Swartzendruber and Bennett, "Clustering, cold work, and the Mössbauer effect doublet structure in Cu-Ni-Fe alloys," *Phys. Lett.* **31A**, No. 10, 581-582 (1970). See also L. H. Bennett, "Nuclear Magnetism," chapter 14 in *Magnetism and Magnetic Materials, 1968 Digest*, H. Chang and T. R. McGuire, editors (New York: Academic Press, 1968) pp. 201-221.

- Judson C. French was presented the 1971 NBS Edward B. Rosa award for:

> Leadership in the standardization of the methods of measurement used to specify the properties of electron devices, the materials from which they are made, and the processes used in their fabrication.[274]

The scientific work done by French contributed substantially to an understanding of the electronic phenomenon of "second breakdown" and to the development of a new basis for specifying safe operating conditions for transistors. French was responsible for a major improvement in the use of four-probe resistivity measurements on germanium and silicon samples.

Center for Radiation Research

Projects undertaken by the staff of the Center for Radiation Research included theoretical studies, dosage standards, and hot-laboratory cleanup methods, described in the following accounts. Already noted in this chapter was the achievement of criticality in the NBS nuclear reactor.

Handling Hot Accelerators

When a particle-accelerator run was finished, the investigators usually went away happy. The accelerator operators, however, faced the problem of replacing samples and preparing the machine for further use. Often, this process was complicated by radioactivity induced in the materials from which the accelerator itself was made. James M. Wyckoff of the Linac Radiation Division provided the Health Physics group with information on the types and intensities of radiation to be expected as a result of induced radioactivity.

Wyckoff obtained data on the spallation products to be expected from the use of several materials commonly used to build accelerators, including aluminum, iron, nickel, and copper.[275] He calculated the energy emitted as photons over the time range of 1 hour to 4 years after irradiation took place, allowing operators to cope with "hot" accelerators, and designers to minimize especially unfavorable materials in accelerator construction.

Measuring Radioactivity Doses

During this period, physicists in the Applied Radiation Division developed a radiation-measurement procedure that used films and gels to measure dosages of radiation. Radiation monitors were a necessity for those involved in industrial radiation processing of foods, medical supplies, and other materials. William L. McLaughlin, Eckhart K. Hussmann—a guest worker from the Max Planck Institute in Frankfurt,

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[274] "Stratton and Rosa awards presented," *NBS Standard,* Vol XVI, No. 6, June 1971, pp. 1, 11, 12.

[275] J. M. Wyckoff, "Photon energy emission from spallation products produced by 3-13 GeV electrons," *Health Phys.* **18**, 693-704 (1970).

Germany—H. H. Eisenlohr of the International Atomic Energy Agency in Vienna, and Lyman Chalkley of LaJolla, California prepared solutions that were initially colorless but assumed a stable blue-violet color when irradiated with doses from 1 krad to 100 krad. The color change provided an easy-to-read visual indication, and more precise dosage information could be obtained by measuring the optical density of the dosimeter.[276]

Hussmann and McLaughlin provided a dosimetric method for a more technical purpose as well. They developed a holographic interferometer technique that relied upon the change of refractive index of a transparent liquid. The spatial distribution of absorbed dose could be determined by observation of the liquid, taking advantage of the fact that small changes in local temperature, arising from the irradiation, were accompanied by changes in refractive index. They found the method to be especially useful for high-intensity pulsed radiation.[277]

In the area of neutron dosimetry, Valentine Spiegel, Jr. and his associates studied the geometry of neutron penetration in a variety of substances, including liquid baths. These studies often involved foils which became radioactive upon exposure to neutrons. The degree of activation allowed evaluation of the dosage at various positions from sources configured in specific geometric forms. With his colleague William M. Murphey, Spiegel prepared a computer code for the calculation of thermal neutron self-absorption for cylindrical and spherical sources, using dosage measurements in a manganous sulfate bath to confirm the results.[278]

Verifying a Nuclear Theory

Robert B. Schwartz, Roald A. Schrack, and Henry T. Heaton of the Bureau's Nuclear Radiation Division puzzled over a scientific bulletin sent from a laboratory in Hungary. Two Hungarian scientists had measured the energy dependence of the scattering cross-section for neutrons and protons.[279] They found regular deviations of about 5 % from smoothness in the cross-section curve that called into question the accepted theory of n-p scattering, which dictated a smooth, monotonic decrease in the cross-section with energy. The three NBS physicists realized that they could quickly measure the cross-sections to verify or refute the new data.

Immediately the Bureau team prepared a polyethylene target for irradiation by the NBS electron linear accelerator. The hydrogen atoms contained in the polyethylene furnished target protons, and the linac electron beam was directed to another target to produce neutrons of varying energy. Plotting the resulting data showing cross section

[276] W. L. McLaughlin, E. K. Hussmann, H. H. Eisenlohr and L. Chalkley, "A chemical dosimeter for monitoring gamma-radiation doses of 1-100 krad," *Intern. J. Appl. Radiation Isotopes* **22**, 135-140 (1971).

[277] E. K. Hussmann and W. L. McLaughlin, "Dose-distribution measurement of high-intensity pulsed radiation by means of holographic interferometry," *Radiation Res.* **47**, No. 1, 1-14 (1971).

[278] V. Spiegel, Jr. and W. M. Murphey, "Calculation of thermal neutron adsorption in cylindrical and spherical neutron sources," *Metrologia* **7**, No. 1, pp. 34-38 (1971).

[279] Gy. Hrehuss and T. Czibók, "Oscillations in the energy dependence of the n-p scattering cross section," *Phys. Lett.* **28B**, No. 9, 585-587 (1969).

Valentine Spiegel, Jr. and his assistant Linda Cline determined neutron penetration depths in a water bath, using foil detectors positioned at precise distances from the source. After neutron activation, the foils were placed in a radioactivity counter to measure neutron fluence.

vs energy, Schwartz, Schrack, and Heaton found a curve that was smooth within 0.5 %, verifying the original theoretical prediction.[280] Similar experiments elsewhere corroborated the NBS work.

Recognition for CRR Scientists

Martin J. Berger, Chief of the Radiation Theory Section, CRR, was awarded the Department of Commerce Gold Medal for his work in radiation-transport theory and its application to radiation-engineering problems. An example of that type of research was produced by Berger and Stephen M. Seltzer, who used a Monte Carlo technique to calculate the penetration of fast electrons through water. They were able to account for multiple atom-electron scattering (both elastic and inelastic) as well as the influence of bremsstrahlung effects, producing information on the spatial distribution of energy deposition, charge deposition, and electron flux.[281] A similar set of calculations, performed for the case of aluminum targets, aided the cause of protection against space radiation.

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[280] R. B. Schwartz, R. A. Schrack, and H. T. Heaton, "A search for structure in the n-p scattering cross section," *Phys. Lett.* **30B**, No. 1, 36-38 (1969).

[281] M. J. Berger and S. M. Seltzer, "Calculation of energy and charge deposition and of the electron flux in a water medium bombarded with 20-eV electrons," *Ann. N. Y. Acad. Sci.* **161**, Art 1, 8-23 (1969).

Berger also utilized point kernel theory to evaluate the effects of beta irradiation dosimetry for medical purposes.[282]

Everett G. Fuller and Evans V. Hayward shared the Department of Commerce Gold Medal in 1971 for:

> Pioneering work in experimental photonuclear physics that provided the scientific basis for various practical applications of high energy x- and gamma rays.

An example of Hayward's work was a monograph on photonuclear reactions in which she reviewed progress in the energy range from 10 MeV to 30 MeV. Hayward compared the predictions of several theories against existing experimental data, noting where discrepancies provided incentives for further work.[283] Similarly, Fuller prepared a discourse on photoneutron reactions.[284]

Progress in Polymer Physics

Lauritzen and Hoffman Share High Polymer Physics Prize

The American Physical Society awarded its High Polymer Physics Prize jointly to two NBS scientists in March 1970. The prize, sponsored by the Ford Motor Company, was given to John I. Lauritzen, Jr. and John D. Hoffman for:

> Their theoretical contributions to the understanding of molecular motions in solids, and, in particular, for their kinetic theory of polymer crystallization.[285]

Lauritzen held the title of Institute Scientist in the Institute for Materials Research at that time; Hoffman was Director of the institute. Both had served NBS since the mid-1950s. An example of recent work by the pair, accomplished in collaboration with Elio Passaglia, Gaylon S. Ross, Lois J. Frolen, and James J. Weeks, was a detailed study of theories treating the kinetics of polymer crystallization.[286] In that work, the scientists reviewed nucleation theories for chain-folded polymers; special attention was given to prior work on fluctuations by Passaglia and Lauritzen. The study contributed new understanding to the developing theory of large polymers.

Receiving awards for their scientific work was not unusual for the two scientists. Hoffman received the Department of Commerce Gold Medal in 1965 and the NBS Samuel Wesley Stratton award in 1967 for his polymer investigations, and Lauritzen shared the Stratton award in 1971 with Passaglia and Edmund DiMarzio.

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[282] M. J. Berger, "Beta-ray dosimetry calculations with the use of point kernels," *Atomic Energy Commission Report* **CONF-691212**, June 1970, pp. 63-86.

[283] E. Hayward, "Photonuclear Reactions," *NBS Monograph 118* August 1970, 46 pp.

[284] E. G. Fuller, "Photoneutron reactions," pp. 359-375 in *Nuclear Structure Study with Neutrons* (Amsterdam: North-Holland Publ. Co, 1966).

[285] "Dr. Hoffman and Dr. Lauritzen share APS physics prize," *NBS Standard,* Vol XVI, No. 5, May 1971, p. 1.

[286] J. D. Hoffman, J. I. Lauritzen, Jr., E. Passaglia, G. S. Ross, L. J. Frolen, and J. J. Weeks, "Kinetics of polymer crystallization from solution and the melt," *Kolloid-Z. Polymere* **231**, Nos. 1 & 2, 564-592 (1969).

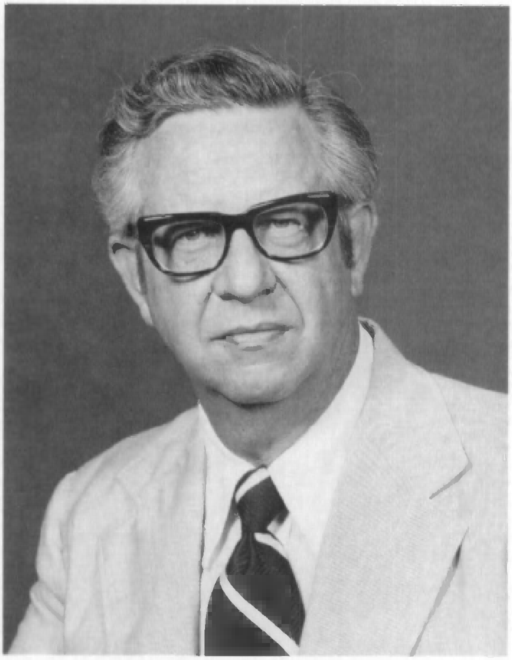
John I. Lauritzen, Jr. joined the NBS Dielectrics Section in 1956 and worked there until his death in 1976. His special interest was the theory of polymer crystallization.

Biting into Dental Problems

The long-standing collaboration between NBS and the world of dentistry produced many advances for the public. George Dickson, Assistant Chief of the Dental Research Section of the Polymers Division, was recognized for his contributions to these advances in March 1972, when the International Association for Dental Research presented him with the Wilmer Souder Award, the highest honor in the field of dental materials.

It is worthwhile to recall the contributions made by Wilmer S. Souder to the Nation's dental health. Souder, a Bureau physicist, responded to a request made during World War I by the Surgeon General that the Bureau of Standards investigate the science underlying dentistry to improve the woeful state of soldiers' teeth. Souder was appalled at the lack of scientific information at the base of dental practice at the time. His review of the situation prompted a commercial laboratory to initiate support of a program of dental studies at the Bureau. Because his administrative efforts were matched by outstanding scientific work on behalf of the Nation's dentists, Souder became known as "The Father of Dental Materials Research."[287]

[287] G. C. Paffenbarger and N. W. Rupp, "History of the International Association for Dental Research Wilmer Souder Award in Dental Materials, with a short biography of Wilmer Souder," *Dental Materials* **2**, pp. 49-52 (1986).



John D. Hoffman retained an active interest in polymer theory even as he served as director of the NBS Institute for Materials Research from 1967-1978 and the director of the National Measurement Laboratory from 1978-1982.

Dickson, a Bureau staff member for two decades, was one of a large group of productive researchers. Work during that period included studies of the properties of dental amalgams and of instrumentation used in dental research.[288]

George C. Paffenbarger and Guest Worker J.B. Woelfel provided some basic data to benefit wearers of dentures as a result of a long-term study. Two sets of upper and lower dentures, one made of vulcanite and one of epoxy, were evaluated periodically for serviceability and shrinkage over a 7-year test in which the dentures were worn on a continuing basis. Paffenbarger and Woelfel reported finding deterioration of the dentures, and they described tests that identified the probable causes.[289]

Paffenbarger, former director of the American Dental Association research unit at NBS, was awarded the Miller International Prize at the 15th World Dental Congress in Mexico City during October 1972, "for the most eminent services to science."[290]

[288] P. L. Oglesby, G. Dickson, M. L. Rodriguez, R. M. Davenport, and W. T. Sweeney, "Viscoelastic behavior of dental amalgams," *J. Res. NBS* **72C**, No. 3, 203-213 (1968). See also G. Dickson, P. Oglesby, and R. Davenport, "The steady-state creep behavior of dental amalgams," *J. Res. NBS* **72C**, No. 3, 215-218 (1968). See also J. D. Eick, H. J. Caul, T. Hegdahl, and G. Dickson, "Chemical composition of dental gold casting alloy and dental wrought gold alloys," *J. Dental Res.* **48**, No. 6, 1284-1289 (1969). See also T. V. Gardner, Jr. , G. Dickson, and J. W. Kumpala, "Application of diffraction gratings to measurement of strain of dental mterials," *J. Dental Res.* **47**, No. 6, Part 2, 1104-1110 (1968).

[289] J. B. Woelfel and G. C. Paffenbarger, "Expanding and shrinking 7-year-old dentures: report of cases," *J. Am. Dental Assoc.* **81**, No. 6, 1342-1348 (1970).

[290] See *NBS Standard*, March 1973, p. 3.

Elio Passaglia had a diverse career at NBS, at various times serving as chief of the Polymer Physics Section and the Metallurgy Division, Deputy Director of the Center for Materials Research, and chief of the Office of Flammable Fabrics. He also wrote a history of NBS covering the period 1951-1969.

Paffenbarger, the first professional dentist to engage in research at NBS, retired in 1968 after 38 years as an ADA research associate. In April 1985, NBS established the Paffenbarger Research Center within the Polymers Division in honor of his contributions to the field of dentistry.

Optical Physics Research

Optical physics research covered a wide range of activities indeed. Many projects that could have been included in this section can be found elsewhere in this chapter. Here we present just a sampling of such projects.

Far Ultraviolet Spectrum of Lithium

A difficult experiment was successfully completed during 1970 through the cooperation of a large group of people, both from NBS and elsewhere. The experiment involved the observation and analysis of the spectrum of atomic lithium in the range 22 nm to 17 nm (56 eV to 70 eV). Lithium is extremely reactive; this property provided a non-trivial complication in any such experiment. In addition, the spectral range of the study, chosen for its significance to astronomical work, was far from the easiest to observe. Finally, interpretation of the results of the experiment presented its own challenge.

David L. Ederer, Thomas B. Lucatorto, and Robert P. Madden of the Optical Physics Division (OPD) built an experimental chamber modeled after a heat-pipe oven developed by C. R. Vidal and J. Cooper of the Radio Standards Physics Division in

Edmund A. DiMarzio, a theoretical physicist, joined the NBS Polymer Physics Section in 1963. He shared the High Polymer Physics prize of the American Physical Society in 1967.

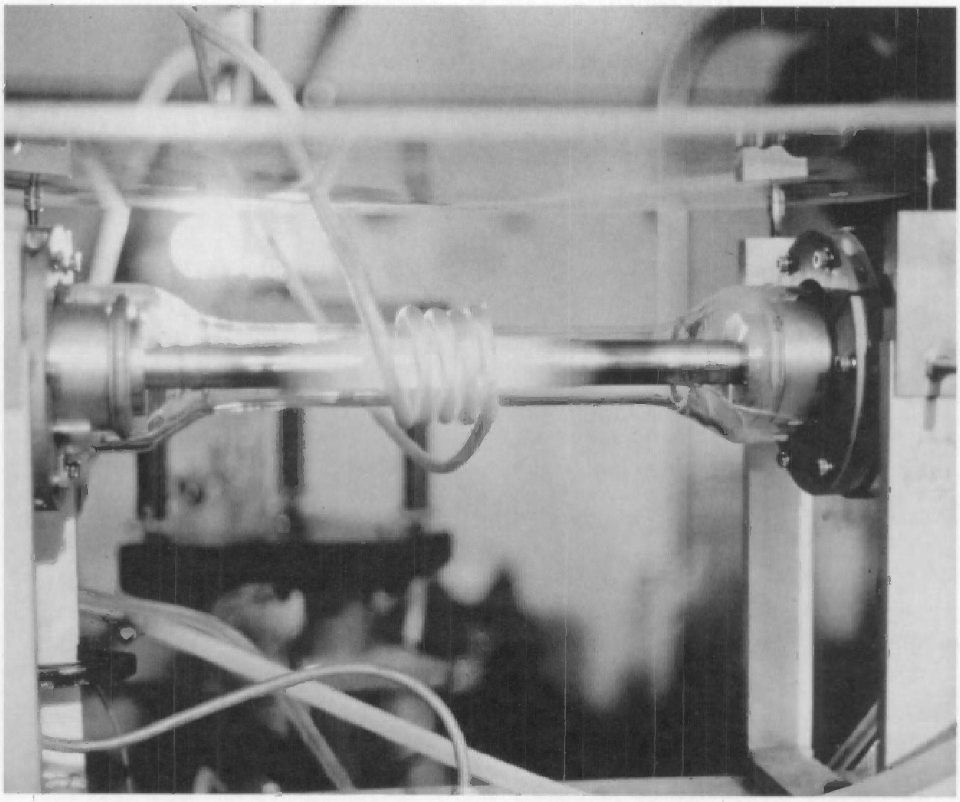
Boulder.[291] In the oven, lithium vapor was isolated within the center portion of a stainless-steel cylinder contained in a quartz vacuum tube. The technique utilized an external rf coil and an internal stainless-steel wick to regulate the temperature of the lithium vapor within 1 °C of 725 °C. The NBS 180 MeV electron synchrotron provided high-intensity radiation, which was directed through thin aluminum windows at the ends of the heat pipe and collected in a grazing-incidence spectrograph.[292] The hot-lithium line spectra were analyzed in terms of the states of excited lithium by Andrew W. Weiss and John W. Cooper of the OPD and colleagues M. J. Conneely, Kenneth Smith, and Stephan Ormonde from the University of Nebraska and Quantum Systems, Inc.[293]

Using the results obtained in this experiment, the investigators were the first to elucidate the autoionizing states of lithium, which were thought to involve K-shell and/or valence electron excitation. Astronomers utilized the new results to refine estimates of the concentration of lithium in the solar atmosphere.

[291] C. R. Vidal and J. Cooper, "Heat pipe oven: a new, well-defined metal vapor device for spectroscopic measurements," *J. Appl. Phys.* **40**, No. 8, 3370-3374 (1969).

[292] D. L. Ederer, T. Lucatorto, and R. P. Madden, "Autoionization spectra of lithium," *Phys. Rev. Lett.* **25**, No. 22, 1537-1540 (1970).

[293] J. W. Cooper, M. J. Conneely, Kenneth Smith, and Stephan Ormonde, "Resonant structure of lithium between the 2^3S and 2^1P thresholds," *Phys. Rev. Lett.* **25**, No. 22, 1540-1543 (1970).



The absorption spectrum of lithium was investigated from 56 eV to 70 eV using the NBS synchrotron and the lithium heat pipe oven shown here. Lithium was vaporized in the stainless steel, horizontal pipe oven (center), which was enclosed within a quartz vacuum tube and heated by an exterior rf coil. Viewing windows were enclosed within the solid cooling sections at each end of the quartz tube.

Transition Probabilities in the Vacuum Ultraviolet

Hard on the heels of the lithium work described above came the first NBS measurements of transition probabilities in the vacuum-ultraviolet spectral region. William R. Ott of the Optical Physics Division used a wall-stabilized arc, operating in a mixture of argon and oxygen, and a new 3-meter high-resolution scanning monochromator to measure the transition probabilities for neutral oxygen.[294] Ott chose

[294] W. R. Ott, "Measurement of transition probabilities for O I in the vacuum ultraviolet," *Phys. Rev.* **A4**, No. 1, pp. 245-251 (1971).

oxygen for the first measurements in an attempt to resolve outstanding discrepancies found in other experiments, and because of the importance of the transition probabilities in determining stellar oxygen densities.

New Test for Quality Optics

Many procedures used in optical physics depended on the quality of optical components. In 1970, James B. Saunders developed a new method to test the quality of optical parts; it was sufficiently simple to be used in the workshop. The technique used a wavefront-shearing interferometer—basically a composite prism of cubical shape—plus a light source. The prism could be prepared so as to yield various amounts of shear; Saunders recommended the range 3 milliradians to 12 milliradians. In use, the operator viewed an interference pattern produced by the interferometer as light was reflected from the optical component under test. The pattern could be interpreted either visually or quantitatively to evaluate the quality of the component, typically a lens or a mirror.[295]

Optical Properties of Laser Materials

Heat and pressure both caused changes in the index of refraction of the materials from which glass and crystal lasers were constructed. Uneven or unsteady application of heat or pressure caused the index of refraction to vary with position or time. In turn, the changing index of refraction caused distortion of the wavefront of the light emitted by the laser. Roy M. Waxler, Given W. Cleek, Edward Farabaugh, and Albert Feldman found that the piezo-optic and thermo-optic properties of laser materials including ruby and five different compositions of neodymium-doped glass were only poorly known, so they set about to measure them.

Measurements of the thermo-optic constants of the materials involved use of a Fizeau interferometer to observe the change of refractive index with temperature over the range 0 °C to 300 °C for the neodymium glasses and 0 °C to 600 °C for the ruby samples. Both hydrostatic and uniaxial stresses were applied to the specimens in the piezo-optic experiments.[296]

[295] J. B. Saunders, "Production of near-perfect interferograms of variable visibility," *J. Res. NBS* **74C**, Nos. 1 and 2, 1-2 (1970).

[296] "Piezo-optic and thermo-optic properties of solid laser materials," *NBS Technical News Bulletin* August 1970, p. 177.

Measuring Laser Energy

Casting about in the mid-1960s for the most accurate method to measure the output energy of pulsed lasers, Donald A. Jennings developed the most confidence in calorimeters. He designed and built a calorimeter that incorporated an absorption cell containing an aqueous solution of copper sulfate, whose temperature was continually monitored by a thermocouple thermometer. He also developed two calibration schemes, one based on the known heat capacity of the absorption cell and the other on the substitution of known amounts of electrical heating to reproduce the final measured cell temperature. The two methods agreed within about 0.3 %.

Jennings employed the new apparatus to measure the output energy of a pulsed ruby laser operating at 694 nm. He found the calorimeter useful at laser energies as high as 30 J and peak power to 200 MW/cm^2.[297]

Before long, calorimetry was the standard method for laser-energy measurements. In 1969, Jennings teamed with E. Dale West, Kenneth M. Evenson, A. L. Rasmussen, and W. R. Simmons to summarize laser power and energy measurements in *NBS Technical Note 382.*

The pursuit of high-accuracy laser calorimetry was maintained by West and his colleague Kenneth L. Churney, who analyzed the theory of isoperibol calorimetry in 1970. The two scientists treated the measurements in terms of the first law of thermodynamics and the boundary value problem describing heat flow in the calorimeter. Their study pointed the way to design principles, minimization of experimental uncertainty, and methods for testing the validity of specific experiments.[298] Based upon the guidelines developed by West and Churney, a Boulder group—West, W. E. Case, A. L. Rasmussen, and L. B. Schmidt—designed, built, and evaluated a small reference isoperibol calorimeter for the measurement of laser energy. They outlined procedures to relate all measurements to NBS standards of voltage, resistance, and frequency, offering the careful user maximum systematic error levels not to exceed 1 %.[299]

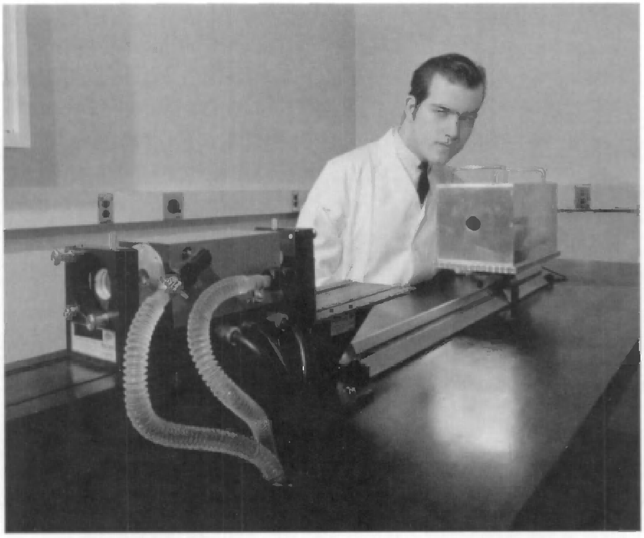
A handy, on-the-spot measurement of the output energy of solid-state lasers, accurate within about 3 % for output energy levels as high as 100 J, was made possible by Arthur H. Neill and John A. Mitchell of the Electronic Technology Division. Neill designed and developed the device and Mitchell fabricated it into a manageable box weighing less than 25 kg.

The calorimeter was composed of an absorber, a light-dispersing reflective cone of aluminum enclosed within a blackened cylinder designed to retain nearly all of the laser energy, and a heat sink which provided reference cold junctions for a ring of series-connected thermocouple thermometers arranged on the absorber. In operation, a

[297] D. A. Jennings, "Calorimetric measurement of pulsed laser output energy," *IEEE Trans. Instr. Meas.* **IM-15**, No. 4, pp. 161-164 (1966).

[298] E. D. West and K. L. Churney, "Theory of isoperibol calorimetry for laser power and energy measurements," *J. Appl. Phys.* **41**, pp. 2705-2712 (1970).

[299] E. D. West, W. E. Case, A. L. Rasmussen, and L. B. Schmidt, "A reference calorimeter for laser energy measurements," *J. Res. NBS* **76A**, No. 1, 13-26 (1972).



Arthur H. Neill, Jr. of the NBS Electronic Technology Division measured the output energy of a solid state laser, using a portable calorimeter that he developed in 1970.

single laser pulse was intercepted by the calorimeter and the thermocouple output provided an energy value for the pulse. Calibration of the device showed it to be accurate within about 2.8 %.[300]

Oscillator Strengths and Transition Probabilities

Accurate determinations of the abundance of iron in the sun were significant to the development of models of the solar atmosphere. Previous determinations indicated, surprisingly, that the fraction of iron present in the sun's photosphere was much smaller than in the corona. The oscillator strength, or f-value, of iron was a key component to resolving the unexpected difference. Studying the question, J. Mervyn Bridges and Wolfgang Wiese found substantial discrepancies between recent f-values for neutral iron and those listed in older tables.

The two atomic physicists remeasured the iron f-values, using a plasma-arc source which they modified to stabilize the light intensity. Careful introduction of iron vapor and comparison and calibration of the resulting line intensities yielded greatly improved determinations of the f-values for iron. In some cases, earlier values were found to be erroneous by factors of 20! Using the new NBS values, astronomers quickly were able to correct estimates of the iron abundance in the solar photosphere by a factor of about 10, resolving the puzzling discrepancy.[301]

[300] A. H. Neill, Jr., "High-energy light detector for use with pulsed ruby and glass lasers," *Appl. Opt.* **9**, No. 10, 2392-2393 (1970).

[301] J. M. Bridges and W. L. Wiese, "Transition probabilities for the prominent red lines of Ne I," *Phys. Rev.* **A2**, No. 2, 285-293 (1970).

The work with Bridges was only one of many for Wiese. He was awarded the Department of Commerce Gold Medal in 1971 for his contributions to atomic and plasma physics. Like many Bureau scientists, Wiese showed leadership in two ways; by personal research and by collaborating with others on larger projects. During this period, his individual publications included two significant papers: one describing the relation between atomic oscillator strength and especially nuclear charge, and a second reviewing the field of transition probabilities.[302] With A. W. Weiss and Mervyn Bridges, he presented two papers on atomic oscillator strengths.[303] With Bridges, Richard L. Kornblith, Daniel E. Kelleher, and Jeffrey R. Fuhr, he wrote one paper and an *NBS Special Publication* on transition probabilities.[304] And with Kelleher, he discussed the possible role of slight systematic shifts in certain stellar spectra in accounting for the redshift in white dwarf stars.[305]

Physical Standards Research

In this section, we present accounts of standards in the areas of time and frequency, viscosity, millimeter-wavelength radiation, microwave power, voltage, and mass.

Telling Time by Television and by Satellite

A new wrinkle in convenience for time-synchronization signals from NBS was described by personnel of the Time and Frequency Division during 1970-71. The innovation involved the use of live network-television broadcasts. Short discussions of the principles of the technique were given by Dicky D. Davis, James L. Jesperson, and George Kamas[306] in a letter to the *IEEE Proceedings,* and, in fuller detail, by Davis and Byron E. Blair in collaboration with James F. Barnaba, a colleague from the Newark Air Force Station.[307] The new method promised 10 μs accuracy in time-synchronization of certain clocks without the necessity of carrying a portable clock to each participating site.

[302] W. L. Wiese, "Dependence of atomic f-values on nuclear charge," chapter in *Beam Foil Spectroscopy II* (New York: Gordon and Breach, 1968) pp. 386-406. Also see "Systematic trends of atomic oscillator strengths in isoelectronic sequences," *Appl. Opt.* **7**, No. 12, 2361-2366 (1968). See also W. L. Wiese, "Atomic transition probabilities—a survey of our present knowledge and future needs," *Nucl. Instr. Methods* **90**, 25-33 (1970).

[303] W. L. Wiese and A. W. Weiss, "Regularities in atomic oscillator strengths," *Phys. Rev.* **175**, No. 1, 50-65 (1968). See also J. M. Bridges and W. L. Wiese, "The oscillator-strength scale for Fe I," *Astrophys. J.* **161**, L71-L75 (1970).

[304] W. L. Wiese, J. M. Bridges, R. L. Kornblith, and D. E. Kelleher, "Transition probabilities for prominent Ar I lines in the near infrared," *J. Opt. Soc. Am.* **59**, No. 9, 1206-1212 (1969). See also J. R. Fuhr and W. L. Wiese, "Bibliography on atomic transition probabilities, July 1969 through June 1971," *NBS SP 320,* Suppl. 1, September 1971, 67 pp.

[305] W. L. Wiese and D. E. Kelleher, "On the cause of the redshifts in white-dwarf spectra," *Astrophys. J.* **166**, L59-L63 (1971).

[306] "The use of television signals for time and frequency dissemination," D. D. Davis, James L. Jesperson, and G. Kamas, *Proceedings of the IEEE,* June 1970, pp. 931-933.

[307] D. D. Davis, Byron E. Blair, and James F. Barnaba, "Long-term continental U.S. timing system via television networks," *IEEE Spectrum* **8**, August 1971, pp. 41-52.

Originating from a technique developed in Europe, the synchronization method involved the insertion of a time code into the live broadcast emanating from the New York transmitter of station ABC, CBS or NBC. The time signal was generated by a highly precise clock maintained by each of the stations in conjunction with their broadcast needs; it was inserted into a particular horizontal line of the broadcast display. As the broadcast was transmitted directly to local receivers or through microwave links to receivers across the United States, the coded time signal went along with it.[308]

Users of similarly precise clocks (those already known to be accurate within one television frame—about 30 ms) could build a decoder circuit as described by Davis, Blair and Barnaba for under $200. Using the decoder, they could read the network time signal and compare it with their own clock, just as NBS employees could compare the network time signal with their master atomic clock. NBS scientists had explored the method as a means of comparing the atomic clocks maintained at WWV in Washington, WWVB in Boulder, and WWVL in Fort Collins, Colorado, as well as comparing these clocks with those maintained at the Naval Observatory in Washington and at Newark Air Force Station in Ohio.

Having measured the difference in reading between any particular clock and the network clock, it was still necessary to interpret the difference so as to evaluate the actual discrepancy between the clocks and, more importantly, to determine the deviation of each of the clocks from the NBS master time clock. This step required a detailed accounting of the time delay resulting from the particular path taken by the network broadcast. Use of the microwave television link involved a delay of about 3 μs per km; the Bureau staff assisted the owners of clocks in remote areas in determining the time-delay corrections needed to relate the television synchronization signals to time differences from the NBS atomic clock.

Many users of the Bureau's time service had no need of the 10 μs accuracy level that the new system could provide. However, those users who did need the service could utilize it without the expense and delay of transporting an atomic clock to their location.

Another breakthrough in time and frequency dissemination occurred on the heels of time-by-television: time-by-satellite.

Beginning in 1971, the NBS time and frequency signals—ordinarily available only through the Bureau's high-frequency radio broadcast—were transmitted also by signals relayed from the National Aeronautics and Space Administration's ATS-3 satellite. The signals were based upon the NBS Frequency Standard and the NBS Coordinated Universal Time Scale that were maintained at the Boulder laboratories of the Time and Frequency Division. The broadcasts were part of an experiment in dissemination of the Bureau's WWV T&F information. First results of the experiment were reported by D. Wayne Hanson and Wallace F. Hamilton.[309]

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[308] A brief discussion of the use of commercial television for broadcasting time and frequency information can be found in "Boulder experimental TV time and frequency system," *NBS Standard,* Vol XVI, No. 5, May 1971, p. 7.

[309] D. W. Hanson and W. F. Hamilton, "Satellite broadcasting of WWV signals," *IEEE Transactions on Aerospace and Electronic Systems,* **AES-10**, No. 5, pp. 562-573, September 1974.

The ATS-3 was not the first satellite to be involved in time and frequency broadcasts; that honor belonged to the Telstar satellite, used in 1962 to compare the clocks at the U.S. Naval Observatory with those at the Royal Greenwich Observatory in England. The satellite technique proved accurate within 1 μs, sometimes better, on an experimental basis.

There was one obvious advantage to the use of the ATS-3 satellite to broadcast time and frequency information: the signals could be received over nearly 40 % of the earth's surface—in North America, South America, much of the Atlantic and Pacific Oceans, and in parts of Europe and Africa. Questions to be answered about satellite transmission included the cost of the system to the users and the accuracy with which the information could be delivered.

The ATS-3 satellite was placed in a geostationary orbit at approximately 70° west longitude. The signals were sent to the satellite at a frequency of 149.245 MHz; its transponder converted the frequency to 135.625 MHz, amplified it, and retransmitted it to all who cared to listen. The timing format consisted of tones, ticks, a time code, and voice announcements, familiar to those users who received the information over WWV and WWVH. Two 15-minute broadcasts were sent each day, beginning at 1700 hours and 2330 hours, Greenwich Mean Time.

Periodical adjustments were made in the broadcasts to improve their usefulness as a dissemination service of NBS.

The Bureau staff calibrated receivers for use with the broadcast experiment, two for sites in North America (Boulder and the Air Force Cambridge Research Laboratory) and two for South America (Smithsonian Astrophysical Laboratories in Arequipa, Peru and in Natal, Brazil). Calibrated cesium atomic clocks, synchronized to Boulder time by portable calibration clocks, were used to evaluate the time-delay involved in the satellite signals (typically about 0.25 s) as well as the effectiveness of the system. Delays occurred because of the length of the broadcast path, transit time in the electronic equipment, and atmospheric conditions. Uncertainties in these delay components placed limits on the accuracy of the dissemination method, as did "wandering" from its nominal position by the satellite itself. Changes in the satellite position resulted in time differences of approximately 1 μs for each 300 m of motion.

During 1972 the experimental broadcasts were received and the delays compared to predicted values. The discrepancies reached magnitudes no larger than 30 μs, a distinct improvement over typical uncertainties of 1 ms found by use of the earthbound radio signals. In addition, the satellite signals presented a "cleaner" electromagnetic pattern than did the earthbound broadcasts. The best news of all was that the cost of satellite reception appeared to be very comparable with the $100-$500 cost of WWV/WWVH receiving equipment.

On the basis of this experiment, time-by-satellite seemed poised to join the panoply of time-dissemination methods—the wristwatch, the telephone, high-frequency (eg., WWV) radio broadcasts, low-frequency (eg., Loran-C) broadcasts—but with improved accuracy available over a large portion of the globe. James L. Jesperson and Lowell Fey neatly summarized these and other techniques for transferring knowledge of time and frequency during this period,[310] as did Jesperson, Byron E. Blair, and Lawrence E. Gatterer in a more technical article.[311]

Before departing from the subject of time and frequency for the moment, we must mention the publication, in 1972, of *Special Publication 300,* volume 5. It contained reprints of more than 80 papers published during the period 1960-1969, separated into sections on standards, time scales, dissemination, statistics, and selected references.[312]

How Well Can We Measure Viscosity?

Viscosity measurements had been around a long time, but there was something wrong with them—they relied on an assumed value for the viscosity of water as a reference. If there were biases (systematic errors) in the water-viscosity measurement, all measurements would be erroneous.

What to do to evaluate the absolute uncertainty of viscosity measurements? Of course—devise two significantly different techniques for absolute viscosity measurement and compare the results. Accordingly, Robert W. Penn, Hobart S. White, and Elliot A. Kearsley replaced the traditional capillary method with two new methods that would, at least, exhibit different biases.

Penn and Kearsley assembled a three-cornered flow channel by clamping two 1 m long stainless-steel rods together, then clamping a glass flat across the two rods. An equation was derived for kinematic viscosity in the resulting geometry. Pressure taps, a standpipe at the entrance to provide calculable entry pressure, a sampling system at the exit, and careful temperature control completed the apparatus. Viscosity measurements were made on a light oil. Using a well-established relation between the viscosity of the light oil and the viscosity of water, the authors derived a value of (1.001 ± 0.001) cP at 20 °C for water.[313]

Meanwhile, White and Kearsley built a 10 cm diameter hollow nickel sphere with a smooth interior surface. The sphere was designed to be filled with the test fluid, hung from a wire, and set into oscillation by applying a small torque. The two derived an equation relating the period of oscillation to the viscosity of the fluid. Timing of the oscillation was accomplished electronically. Again, the system was placed under careful temperature control. Their measurements, performed on a different light oil, could be corrected to yield a value for the viscosity of water. The value so deduced was $(1.006 + 0.001)$ cP. This value was about 0.5 % higher than the one obtained by the channel-flow technique.[314]

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[310] James L. Jesperson and Lowell Fey, "'Time-telling' techniques," *IEEE Spectrum* **9**, pp. 51-58, May 1972.

[311] James L. Jesperson, Byron E. Blair, and Lawrence E. Gatterer, "Characterization and concepts of time-frequency dissemination," *Proc. IEEE* **60**, No. 5, pp. 502-521, May 1972.

[312] B. E. Blair and A. H. Morgan, Editors, "Precision Measurement and Calibration: Selected papers on Frequency and Time," *NBS Special Publication 300,* Vol. 5, 565 pp., June 1972.

[313] R. W. Penn and E. A. Kearsley, "An absolute determination of viscosity using channel flow," *J. Res. NBS* **75A**, No. 6, 553-560 (1971).

[314] H. S. White and E. A. Kearsley, "An absolute determination of viscosity using a torsional pendulum," *J. Res. NBS* **75A**, No. 6, 541-551 (1971).

Elliot Kearsley inspected the height of the liquid inside a hollow sphere that, when excited, became a rotational pendulum, turning first in one direction and then in the other. It could be used to make absolute viscosity measurements, the viscosity of the sample liquid being calculated from observed parameters, including the period of oscillation.

Robert S. Marvin, comparing the two experiments with previous determinations, suggested that systematic errors remaining in viscosity measurements limited their accuracy to about ±0.25 %, a much larger figure than ±0.1 %, the irreproducibility of carefully performed measurements.[315]

New Calibration Service for Millimeter Waves

The Boulder Radio Standards Engineering Division announced in February 1972 the initiation of a calibration service to extend their microwave calibrations into the 55 GHz to 65 GHz range. Types of measurements provided included the following:

- Power, measured using a microcalorimeter, accurate at the ±3 % level.
- Attenuation at the level of ±0.05 dB per 10 dB, from 0 dB to 50 dB.
- Impedance (measured as the reflection coefficient) over the range 0.001 Γ to 1.0 Γ.
- Antenna gain, measured both indoors and out.
- Noise, to an accuracy of 2.3 %, depending on the equipment involved.

The new service was operated by Frances X. Ries.

Changing Time by Leap Seconds

All early efforts towards more accurate timekeeping were driven by the desire for better navigation. Therefore, the most useful clocks were those that most closely represented the earth's rotation rate. *Greenwich Mean Time* became the official source of earth-based timekeeping in the 1840s, and it held its position as the world standard of time until January 1, 1972. Ingenious pendulum clocks offered timekeeping accuracy at the level of about one part in ten million. Quartz oscillator clocks performed even better.

When Harold Lyons, Chief of the NBS Microwave Standards Section, began to use an absorption line of ammonia as an "atomic clock" in 1948, he opened the door to a new level of accuracy in timekeeping. Also lurking behind that door was an inevitable collision with *Greenwich Mean Time.*

The idea of basing time and frequency measurements on atomic transitions was revolutionary. Unlike pendulum clocks or quartz crystals, all ammonia atoms were alike; the frequency of the chosen transition was invariant. "Atomic clocks" made anywhere would, in principle, keep exactly the same time. More advanced clocks based on the measurement of a 9192 MHz transition in atomic beams of cesium agreed within 2 parts in 10^{11} by 1960.[316]

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[315] R. S. Marvin, "Accuracy of measurements of viscosity of liquids," *J. Res. NBS* **75A**, No. 6, 535-540 (1971).

[316] R. E. Beehler, R. C. Mockler, and C. S. Snider, "A comparison of atomic beam frequency standards," *Nature* **187**, August 20, 1960, pp. 681-682. According to Bragaw and Snyder, *Achievements in Radio*, p. 301, other Bureau staff members who participated in the early work on atomic clocks included Jesse E. Sherwood, Robert N. McCracken, Richard C. Mockler, David W. Allan, James A. Barnes, R. Lowell Fey, David J. Glaze, Donald W. Halford, F. Russell Petersen, Jack B. Snider, Richard L. Strombotne, Henry F. Salazar, and Arthur E. Wainwright.

The very high accuracy reached by the atomic clocks made painfully obvious the fact that the earth's rotation was not uniform, but instead varied by a few thousandths of a second a day (about one part in 10^8). The question became one of how to take advantage of the accuracy of modern atomic clocks while still keeping terrestrial clocks in time with the earth's movements. Various techniques involving Ephemeris Time, Universal Time, and "rubber seconds" were not successful.

The eventual resolution of the earth-clock *vs* atom-clock problem involved a compromise. On January 1, 1972, the International Bureau of Weights and Measures began to administer a new time scale, *Coordinated Universal Time,* or UTC. The accumulation of time on the UTC followed the atomic clocks. However, a one-second adjustment to the UTC would be made whenever earth time deviated as much as one second from atomic time. Because of the similarity to the "leap year" concept, the one-second adjustments were called "leap seconds."[317]

High-Level and Wide-Range Power Measurements

New techniques for the measurement of continuous-wave microwave power at high levels and for the measurement of power over wide ranges of power and frequency were developed by members of the Radio Standards Engineering Division in Boulder.

W. E. Little, K. E. Bramall, and E. Andrusko, collaborating with R. Gray of the Rome [New York] Air Development Center of the U.S. Air Force, demonstrated the feasibility of measuring with unprecedented accuracy the output of a 60,000 W, 8 GHz klystron amplifier. Using standard NBS microwave power calibration equipment with a new type of power divider, the group visited the Air Force installation and measured the large radar source with an estimated uncertainty less than 4 %.[318] It was considered important to refine the measurement of microwave power—commonly only accurate to 10 % at that time—to avoid the "overdesign" of equipment as well as to minimize hazards from radar installations, microwave ovens, and communications gear.

In a separate project, R. A. Lawton, C. M. Allred, and P. A. Hudson developed a new technique useful for the measurement of power levels as low as 10^{-14} W over the entire radio-frequency range.[319] A standard power meter was employed in the process to determine a reference level, then a set of precision attenuators and a null detector were used to obtain power values with uncertainty levels of about 0.5 % to 1.5 %. These results represented an improvement over previous accuracy figures by factors of 2 to 6. It was expected that the new method could be used to measure power levels as high as 100 kW, and to be useful in the calibration of detectors, receivers, radiometers, and other instruments.

[317] James Jespersen and Jane Fitz-Randolph, "From sundials to atomic clocks: understanding time and frequency," *NBS Monograph 155*, December 1977, 175 pp.

[318] "High-level microwave power measurements," *NBS Technical News Bulletin,* July 1970, pp. 146-147.

[319] R. A. Lawton, C. M. Allred, and P. A. Hudson, "A wide-range cw power measurement technique," *IEEE Trans. Instr. Meas.* **IM-19**, No. 1, 28-34 (1970).

Analyzing High-Intensity Electric Fields

In studies of liquid dielectrics, where distortions of the electric fields by space charge made analytical determinations of the field distributions difficult or impossible, a new technique devised by Esther C. Cassidy and Harold N. Cones of the Electricity Division permitted accurate mapping of field intensity between electrodes immersed in liquid dielectrics.

The new method was based on the observation of the Kerr effect in nitrobenzene-filled cells. An expanded beam from a helium-neon laser was passed through a polarizer prior to entering the Kerr cell, then detected after passing through a second polarizer. The effect of high voltages on the refractive index of the nitrobenzene rendered the field profile visible in cases where the fields were non-uniform. Mapping of the fringe patterns allowed space-resolved measurements of relative field strength, actual field strength, and electrical potential. Visual examination could immediately detect regions of high electrical stress, where arcing and breakdown were likely.

The new technique was expected to lead to a better understanding of the behavior of dielectrics exposed to high-intensity electric fields.[320]

New Mass Standards from Ion Exchange Beads

David H. Freeman came to the Bureau's Analytical Chemistry Division in 1965, young but highly trained in the science of ion exchange. By 1968 Freeman was chief of the Separation and Purification Section of the division.

In March of that year, he spoke on ion exchange during an NBS *Symposium on Future Standards For Analysis,* staged by the Institute for Materials Research as part of the *Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy* (held, strange as it may seem, in Cleveland, Ohio, in 1968). Freeman predicted that ion exchange resins in the form of small, spherical particles would soon be perfected as mass standards at the Bureau. The advantage of the spherical beads lay in their chemical uniformity and the fact that they could be implanted with electrically charged counterions, either singly or in combination. Each bead's counterion content was directly related to the bead diameter, said Freeman, so that careful measurement of the bead diameter could produce a chemical microstandard.

Freeman quoted the results of a recent National Academy of Sciences-National Research Council survey of 78 analytical laboratories to indicate the types of activities in which such standards were expected to become useful. These included the convenient setting of analytical detection limits, microscale calibration of chemical measurements, flux standards for neutron irradiation, microspectrophotometric absorption standards, electron probe microanalysis, and mass spectrometry.

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[320] E. C. Cassidy and H. N. Cones, "A Kerr electro-optical technique for observation and analysis of high-intensity electric fields," *J. Res. NBS* **73C**, Nos. 1 and 2, 5-13 (1969).

By 1970 the first of the new standards was ready. Freeman, Lloyd A. Currie, Edwin C. Kuehner, Herbert D. Dixon, and Rolf A. Paulson described their development and characterization in a detailed article in the journal *Analytical Chemistry.*[321] Beads were available with diameters in the range 1 mm to 1 µm, as measured by photomicroscopy and electron microscopy. These diameters corresponded to masses in the range 10^{-3} g to 10^{-12} g. Encapsulation of both sodium and calcium particles had been accomplished. Samples of well-characterized beads were immediately made available through the Office of Standard Reference Materials.

Clearly, work to take full advantage of the new microstandards was still in the early stages, but ground had been broken in yet another standards area.

Director Lewis Branscomb gave the work on new mass standards high praise:

> This advance in measurement science illustrates the way sophisticated scientific work helps solve major problems affecting our Nation. Inability to measure accurately the minute quantities of pollutants in air and water is a tremendous obstacle in all anti-pollution efforts. This significant step along this road will help make both research and regulation easier and more effective.[322]

A New Standard for Voltage Ratios

In 1970 Ronald F. Dziuba and Bernadine L. Dunfee developed a new electrical standard. Built especially for dc and low-frequency ac calibrations, the new standard was capable of evaluating voltage ratios involving voltages as high as 1000 V with uncertainty levels as low as 0.2 ppm.

The standard was a stable, guarded unit enclosed in a sealed, thermostated container. The two scientists provided discrete ratios from 1:1 to 1000:1. Each successive ratio was measured by a substitution method and by satisfying the conditions of the series-parallel principle. A measuring network and the techniques to be followed in the use of the standard were important parts of the measuring system.[323]

Forest K. Harris Retires

Forest K. Harris "retired" from the Electricity Division, where he had served as chief of the Absolute Electrical Measurements Section, in April 1971. In retirement, however, he continued to assist the Division as a consultant. In June 1972, the Institute of Electrical and Electronic Engineers honored Harris with the award of the Morris E. Leeds prize for:

[321] David H. Freeman, Lloyd A. Currie, Edwin C. Kuehner, Herbert D. Dixon, and Rolf A. Paulson, "Development and characterization of ion-exchange bead microstandards," *Anal. Chem.* **42**, No. 2, 203-209 (1970).

[322] "Ion exchange beads: the "micromini" calibrators," *NBS T*ech. Newa Bull., April 1970, p 82.

[323] R. F. Dziuba and B. L. Dunfee, "Resistive voltage-ratio standard and measuring circuit," *IEEE Trans. Instr. Meas.* **IM-19**, No. 4, pp. 266-277 (1970).

> A lifetime of making outstanding advances in the science of high accuracy electrical measurements, and of stimulating further advances through his teaching, authorship, and committee activity.[324]

A Bureau staff member since 1925, Harris was no stranger to awards for excellent scientific work. In 1955, he received the DoC Meritorious Service Award for his book *Electrical Measurements*, a classic in its field. In 1967, he received the NBS Edward B. Rosa award for his contributions to the development of standards for electrical measuring instruments.

Problems with an Unseasoned Temperature Scale

We mentioned in Chapter 1 the *Treaty of the Meter*, signed in 1875 in Paris by the United States and some 16 other nations. Agreements on new international measurement standards involved national laboratory staffs throughout the world, as well as the International Bureau of Weights and Measures and other Treaty organizations. Usually, new standards were suggested to the International Committee for Weights and Measures (CIPM) by the appropriate Consultative Committee, composed of working scientists. But this was not always the case.

In 1968, the international Consultative Committee for Temperature (CCT) could no longer resist the call of the CIPM to amend—if not replace entirely—the *International Practical Temperature Scale of 1948*. The result was a new temperature scale that was unready for service.

The CCT had been loath to call for a new scale, because its members felt that many of the projects on fundamental thermometry that were needed for such an amendment were not yet complete. Although international bodies tend to accept progress in deliberate, measured doses, the CIPM—as recorded by Hugh Preston-Thomas later, when he was President of the CCT—had, for over a decade, dropped more and more pointed hints that the time for renovation or replacement of the IPTS-48 was at hand.[325]

Replacement of the 1948 temperature scale was considered an urgent matter primarily because of international programs involving temperatures beyond its lower limit. The most obvious of these concerned liquid hydrogen, used in the development of thermonuclear weapons and in NASA's rocketry. NASA also made extensive use of liquid helium as a coolant. At ordinary pressures, hydrogen is a liquid only below 20 K, and helium liquefies below 4.2 K; the lower limit of the 1948 scale was 90 K—above even the normal boiling point of nitrogen.

Thus it happened in 1968 that the CCT transmitted to the CIPM a tentative outline for a new temperature scale extending down to 14 K, a scale that one of its subcommittees had prepared during the previous year. The CIPM wasted no time in

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[324] "Dr. Forest K. Harris to receive IEEE award," *NBS Standard* Vol. XVII, No. 3, April 1972, pp. 9, 15.

[325] H. Preston-Thomas, "The origin and present status of the IPTS-68" in *Temperature, Its measurement and Control in Science and Industry*, Vol. 4, H. H. Plumb, Editor-in-Chief, Instrument Society of America, 1972, pp. 3-14.

notifying members of the General Conference on Weights and Measures that a new scale was at hand. During the fall of the year, the 13th General Conference passed a resolution permitting the CIPM to promulgate the new scale, and delegates to the CIPM meeting separately but essentially simultaneously designated the tentative outline as the *International Practical Temperature Scale of 1968*. All that was wanting were a few details: a text that would prescribe the means by which temperatures on the new scale could be determined; some knowledge of the relation of the new scale to the 1948 version; and estimates of the uncertainties of the new scale with respect to thermo-dynamic temperatures in the various parts of its range.

It is a testament to the resourcefulness of the thermometrists involved that a complete text for the 1968 temperature scale was published early in 1969.[326] Rapid correspondence among laboratories that had developed provisional scales ranging from 14 K upwards produced the required extension to lower temperatures. New values, more in accord with the then-current perception of the thermodynamic scale, were assigned to fixed points throughout the new scale. Adjustments were made to calibration procedures for standard platinum resistance thermometers in the range 14 K to 904 K (–259 °C to 631 °C), for standard platinum *vs* platinum-rhodium-alloy thermocouple thermometers in the range 904 K to 1337 K (631 °C to 1064 °C), and for spectral radiance thermometers in the range above 1337 K.

But given the hurried nature of its production, it was no surprise that thermometrists quickly found inconsistencies in the 1968 temperature scale. Two of the earliest protests came from NBS.

John P. Evans and Sharriil D. Wood, convinced that platinum resistance thermometry might provide a better scale in the range 904 K to 1337 K than could be realized using standard thermocouple thermometers, carefully compared nine specially prepared platinum resistance thermometers with eight standard thermocouple thermometers.[327] They found the resistance thermometers considerably more reproducible than the thermocouple thermometers: uncertainties of about 0.004 K for the former, 0.025 K to 0.030 K for the latter. But of equal interest was a curious discrepancy—reaching 0.4 K in mid-range—between temperatures determined using simple quadratic interpolation schemes for the two types of thermometers from 904 K to 1137 K. These results would be mirrored in a major renovation to the 1968 scale, promulgated in 1990, when it was decided that a quadratic equation did not accurately portray the relationship between the electromotive force of a standard thermocouple thermometer and thermodynamic temperatures.

A more direct attack on the accuracy with which the 1968 temperature scale represented thermodynamic temperatures came from Leslie A. Guildner, Richard L. Anderson, and Robert E. Edsinger. These scientists, continuing an NBS gas thermometry program started decades previously, found a surprisingly large discrepancy at

[326] "International Practical Temperature Scale of 1968," *Metrologia* **5**, 35 (1969).

[327] J. P. Evans and S. D. Wood, "An intercomparison of high temperature platinum resistance thermometers and standard thermocouples," *Metrologia* **7**, No. 3, pp. 108-130 (1971).

Sharill Wood welded platinum wires to fabricate a platinum resistance thermometer intended for use at temperatures as high as 1100 °C.

373 K, only 100 K above the major defining temperature of the 1968 scale provided by the triple point of water.[328] Instead of differing by 100 K exactly, as assumed in constructing the IPTS-68, the three Bureau authors found that the steam point was only 99.973 K above the ice point. The discrepancy, 0.027 K, was five times larger than the estimated thermodynamic uncertainty of the 1968 scale at that temperature.

[328] L. A. Guildner, R. L. Anderson, and R. E. Edsinger, "Effects of sorption on the realization of the thermodynamic scale," pp. 313-322 in *Temperature, Its Measurement and Control in Science and Industry,* 4, Harmon H. Plumb, editor-in-chief, Part 1 (Pittsburgh: Instrument Society of America, 1972).

Leslie A. Guildner adjusted the extremely accurate mercury manometer that he developed with colleagues Richard L. Anderson and Robert E. Edsinger for use with the NBS gas thermometer.

The usefulness of the IPTS-68 reference temperatures was challenged by George Furukawa, John Riddle, and William Bigge of the Heat Division's Platinum Resistance Thermometer Calibration laboratory. They had employed the freezing point of tin (232 °C) as a reference temperature for the calibration of platinum resistance thermometers for many years. They found it substantially more reliable than the boiling point of water (100 °C), specified as a calibration temperature in the IPTS-68.[329]

[329] George T. Furukawa, John L. Riddle, and William R. Bigge, "Investigation of freezing temperatures of National Bureau of Standards tin standards," pp. 247-263 in *Temperature, Its Measurement and Control in Science and Industry* 4, 1972, H. H. Plumb, Editor.

The authors collaborated with the NBS Standard Reference Materials program in evaluating tin freezing-point temperature as part of the issuance of two grades of tin as SRM-42G (10 ppm maximum impurities) and SRM-741 (1 ppm maximum impurities).[330] They carefully filled several freezing-point cells with samples of each purity. The results showed consistency of samples of a given purity within 10^{-4} °C; the less-pure tin was found to exhibit a slightly lower freezing temperature (5×10^{-4} °C) than the purer samples. On balance, tin appeared to be a good candidate for a reference temperature for an eventual replacement temperature scale. In fact, their work was adopted as part of the new scale that was promulgated in 1990.

Although the 1968 temperature scale would survive for 22 years, its eventual replacement was almost a certainty from the date of its birth.

[330] Robert L. Powell of the NBS/Boulder Cryogenics Division also participated in the certification of the tin samples by determining the ratio of the electrical resistivity at 0 °C to that at 4.2 K.