CHAPTER ONE

A UNIQUE INSTITUTION

CHANGE COMES TO A MIDDLE-AGED AGENCY

In 1968 the National Bureau of Standards was about to lose a Director who nearly had become an institution himself. With that loss the nature of the agency would begin to change, although no one could foresee the manner of change, so subtle were its beginnings.

Allen Astin, leader of the Bureau for a decade and a half, was a scientist of the old school, not different in material ways from his four predecessors as Director: his most precious possessions were his scientific and personal integrity; his devotion to the institution was absolute; the efforts of his hours, days and years hewed to the goal of providing useful purpose for his staff and obtaining for them the best working environment he could provide.

In the exercise of his duties Astin had asked no quarter from his superiors. And in truth, he had received but little. A more desired commodity, however, he had been granted in abundance by all who crossed his path—respect for his ability and for his unflinching honesty.

Our story begins with Astin's last year as Director. Most of his work is chronicled in the volume that serves as companion to this one.[1] As we assess the institution that he left behind, however, we shall see that its uniqueness in 1968 derived in no small measure from the careful and devoted nurture of Allen Astin and his predecessors.

The end of Astin's career as Director came as the Nation's funding of scientific research and development had ceased to grow at a double-digit rate. In fact, by every mark, funding of basic science and both civilian and military research and development reached a standstill during this period.[2] The events that had led to the flagging of support for America's scientific establishment were linked tightly to the origins of impending change for the National Bureau of Standards.

Gradually, during the decades of the 1950s and 1960s, America began to lose the world dominance won at so great a price in World War II. The post-war boom in the U.S. economy had fueled a corresponding jump in its standard of living, with America leading a world-wide increase in trade. But the party became noticeably quieter as the strain of war—first in Korea, then in Vietnam—coupled with a multitude of problems within the Nation's borders to unsettle the lives of ordinary Americans. Growing

[1] Elio Passaglia with Karma A. Beal, *A UNIQUE INSTITUTION: The National Bureau of Standards, 1950-1969* (Washington, DC: U.S. Government Printing Office, 1999).

[2] Deborah Shapley and Rustum Roy, *Lost At The Frontier: U.S. Science and Technology Policy Adrift,* (Philadelphia: ISI Press, 1985), pp. 4-5, Figs. 1A, 1B, 1C.

inflation and interest rates, anti-trust actions, worry over pollution and loss of natural resources, all these factors created doubt in the minds of U.S. citizens that more and more science would provide the quality of life that they wanted for themselves and their children.[3]

As a result of environmental and health concerns, Americans demanded better protection from the poisonous side effects of U.S. industrial production. There began a series of ecologically based actions by the Congress—the Land and Water Act of 1964, the Water Pollution Act and the Clean Air Act of 1965, the Clean Water Restoration Act of 1966, and later the Environmental Protection Act, the Toxic Substances Control Act, the Occupational Health and Safety Act, and amendments to the Clean Air Act. This legislation would engender compliance costs estimated at $63 billion for the year 1976 and $100 billion by 1979.[4]

Not until 1980 would the balance of payments shift dramatically to the negative for the United States, but worrisome signs abounded in 1968. As Astin prepared to retire, many members of Congress contemplated ways in which they could help American industry maintain leadership in the world economy. The solution seemed to lie in helping U.S. industry to apply modern technology more effectively. NBS was known—to the relatively few Congressmen who knew it at all—as a center of technical competence. It was the Nation's "problem-solver" as well as the final authority on measurement standards. If NBS were to exert more leadership in applying new technology, perhaps it could play a larger part in keeping America's production strong . . .

But we get ahead of ourselves. Let us take the time to examine the National Bureau of Standards to see why, indeed, it should be known as a unique institution.

Origin of the National Bureau of Standards

The Federal agency that is now called the National Institute of Standards and Technology was created as the National Bureau of Standards by the 56th Congress of the United States. The chartering legislation, reported in "The Statutes at Large of the United States of America," Volume XXXI, Chapter 872, page 1449, was approved on March 3, 1901, during the second session of the 56th Congress. The shorthand reference to the chartering act is 31 Stat. 1449 (the act is now known as Public Law 56-177); it occupies less than two pages of text.

The ten relatively short sections of Public Law 56-177[5] do not appear remarkable from the distance of ninety-odd years, but they outline in succinct form a strong, laboratory-based agency with well-developed functions and a small but highly technical staff.

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[3] Paul Johnson, Modern Times: *The World From the Twenties to the Nineties, Revised Edition,* (New York: Harper Perennial, 1991), Ch. 19.

[4] Robert DeFina, *Public and Private Expenditures for Federal Regulation of Business* (St. Louis: Washington University, 1977). Murray L. Weidenbaum, *Governmental Power and Business* (Stanford, 1980).

[5] Reproduced in Appendix A.

The birth of the National Bureau of Standards followed a surprisingly long gestation. However, by virtue of the comprehensive powers given to it by its chartering legislation, the infant agency was able to develop quickly into an effective organization. The only ingredient that Congress, on its own, could not supply was spirited and forward-looking leadership. Fortunately, that ingredient quickly materialized in the person of Samuel W. Stratton, whose contributions will be discussed shortly.

Constitutional Authority

The founding fathers provided to Congress all the authority it needed for the creation of a National Bureau of Standards more than a century before its actual founding. This authority is explicit in the U.S. Constitution. There can be no doubt that the men who wrote the Constitution recognized the importance of uniform standards of measurement to ensure an equitable and orderly commerce for the new country, for they juxtaposed that authority with the basic monetary authority. The text of Article 1, Section 8 of the Constitution reads, in part: "The Congress shall have Power . . . To coin Money, regulate the Value thereof, and of foreign Coin, and fix the Standard of Weights and Measures . . . "

Following the organization of the major executive, legislative, and judicial branches of the new government, the Congress quickly acted to regulate the coinage of the new nation. A United States Mint was established by congressional action on April 2, 1792, a scant three years after the inauguration of George Washington as the first President. Curiously, however, the Congress was hesitant to act on its co-equal authority with respect to weights and measures, despite the clear and growing need for uniformity in manufacture and commerce and despite specific requests from President Washington.

"Customary Standards"

The need for Congress to "fix the standard" for weights and measures arose in substantial part from the complex state of industrial and commercial measurements prior to the 19th century. Early citizens of the United States, harking back to origins throughout Europe and, to some extent, in lands beyond, made use of a staggering variety of measured quantities and their scales. The "inch," the "hand," the "foot," the "yard," the "fathom," the "chain," and the "rod" were just a few of the linear measures in use during that time. Area was measured in terms of the "perch," the "square inch," the "square meter," the "acre," and the "hectare," among others. Volumetric measures included the "fluid ounce," the "gallon," the "peck," the "dry quart," the "bushel," the "cord," and the "firkin." Weight units were as diverse as the "grain," the "pound," the "troy ounce," the "ton," the "short ton," and the "long ton." The relationships among the various industrial and commercial measures were tenuous at best. Even merchants with the most honest intentions could not deliver uniform amounts of their goods to their customers for want of adequate measuring devices. The occasional instance of a vendor's greed, added to the difficulty of accurate measurement, made shopping a punishing exercise indeed for the early consumer!

A Baltimore city inspector tested a grocery store scale for accuracy, about 1920. Photo appears courtesy of the Maryland Department of Agriculture (Weights and Measures Section).

The variety of coins that were intimate parts of the lives of America's citizens at the time it became a nation was not nearly so large as the panoply of weights and measures. Why did the Congress quickly choose to set up a system of coinage and a mint to regularize the monetary system, yet hesitate to select or concoct a standard set of commercial and manufacturing measures? From a distance of nearly two centuries, this inconsistency is puzzling.

As the decades passed, various Congresses, urged on by a citizenry suffering under the chaotic state of U.S. measurement standards, made only halting efforts in the direction of establishing a National Bureau of Standards.[6] The Congresses received periodic requests for action on standards from representatives of U.S. science and industry, reinforced by louder and louder outcries from hard-pressed citizens who clamored for uniformity in commercial weights and measures. Technical workers needed measurement standards in order to produce useful goods; ordinary citizens desperately wanted fair and uniform measurements from vendors of foods and other goods whose scales either were inaccurate as a result of poor construction or had been adjusted so as to maximize profits. Surely, something could be done for these people . . .

[6] John Perry, *The Story of Standards* (New York: Funk & Wagnalls Company, 1955) Chapters 1-6.

In 1816 President James Madison called for the adoption of a decimal system of measurement that had been proposed by Thomas Jefferson when the latter was Secretary of State. Considerable congressional discussion followed this suggestion, including an extensive report by then-Secretary of State John Quincy Adams. Nothing came of these efforts directly; it may be that the dominance of English roots among America's leaders kept them from embracing an idea that arose in France, or a lack of agreement over certain of the metric definitions. Nevertheless, the discussions became part of the legislative dossier that led eventually to the creation of a national standards bureau.

The Office of Weights and Measures

A palpable step towards creation of national weights and measures for America occurred in June of 1836 when a Joint Resolution of Congress (5 Stat. 133) was passed directing the Secretary of the Treasury to "... cause a complete set of all the weights and measures adopted as standards ... to be delivered to the Governor of each State in the Union ...." The astute reader will notice immediately the incongruity of the phrase in the resolution "... weights and measures adopted as standards ... " in comparison with the constitutional authority to "fix the standard of weights and measures." One is impelled to ask, why did not the Congress adopt standards as the Constitution gave them the authority to do? Who *did* adopt measurement standards? What standards were available to be adopted? The answers to these questions will lead us to the creation of the National Bureau of Standards.

The situation behind the curious phrase in the 1836 resolution relates particularly to a man named Ferdinand Hassler. We need to know something about Hassler—and Charles Peirce, another metrologist who carried forward Hassler's principles—if we are to understand the growth of the standards movement in America. The following material is based upon Cochrane's well-written and informative account in "Measures for Progress."[7]

Ferdinand Rudolph Hassler

Ferdinand Hassler was the first Superintendent of the Coast Survey and the first Superintendent of Weights and Measures. He has been described as "the first scientist of rank in the employ of the Federal Government."[8] He certainly provided the U.S. Congress with first-hand knowledge of both the inspirations and the exasperations involved in dealing with a determined scientific mind.

Born to a well-to-do family in northern Switzerland in 1770, Hassler entered the University of Berne at age 16. His inquisitive and agile mind was captured by the subjects of mathematics, astronomy, and geodetics. With a professor from the school, Hassler began a lifelong pursuit of practical geodetics. While mapping the countryside

[7] Rexmond C. Cochrane, *Measures For Progress* Natl. Bur. Std. (U.S.) Miscellaneous Publication 275 (Washington DC: U.S. Department of Commerce, 1966), Ch. I and Appendices A, B, and C. Hereafter, *Measures For Progress* will often be abbreviated as MFP.

[8] MFP, p. 525.

Ferdinand R. Hassler as a young man in the 1790s. Born and educated in Switzerland, he became America's first great metrologist. Photo appears courtesy of the American Philosophical Society.

near the university, the two men found it difficult to use the measuring instruments at hand. The devices were imprecise and there were few measurement standards. Has sler's future life as a metrologist very probably was formed by this experience.

Hassler decided to leave Switzerland because of the widespread turmoil that accompanied the French Revolution. In 1804 he conspired with a chance acquaintance to found a Swiss colony in the United States, entrusting the stranger with most of his fortune to precede him and buy land for this purpose. Meanwhile, Hassler assembled an entourage consisting of his wife, four children, considerable baggage, and some 120 craftsmen and their families; he then chartered a small ship to carry his nascent colony to Philadelphia.

Hassler's colonial venture disintegrated quickly when his erstwhile partner confessed to having gambled away the money that Hassler had entrusted to his care!

Undaunted, Hassler contacted the Secretary of the Treasury, Albert Gallatin, a fellow Swiss by birth; through Gallatin, Hassler met President Thomas Jefferson. Perhaps they shared a common interest in metrology. In any case, when the 9th U.S. Congress appropriated funds in 1807 for a coastal survey of the United States, Hassler's plan for the survey was judged most satisfactory. Hassler advocated the use of astronomy to locate geographic positions at key coastal points, to establish networks of precise triangulation connecting them, and to create topographical surveys of coastal regions including coastal waters.

Delighted with his new position, Hassler soon traveled to London to oversee the production of suitable instruments for the task. He stayed in England and France for four years, consulting with geodesists on the techniques of measurement and designing astronomical instruments for purposes well beyond his statutory requirements.

In 1815 Hassler returned to America. He already had overspent his budget by about 10 percent, and only then was he about to begin working on the survey. The next year, hard at work training a cadre of assistants, Hassler was given the title of Superintendent of the Survey of the Coast, a salary, and permission to start the project.

Hassler's progress was much too slow to satisfy Congress. In 1818 the 15th Congress took the project away from him and gave it to the military in the hope of obtaining quicker results. While it is true that Hassler had made no maps of the coast to show Congress by that time, historian Elliott Roberts noted in 1957 that the survey was then still in progress with no end in sight.[9]

For 10 years after losing his commission, Hassler tried more mundane occupations—farming, teaching, and writing textbooks. His temperament, erratic at best, prevented economic success.

In 1829 Hassler took a position as gager (a measurement specialist) at the New York Custom House. American measurement standards were still in poor condition—in fact, Congress was of the opinion that the backward state of U.S. standards was hampering the Nation's progress in international trade. Fortune smiled upon Hassler then, for Congress authorized a comparison of the standards used in U.S. customhouses and Hassler was selected by President Andrew Jackson to head the project.

Characteristically, Hassler immediately planned a bigger project than had been contemplated by Congress. He not only produced overwhelming evidence of serious deficiencies in American measurement standards—they were faulty in their definition and construction, and inconsistent in their results—but he also undertook to adopt, produce, and distribute better standards.

With the approval of Treasury Secretary Samuel Ingham, Hassler selected units of measure and prepared new devices to realize the units. In 1832 the Treasury Department adopted Hassler's suggestions for length, mass, and capacity; it was these "adopted standards" to which Congress referred in its resolution of 1836.

Historians regard the 1836 Resolution as the instrument of creation of the Office of Weights and Measures within the Coast Survey of the Treasury Department, with Ferdinand Hassler as its first Superintendent. This Office, 65 years later, would be subsumed into the National Bureau of Standards.

Hassler was in certain respects a prototypical metrologist. He had set his own goals for the Coast Survey—to see first to the construction of instruments of the highest quality, never mind the time or cost. He endured the loss of his post that resulted from his choices; when his project was passed to the military because of his apparent lack of progress, he continued doggedly along his chosen path until he exhausted his personal fortune. It is entirely suitable that his abilities should have been recognized in 1922 by Samuel Stratton, first Director of the National Bureau of Standards, in the words "I

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[9] Elliott B. Roberts, "United States Coast and Geodetic Survey, 1807-1957," *Ann. Rep. Smithsonian Institution*, 1957, p. 222.

doubt if there were more than half a dozen people in the world at that time who possessed the scientific knowledge and the deftness of the artisan necessary to undertake his work."

Charles Sanders Peirce

Charles Peirce, born near the end of Hassler's tumultuous life, is remembered as an outstanding scientist and philosopher, with a strong bent for metrology. He spent 20 years with the U.S. Coast and Geodetic Survey, much of it in the study of weights and measures. Long before the advent of laser metrology, Peirce evaluated the meter in terms of a wavelength of light, and he spent considerable effort in the determination of relative values of gravity both in the United States and in Europe. In the process of these and other studies, Peirce advanced noticeably the scientific approach to measurement problems. [10]

During Peirce's brief tenure as head of the Office of Weights and Measures, a subsidiary of the Coast and Geodetic Survey, it happened that a Joint Commission of Congress was appointed under the chairmanship of Senator William B. Allison to "consider the present organization of the Signal Service, Geological Survey, Coast and Geodetic Survey, and the Hydrographic Office of the Navy Department." Asked to testify before the Allison Commission in January 1985, Peirce called attention to the inadequacy of then-current standards of weights and measures. He followed by noting a resolution of the American Metrological Society that called for the strengthening of the Office of Weights and Measures—in fact, the resolution sought the creation of a "national bureau of weights, measures, and physical units."

Like the work of Hassler a half-century earlier, Peirce's efforts became part of the congressional dossier that culminated in the creation of the National Bureau of Standards.

The Metric System

As the United States of America came into being at the end of the 18th century, the so-called "metric system" was initiated in France.[11] In this system, all quantitative measures are based upon the "metre" (herein we use the American spelling, "meter") and the "gramme" (herein spelled "gram").[12] The meter was to be the standard of length, defined by a committee of the French Academy of Sciences as one ten-millionth part of the distance from the equator to the North Pole.[13] The gram was to be

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[10] Victor F. Lenzen, "The contributions of Charles S. Peirce to metrology," *Proc. Amer. Philosophical Soc.* **109**, pp 29-46 (1965).

[11] Chester H. Page and Paul Vigoureux, editors, *The International Bureau of Weights and Measures 1875-1975,* Natl. Bur. Stand. (U.S.) Special Publication 420, May 1975.

[12] Barry N. Taylor, The International System of Units (SI), NIST (U.S.) Special Publication 330, August 1991, Foreword.

[13] It is recorded (see MFP, Appendix B) that members of the French Academy actually participated in measurements evaluating the meter along the meridian that passes through Barcelona, Paris, and Dunkirk (approximately 2.4 degrees east of the Greenwich meridian), traveling through hilly terrain to do so.

the standard of mass,[14] defined as the mass of one cubic centimeter of pure water at its maximum density (the maximum occurs near 4 °C).

The metric system had two very attractive features. First, it was defined in terms of natural units—in principle, any competent technician could duplicate the meter and the gram without recourse to artifacts. Second, the system was defined in a decimal fashion—multiples and sub-multiples of the units were derived by use of the factor 10. A simple system, indeed, compared to the complicated alternatives!

The principle of a decimal system of weights and measures embodied in the French metric system was put in place in Switzerland during the first half of the 19th century. Twelve Swiss cantons entered an agreement to employ a set of decimal units for certain of their measurements.[15] It was only a small step, but one that accurately forecast the direction for future international standards.

Although adoption of the metric system for measurement standards in the U.S. was recommended by—among others—President Jefferson, only in 1866 did the Congress authorize the use of metric standards. Even then, the system was not made compulsory—merely lawful.

By 1869 the metric system was considered ready for use in international technology and trade. The system already was specified by law in France, Holland, Belgium, Luxembourg, Spain, Colombia, and Mexico, and was recognized in England, Germany, and the United States. In 1869 the government of France invited many countries to send delegates to Paris to attend an "International Commission for the Meter." A highlight of the meeting would be discussion of the designation of the French meter and kilogram, preserved in the Archives of Paris, as references for international measurement standards. As matters proceeded, meetings of the Commission were delayed until 1872 because of political unrest in France.[16]

On March 1, 1875, the French government convoked the Diplomatic Conference on the Meter. Its aims were substantially those of the earlier Commission. The conference was attended by representatives of 20 nations, including Elihu Benjamin Washburne—"Envoy Extraordinary and Minister Plenipotentiary"—and Joseph Henry—first Secretary of the Smithsonian Institution—representing U.S. President Ulysses S. Grant. By May 20, the conferees had created an impressive organization for international standards of measurement. The organization included the following entities:

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[14] The careful reader will note that the words "mass" and "weight" have been and often still are used interchangeably, as if they represent identical quantities. Strictly speaking, they do not; weight is actually a force, equal to mass times the acceleration due to gravity. The distinction is often overlooked because most masses are evaluated by weighing and because geographical variations in gravitational acceleration are small. Later in this book (Sec. 2.8.5, Force Testing on a Large Scale) we provide more details on the difference between mass and weight.

[15] W. Schwitz, *Formation and Development of the Swiss Federal Measurement System,* translation by H. Steffen Peiser.

[16] Actually, the word "unrest" hardly does justice to that period of time in France. The Franco-Prussian War took place in 1870. The same year saw the end of the reign of Louis Napoleon and the formation of the Third Republic of France. Unrest, indeed!

- An International Committee for Weights and Measures (known today by the acronym CIPM, corresponding to its title in French), intended to oversee the production of prototype standards.
- An International Bureau of Weights and Measures (BIPM), an administrative organization and a building where the standards would be prepared and where the administrative offices would be housed.
- Periodic General Conferences on Weights and Measures (CGPM), during which the signatory nations could adopt suitable standards for international reference.[17]

The United States was one of 17 countries that signed the "Convention du Mètre" (*Convention of the Meter,* the oldest treaty of which the United States is still a signatory). Despite its agreement to recognize the 1875 Convention, and despite the growing use of metric measurements throughout the world, the U.S. Congress never enacted legislation to adopt the metric system as the compulsory national standard for weights and measures in America.[18]

We shall return again and again to discussions of the International Bureau of Weights and Measures, because its history and that of NBS were tightly intertwined.

In later sections we shall also note a rebirth of congressional interest in mandating the metric system of measurement for everyday use in the United States. However, this issue has lost much of its urgency with the passage of time, inasmuch as all the units of the so-called "customary U.S." or "English" measures have long since been evaluated in terms of metric equivalents. Individuals or companies that need to use the metric system in manufacturing or in sales literature can readily make the transition—though often at the cost of duplication of equipment and inventories.

At Last, a National Bureau of Standards

As the 20th century opened, the House Committee on Coinage, Weights, and Measures received a letter from Lyman Gage, Secretary of the Treasury, who suggested the creation of a national standardizing bureau. This letter was the product of a meeting of the minds of Secretary Gage and one Samuel W. Stratton, a professor at the

[17] In 1927, the CIPM began to establish Consultative Committees to assist it in preparing new statements on standards. These committees were composed of scientists expert in one of the metrological areas. Eventually, most measurement units (for time, mass, length, temperature, electrical quantities, etc.) came under the care of a consultative committee.

[18] It is perhaps worth noting that the metric system of measurements *was* prescribed for use by the American Expeditionary Forces during World War I. A U.S. Army General Order dated January 2, 1918 specified that the metric system was to be used ". . . for all firing data for artillery and machine guns, in the preparation of operation orders, and in map construction." Metric literature that was distributed to both Army and Navy technical personnel included wall charts, sets of equivalents between metric and customary units, and National Bureau of Standards Miscellaneous Publication No. 21 "Metric Manual for Soldiers—The Soldier's Manual of the System—An International Decimal System of Weights and Measures, adopted as the legal standard by France and 33 other nations and in world-wide use." Reference to NBS MP No. 21 can be found in *War Work of the Bureau of Standards,* Natl. Bur. Stand. Miscellaneous Publication 46, 1921, pp. 220-221.

University of Chicago. Stratton was convinced that the time for creation of a national bureau of standards had arrived. He had responded to a lesser offer from Gage—to appoint him chief of the Office of Weights and Measures—with a suggestion for a grander goal.

Gage's letter to the House committee, written with the direct assistance of Prof. Stratton, was only the latest in a long series of requests for congressional action on national standards. But this time, the spark ignited a flame. Testimony from U.S. technical leaders, encouraged to speak before the Committee, offered enthusiastic support for the idea. Members of the Committee were disposed to offer HR 1452, "National Standardizing Bureau," to the House on May 14, 1900. The Act worked its way through the 56th Congress in accordance with the usual Congressional practice.

On March 3, 1901, the legislation now known as Public Law 56-177, written by the Senate and the House of Representatives of the United States of America in Congress assembled, was approved. It established the National Bureau of Standards. The act decreed that the Office of Standard Weights and Measures should thereafter be known as the National Bureau of Standards. However, the provisions of the act made it clear that "National Bureau of Standards" was not simply a new name for an old office. A wholly new agency was being created—one with considerably more responsibilities than its forerunner. In Appendix A we provide excerpts from all of the legislation affecting NBS, beginning with the U.S. Constitution.

A Word About Standards

It might be helpful at this point to consider for a moment the question "What are standards?" The question is not an idle one. Over the years, millions of dollars have been appropriated by one Congress or another for work at NBS that various members of Congress have criticized as lying beyond the scope of Public Law 56-177.

Webster's New International Dictionary, 2nd Edition, defines "standard" as "That which is set up and established by authority as a rule for the measure of quantity, weight, extent, value, or quality, esp., the original specimen weight or measure sanctioned by government, as the standard pound, gallon, yard, meter, or the like."[19] From that definition, one can readily construct a menu of standards that includes all the physical metrics—units such as those of length, mass, time, frequency, temperature, pressure, electrical resistance, electrical current, voltage, electrical capacitance, electrical impedance, radiant flux, hardness, and a raft of derivative measures; and metrics for chemistry, biology, radioactivity, sound, color, and other measurement-intensive fields. But what about standards for concrete fabrication? For computer security? For flammability of fabrics? For the safety of toys or tools? For the audibility of voice transmission? For tire wear? For police equipment? For home insulation? For earthquake-resistant buildings and bridges? Are these activities consistent with the instructions of Public Law 56-177?

[19] Walter G. Leight kindly points out that use of a single word—"standard," in the United States—both for scientific measurement methods and for guides to effective technical practices is not the case everywhere. In many countries, different words are used to refer to physical standards and to documentary guidelines.

Questions regarding the reasonable extension of the mandate contained in its Organic Act to new fields of derivative and applied standards of measurement surfaced on a regular basis after the Bureau was established in 1901. Sometimes a particular question has been avoided—by the Congress or by NBS management—and sometimes faced squarely (usually by modification of the Organic Act to include the contemplated project).

We shall have more to say later about arguments on the suitability of particular projects for the NBS mission, because such debates often help define the nature of the agency.[20] In proposing these projects, however, refining the mission of the Bureau was not ordinarily the intent of the petitioners for unusual work by the NBS staff. Instead, these people simply had problems to solve—and people with problems to solve tend to seek advice from other people whom they regard as experts.

It is to the credit of its leadership that, whatever its mandate, the Bureau has consistently been fortunate enough to house world experts on an amazing variety of technical subjects. The ability of a relatively anonymous government agency to attract and hold a distinguished staff in the face of continuing restrictions on hiring, salaries, and operating funds is itself remarkable. By creating a strong sense of shared mission to function as the Nation's measurement and data experts, the Bureau management has made it routine.

Responsibilities of the Newborn NBS

At its beginning, the National Bureau of Standards—"NBS" as it quickly became known throughout the metrological world—was only a tiny entity, hardly a match to its grand charter.

Public Law 56-177 decreed that the Office of Standard Weights and Measures should thenceforth be known as the National Bureau of Standards. The law designated a substantial list of functions for the new agency. They included the following:

- Custody of the standards.
- Comparison of standards used in science, engineering, manufacturing, commerce, and educational institutions.
- Construction of needed standards.
- Testing and calibration of measurement apparatus.
- Solution of standards-related problems.
- Determination of physical constants.
- Determination of properties of materials needed for science or industry, whenever such information might not be readily available from other sources.

The agency was directed to serve the standards needs of a great many communities: government at the national, state, and municipal levels; scientific societies; educational

[20] See Appendix A.

institutions; and corporations or individuals in the United States who were engaged in pursuits requiring the use of standards or standard measuring instruments. Its mandate was sufficiently broad as to permit nearly any activity in science or technology.

To accomplish so many tasks the act provided only a minimal work force—a director, a physicist, a chemist, an engineer, five technical assistants, and four nontechnical staff. The total salary cost was not to exceed $27,140 per year. Approximately $135,000 was appropriated toward the siting, construction, and equipping of a new laboratory building.

This was indeed a modest investment by a frugal Congress—but who could have foreseen the demands that would so soon be placed on the new Bureau by a nation that was rapidly becoming an industrial giant? It was a modest beginning, but it was a beginning nonetheless.

As we examine the work done within the National Bureau of Standards we shall see how the new agency not only fulfilled the responsibilities of the Office of Weights and Measures but also performed many vital tasks that provided the scientific basis for measurements and standards in industry and commerce. In addition to maintaining custody[21] of the standards, it was to offer a calibration service—free to governmental customers, at cost for others—and to harmonize the standards as used in the many technical aspects of U.S. life—for science, engineering, manufacturing, commerce, and education. Furthermore, the Bureau was required to "construct needed standards," a statement that is subject to differing interpretations but which literally directs the agency to respond to needs for measurement tools as expressed by its multi-faceted constituency. In time, these needs would include items as varied as radioactive standards, standard paint samples, a standard for iron in spinach, and standards for computer security.

Two entirely new directions, not formerly given to any agency, were the authority for "solution of standards-related problems" and "determination of physical constants and properties of materials such as might be needed by science or industry." Some members of Congress must have seen that they were thus mandating a vigorous laboratory enterprise, one that perforce must be staffed by first-rate scientists and engineers.

Similarly, the constituency of the new bureau was specified in the broadest of terms, as we have noted.

After failing to act on its constitutional prerogative for a hundred years, the Congress compensated for its procrastination by endowing the new National Bureau of Standards with all the authority it might ever need to serve the standards requirements of the United States. To help it maintain a suitable level of fiscal support for its new

[21] The word "custody," suggesting as it does the physical possession of an object, applied very well to the first standards maintained by the Bureau—standards such as a platinum-iridium-alloy meter bar and a platinum-iridium-alloy kilogram mass. In fact, these standards *did* reside in safekeeping at NBS. However, the word seems inappropriate when applied to the many modern standards that do not exist as artifacts at all. The position of the Bureau with respect to more recent standards such as length, defined in terms of a wavelength of light, or temperature, defined in terms of phase transitions in pure substances, seems better described by a word such as "responsibility." In this volume, we generally use the term "custody" only where an artifact standard is under discussion.

creation, Congress provided for oversight of the new bureau. This oversight was embodied in a "visiting committee," composed of five nongovernmental standards leaders appointed by the Secretary of the Treasury; the committee would visit the NBS annually and report to the Secretary on the efficacy of its work and the condition of its equipment.

Public Law 56-177, usually known as the "enabling legislation" of NBS but occasionally described in congressional jargon as its "Organic Act," was modified substantially in 1950, in 1968, and again in 1988,[22] but its foundation—the dual responsibilities for the Nation's standards and for resolving standards-related national problems—has remained in force throughout the agency's existence.

One feature *not* placed in the Organic Act of the NBS by the 56th Congress is any explicit reference to international standards of measurement. The absence of any such reference seems surprising from a modern perspective, particularly in view of the great importance to present-day science and industry of international standardization. When this history was written, all scientific and industrial measurements were validated in terms of international scales that were promulgated by the International Committee of Weights and Measures.

Why did the legislation establishing NBS not include a statement directing its staff to correspond with the BIPM, as the International Bureau of Weights and Measures is commonly known, the better to facilitate U.S. participation in world trade? Perhaps because the BIPM and its sister organizations were unknown to most members of Congress! Congress could not anticipate that the entities created by the Metric convention in 1875 would flourish with the years even as the National Bureau of Standards has done. In any case, this oversight has long since been rectified in practice; the newborn NBS soon found it necessary to participate in all areas of international standards work. Indeed, NBS has become a world leader in the development of international measurement standards.

HISTORIES OF NBS

The story of the growth of NBS, during its first 60-odd years, into a world-respected standards authority and a formidable scientific and engineering laboratory—literally a unique institution—is an important and fascinating one. However, it is not a story that we shall recount in detail here, because the interested reader can readily learn it from existing books.

In several histories, the reader can trace the transition in American commercial life that has resulted from the efforts of the Bureau. From the missing, inadequate, or dishonest weights that characterized the U.S. marketplace before the founding of the Bureau, to the economic ruin that occasionally accompanied a lack of standards in fire safety, transportation, and manufacturing, to the flowering of engineering standards during and after two world wars, the role that NBS played at the forefront of progress in measurement and standards for nearly seven decades has been documented by several authors.

[22] See Appendix A.

We mention here seven histories. To facilitate review by the interested reader, we list chapter titles and appendices for each book in Appendix B.

The careful reader will note that the titles of the first two histories refer to NBS not as "the National Bureau of Standards," but simply as "the Bureau of Standards"; these references do not indicate carelessness on the part of the authors, but rather a curious historical fact: in 1903, when the agency was transferred from the Treasury Department to the new Department of Commerce and Labor, the word "National" was eliminated from its title by George B. Cortelyou, the new secretary of Commerce and Labor. For about 30 years, the agency was known officially as the "Bureau of Standards." Through the efforts of Lyman J. Briggs, the agency's third director, the change was reversed.[23]

1. ***War Work of the Bureau of Standards,*** by an anonymous author, *Bureau of Standards Miscellaneous Publication 46,* U.S. Government Printing Office, 1921, 299 pp. This book contains fairly detailed discussions of some fifty groups of projects undertaken by Bureau staff members during WW I.

"Miscellaneous Publication 46" is particularly interesting because of its absolute anonymity. It contains virtually no names of persons. Not only are the descriptions of individual projects bereft of any reference to the staff members who accomplished them, but the monograph itself has no author—not even a reference that would identify where in the Bureau it was written. The apparent intention of this anonymity—not an uncommon trait during this time in the history of American government—was to avoid any appearance of immodesty on the part of the agency staff. Instead, each staff member was expected to take pride in all the work of the agency. Certainly, the attitude of belonging to a highly effective team has permeated NBS during most of its existence.

A glance at the NBS technical literature indicates that the names of scientific authors were listed under the titles of their scientific papers from the earliest days of the Bureau, but that summary accounts written by or for administrators generally were anonymous at least until the end of World War II.[24,25]

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[23] Cochrane, *Measures for Progress* p. 47.

[24] Churchill Eisenhart once mentioned an incident that occurred during the time when he was chief of the Statistical Engineering Section. Another Section staff member, Mary Natrella, prepared an extensive discussion of experimental statistics for the Office of Ordnance Research which was promulgated as U.S. Army Ordnance Pamphlets ORDP 20-110, ORDP 20-111, ORDP 20-112, ORDP 20-113, and ORDP 20-114. It was necessary for Eisenhart to negotiate with the sponsor the right to identify Ms. Natrella as the author, inasmuch as it was not the Army's policy to identify authorship of such documents. Later, the series was reprinted in book form under the title *Experimental Statistics* (NBS Handbook 91, 1963). Recollection of W. Reeves Tilley, former chief of the Technical Reports Section.

[25] The tendency to modesty among the staff of the NBS reminds this writer of a statement he once heard in the NBS Heat Division from William R. Bigge, a physicist who operated a six-dial potentiometer at—and occasionally beyond—its uncertainty limit. Asked how he had mastered the arcane use of the device, Bigge shrugged, "Any high-school graduate could run this thing as well as I do—after, maybe, twenty years of practice."

Another interesting feature of this history is a statement in the Introduction revealing that " . . . practically all the time and energy of the Bureau's personnel were devoted to military problems during the period of hostilities . . . "

2. ***The Bureau of Standards: Its History, Activities, and Organization,*** by Gustavus A. Weber, Johns Hopkins Press, 1925, 299 pp., is a concise, matter-of-fact summary of the NBS as it appeared in the period following the First World War. It was written under the auspices of the Institute for Government Research, Washington DC, as one of a series of "Service Monographs." As of 1925, there were 36 titles in this series. In the course of describing the work of the Bureau, Weber provides details of various acts of Congress in which the Bureau was given new projects to supplement—either temporarily or permanently—its original mandate. These include such topics as flame standards (35 Stat. 904, March 4, 1909), accuracy in coin weights (36 Stat. 1354, March 4, 1911), and accuracy of scales used in coal mines (43 Stat. 205, May 28, 1924; 43 Stat. 364, June 30, 1926).

As was the case in Miscellaneous Publication 46, Weber allows the NBS staff to toil in virtually complete anonymity.

3. ***NBS War Research—The National Bureau of Standards in World War II,*** by Lyman J. Briggs (Director Emeritus), U.S. Government Printing Office, September 1949, 188 pp. In the Foreword, Director Emeritus Briggs states that this book was written at the behest of Secretary of Commerce Henry A. Wallace, who wrote, " . . . You owe it to yourself, to the Bureau, to the Department, and to the country to shake off some of your customary modesty and let the world know something of what was done." Briggs acknowledges in his Foreword that much of the writing was done by staff members who had participated in the actual work, but these authors are not identified. And sufficient modesty remained in the authors that—from the atomic bomb to concrete ships—only a few names of staff members are given. Nearly no actions or ideas are ascribed to people.

4. ***The Story of Standards,*** by John Perry, Funk & Wagnalls, 1955, 271 pp, is a sprightly collection of stories about the need for standards in many phases of American life before the advent of NBS. In addition, Perry highlights some of the important technical work done at the Bureau during its first 50 years.

Individual Bureau staff members occasionally receive personal mention by Perry, but once again the emphasis is on NBS as an anonymous—though highly effective—force for improved standards.

5. ***Measures For Progress: A History of the National Bureau of Standards,*** by Rexmond C. Cochrane, Natl. Bur. Std. Miscellaneous Publication 275, 1966, 703 pp. This book is a well-written, complete history of the Bureau during its first 50 years of existence. Prepared under the supervision of James R. Newman, a professional historian and well-known scientific editor, it presents comprehensive views of the origin and growth of NBS, its participation in research and development during two world wars, its continually growing standards work, and its intimate involvement with the U.S. standards movement.

In contrast with the writing of his predecessors, Cochrane's book fairly sings about the who and the why of Bureau work. The high level of his scholarship is obvious throughout the text, and the people of NBS, Congress, and the public at large come to life in vivid anecdotal descriptions.

In addition to eight chapters of interesting and informative discussion of the Bureau, set within the framework of the national and international technical scene, Cochrane provides 15 appendices containing many details relative to NBS activities during its first half-century.

6. ***Achievement in Radio: Seventy Years of Radio Science, Technology, Standards, and Measurement at the National Bureau of Standards,*** by Wilbert F. Snyder and Charles L. Bragaw (Boulder, CO staff members), Natl. Bur. Std. Special Publication 555, 1986, 842 pp. including 30 chapters, 7 appendices, and an excellent index. Although it is one of several existing histories of particular technical fields at NBS rather than a general history, this book is well worth the time of the interested reader. The authors set out to prepare an account of the work of NBS in the vital and pervasive field of radio. Beginning before the time of the Bureau itself, their text documents the origins of radio as well as the growing body of radio research and service within NBS. Also included is a detailed account of the creation of the radio laboratories at the Boulder, Colorado, site from 1950-54.

7. ***A Unique Institution: The National Bureau of Standards, 1950-1969,*** by Elio Passaglia with Karma A. Beal, *National Institute of Standards and Technology Special Publication 925,* 1999. Elio Passaglia, a long-time Bureau staff scientist, describes the history of NBS during the period 1950-1969. Passaglia's approach and writing skills provide an excellent successor volume to Cochrane's history. The many descriptions of administrative and scientific projects that are presented in Passaglia's book benefit substantially from his background: scientific excellence, particularly in the areas of metallurgy, polymers, and crystallization, as well as experience in a variety of leadership positions at the Bureau, including nine years as chief of the NBS Metallurgy Division. But for his untimely death in 1994, Passaglia no doubt would have been the author of the present volume.

The AD-X2 battery-additive incident, so traumatic for former Director Allen Astin, and the communist-hunting hysteria precipitated by the House Committee on Un-American Activities, which directly affected former Director Edward U. Condon and indirectly affected many others at the Bureau, are recalled in vivid detail in this history. Also recorded are the rise and divestiture of NBS efforts in military research and development during and after World War II. Passaglia's account provides a comprehensive record of the many-faceted activities that characterized NBS during some of its most productive years.

Former Directors of NBS

The Bureau had only five directors during its first 68 years of existence. Significantly, each was a dedicated professional scientist. One could surmise that all issues regarding the agency might first have been approached by these men from the viewpoint of science, rather than that of politics—though none of the five could have been successful without some facility in politics. It is worthwhile to mention these leaders here, because their influence on the young and growing organization was profound.

Similarly potent in determining the orientation—and in many cases, specific activities—of NBS have been the government officials who supervised the NBS Director. These officials included the U.S. Presidents at whose pleasure the NBS Directors served, the Secretaries of Commerce and—when their offices existed—subsidiary officials of the Department of Commerce such as Assistant Secretaries of Commerce for Science and Technology. A chronological listing of these officials is presented in Appendix C.

Cochrane's *Measures for Progress* is an excellent source of biographical information on the first four directors of the NBS. Most of the information for the following sketches have been abstracted from that book.

Samuel Wesley Stratton

The founder and first director of the Bureau was Samuel W. Stratton. Trained in mechanical engineering, physics, and mathematics, Stratton served on the physics faculty of the University of Chicago from 1892 until he was appointed director of NBS in March 1901 by President William McKinley.

First NBS Director Samuel W. Stratton at his desk in the South Building, 1905.

As we noted earlier in this chapter, Stratton was instrumental in the establishment of the Bureau, collaborating with Treasury Secretary Lyman Gage in drawing up a plan for a national standards agency. It was this plan that the Congress accepted in 1901. When the enabling act was passed, Stratton became a logical choice for its first director. Stratton's enthusiasm for the concept led him to accept the post forthwith.

A bachelor whose consuming passion was the practice of science, Stratton devoted himself wholly to making the Bureau strong in its science and in its integrity as an arbiter of standards. He succeeded brilliantly.

Stratton served as director from 1901 until 1922. He saw the NBS staff grow from 12 to more than 850. And as the reader might imagine, he continually testified before Congress, requesting more staff and more funds to accomplish an ever-expanding menu of services. Stratton was successful in making the Bureau grow because he could always demonstrate to Congress' satisfaction that the increased funding led directly to enormous advances in the technical capabilities of the Nation. A graphic example of those advances can be seen in "Miscellaneous Publication 46," mentioned previously, in which more than 50 groups of World War I projects appear; prodigious production for a teen-aged agency!

After leaving the post of NBS Director in 1922, Stratton became the President of the Massachusetts Institute of Technology—indeed, it was the offer of the MIT presidency, coupled with the deaths of three of his long-time Bureau colleagues, that precipitated his departure. His annual salary increased by a factor of approximately three with his new position.

Following his departure from the Bureau, Stratton agreed to become Chairman of the NBS Visiting Committee. His advice to the Bureau thus continued unabated for another eight years.

George Kimball Burgess

The second director of the Bureau, confirmed on April 21, 1923, was George K. Burgess. At the time of his appointment to serve under Herbert Hoover, then Secretary of Commerce, Burgess was Chief of the NBS Metallurgy Division and the senior Bureau physicist.

UNITED STATES
DEPARTMENT OF COMMERCE
WASHINGTON

Number 306 August 28 1918

This is to certify that George K. Burgess having been appointed Physicist, qualified in Optics in the Bureau of Standards Department of Commerce, is authorized to exercise and perform the duties of said office in accordance with the laws of the United States and the regulations of the Department of Commerce, and his authority will be respected accordingly.

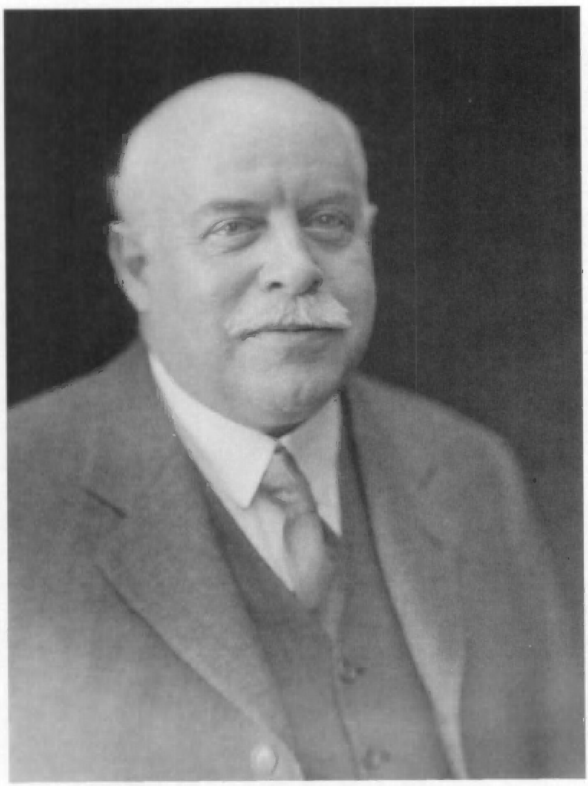
Secretary of Commerce.

(Signature of Employee.)

Department of Commerce identification badge used by George K. Burgess in 1918. At that time he was Chief of the Bureau's Metallurgy Division.

Trained at MIT and the Sorbonne, Burgess worked at NBS in high-temperature research and organized the Metallurgy Division from scratch, turning it within a decade into a 50-man group with international renown.

Burgess proved to have been a felicitous choice as successor to Stratton, being not only a scientist of great competence but also an extremely able administrator. He did not attempt to know all the Bureau projects first-hand, as had Stratton; instead, he concentrated his efforts on careful leadership of his division chiefs. This technique enabled the Bureau to function smoothly even though its staff grew in number to more than 1000 employees. NBS became the largest scientific laboratory in the world and one viewed with great respect for its technical competence.



George K. Burgess, second Director of the Bureau of Standards.

In 1927 Burgess initiated a "Standards Yearbook" "as a companion volume to the Commerce Yearbook."[26] In his "Letter of Submittal," written to Hon. Herbert Hoover, Secretary of Commerce, Burgess succinctly explained his intention:

> I have the honor to submit herewith for publication the first issue of the Standards Yearbook, which will be brought out annually hereafter.

[26] *Standards Yearbook, 1927*, compiled by the National Bureau of Standards, George K. Burgess, Director, BS Miscellaneous Publication 77, 1927. "Price $1.00, clothbound."

Burgess had a grand goal for the book:

> (To) present an adequate picture of the diversification and ramification of the standardization movement which has spread throughout the world with astonishing vitality during the 25 years that have elapsed since the establishment of the National Bureau of Standards.

Within the 250-odd pages of the book, Burgess and his colleagues presented synopses of work done not only at NBS, but throughout both the United States and the rest of the standardizing world; included were summaries of many individual projects in all of these institutions. As might be expected, a comprehensive treatment of this large and growing topic could not long be sustained. The last of the Standards Yearbook series, the 7th, was prepared during the directorship of Lyman Briggs.[27]

Burgess died of a stroke while at his Bureau desk on July 2, 1932. He was not yet 60 years of age.

Lyman James Briggs

The third director of the Bureau was Lyman J. Briggs. As assistant director of NBS for research and testing, he became Acting Director upon the death of Burgess. He was confirmed as Director on June 13, 1933, following the election of Franklin D. Roosevelt to his first term as President.

Trained at Michigan State University, the University of Michigan, and the Johns Hopkins University, Briggs had been personally interested in soil science. He had come to NBS during World War I on an assignment from the Bureau of Plant Industry. Briggs became involved in aviation research at NBS and soon came to enjoy the work immensely. He later became Chief of the Mechanics and Sound Division of the Bureau, a post he held at the time Stratton left NBS.

Burgess appointed Briggs to be Assistant Director for Research and Testing in 1927. Briggs, a modest man, had not particularly wanted the job, but he was well-qualified for it and accepted it the second time it was offered.

Burgess died just as a severe retrenchment in funding and manpower hit NBS as a result of the Great Depression. It fell to Briggs to strive mightily to preserve the Bureau's competence in the face of nationwide unemployment.

An amiable man and a capable scientist, Briggs succeeded in saving the Bureau from destruction during the depression era. Ironically, he subsequently supervised the rapid re-growth in Bureau responsibilities, staffing, and funding that accompanied its heavy participation in military research and development during World War II.

During the directorship of Lyman Briggs, the value of NBS as a national scientific resource was underscored by the events surrounding the initiation of work on the

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[27] Briggs nevertheless testified in *his* Letter of Submittal to the Hon. Roy D. Chapin, Secretary of Commerce, that the yearbook was "proving of much value to manufacturers, industrial experts, and engineers, as well as to purchasing agents, both governmental and general" (see BS Misc. Pub. 139, "Price $1.00, clothbound.")

Lyman J. Briggs, third Director of NBS, guided the Bureau through the hard times caused by the Depression and the expansion caused by World War II.

atomic bomb. As detailed by Richard Rhodes,[28] when President Franklin Roosevelt was first approached on October 11, 1939 by Alexander Sachs—acting on behalf of Leo Szilard, Edward Teller, and Eugene Wigner—Roosevelt quickly realized the significance of German work on an atomic bomb and the importance of initiating an American program to counter it.

Roosevelt ordered his assistant, General Edwin M. Watson, to form a small group to investigate the possibilities. Rhodes wrote:

> Watson went by the book. He proposed a committee consisting initially of the director of the Bureau of Standards, an Army representative, and a Navy representative. The Bureau of Standards, established by Act of Congress in 1901, is the nation's physics laboratory, charged with applying science and technology in the national interest and for public benefit. Its director in 1939 was Dr. Lyman J. Briggs, a Johns Hopkins Ph.D. and a government scientist for forty-three years who had been nominated by Herbert Hoover and appointed by FDR. Briggs set a first meeting of the Advisory Committee on Uranium for October 21 in Washington.

[28] Richard Rhodes, *The Making of the Atomic Bomb* (New York: A Touchstone Book published by Simon and Schuster, Inc., 1988) pp 313-315. The author is grateful to Donald H. Tsai for furnishing this reference.

Thus began America's entry into the atomic age.

Briggs celebrated his 71st birthday in May 1945, only a month after the sudden death of Franklin Roosevelt. Within another month, he had submitted his resignation as Director. However, he had no intention to retire to a vine-covered cottage in the country; rather, he desired to return full-time to the laboratory that he had tried not to desert entirely during his tenure as Director.

As we noted in the section on NBS histories, one of Briggs' first post-retirement projects was to write, at the request of Commerce Secretary Henry Wallace, a history of NBS activities during the Second World War.

Briggs may be best known to the general public for his demonstration, more than 10 years after his retirement, that a pitched baseball can be made to curve as much as one-third of a meter as it approaches home plate.[29] Batters and catchers had long known for a fact that good pitchers could throw a curve with "at least a foot of break" to it, but Briggs proved it with scientific instruments, to the delight of baseball fans throughout the Nation. He also wrote two popular articles about the Bureau for the National Geographic Magazine; "Uncle Sam's House of 1,000 Wonders"[30] and "How Old Is it?: Telltale Radioactivity in Every Living Thing Is Cracking the Riddle of Age."[31]

Edward Uhler Condon

The fourth director of NBS (formally appointed on November 7, 1945) was Edward U. Condon, a brilliant physicist who had been in the thick of research on atomic physics and, subsequently, on various World War II projects.

Condon was born, coincidentally, in Alamagordo, NM, site of the first atomic bomb test. He was educated at the University of California at Berkeley and in Germany, where he immersed himself in the new quantum physics. He later served on the physics faculty of Princeton University, collaborating with colleagues on several fundamental advances in the theory of atomic physics and, with George Shortley, writing a treatise on atomic spectra that quickly became a standard text on the subject.

In 1937 Condon was hired as an associate director of research by Westinghouse Electric Corporation: while there, he organized a program of nuclear studies. Later, he helped create a Radiation Laboratory at MIT. In 1943, he became second-in-command to J. Robert Oppenheimer on the Manhattan Project at Los Alamos; his first-hand knowledge of the terrible power of the nuclear-fission atomic bomb led him thereafter to continually seek ways to prevent the use of nuclear energy for weapons of war.

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[29] The scientific reference for this work is Lyman J. Briggs, "Effect of spin and speed on the lateral deflection (curve) of a baseball; and the Magnus effect for smooth spheres," *Am. J. Phys. 27,* 589 (1959). Briggs' demonstration was also reported in many U.S. newspapers, including the *New York Times* on March 29, 1959, and in the magazine *Newsweek* (April 6, 1959).

[30] Lyman J. Briggs and F. Barrows Coulton, "Uncle Sam's House of 1,000 Wonders," *National Geographic 100,* No. 6, December 1951, pp. 755-784.

[31] Lyman J. Briggs and Kenneth F. Weaver, "How Old Is it?: Telltale Radioactivity in Every Living Thing Is Cracking the Riddle of Age," *National Geographic* August 1958, pp. 234-255.

Edward U. Condon, fourth Director of NBS. An accomplished theorist in physics, Condon was blunt, impatient, and inspiring.

Energetic, a clear thinker and a prolific writer, Condon was thoroughly involved in the technical activities of the United States at the highest level.

Condon was not the first choice of Lyman Briggs as his successor. That honor went to Hugh Dryden, a long-time Bureau colleague of Briggs and a distinguished scientist in his own right; Briggs sent Dryden's name to the NBS Visiting Committee for the consideration of Secretary of Commerce Henry Wallace. The committee was slow in transmitting Briggs' suggestion, however, and Wallace, interested in bringing new blood from outside the Bureau to the directorship, was captivated by Condon's obvious qualifications. President Harry Truman agreed with Wallace's choice, and so did the U.S. Senate.

It surprised no one that Condon, once appointed to head NBS, decided that substantial changes in the organization of the Bureau were long overdue. Both the Congressional oversight committees and the senior staff of NBS, used to the gentle demeanor of Lyman Briggs, saw Condon as the proverbial "bull in the china shop."

Under Condon's leadership the NBS administration—indeed much of the staffing—changed markedly. Many of its most senior leaders were of retirement age; many of its most capable technical members had been diverted to war projects, leaving the standards projects understaffed. Perhaps most noticeable of all to Condon, the Bureau organizational structure did not fully reflect the impact of the new science that had developed during the war years. These problems were seen simply as challenges by Condon; with energy and enthusiasm, and not always gently, he attacked them all.

Condon's intellect, his vigor, and his loyalty to America were highly respected by President Truman and by those members of Congress who knew him personally. However, his sometimes caustic *repartee*—particularly noticeable in the presence of slow or mediocre minds—almost certainly annoyed other members. In any case, Condon rather quickly ran afoul of a new phenomenon—the congressional witch-hunt for communists in the Government. Although the Soviets had been U.S. allies throughout World War II, their belligerence after the onset of the Cold War and the fear that they might wrest nuclear leadership from America through the efforts of spies and sympathizers terrified many leaders in and out of Congress.

Condon, like many scientists who were personally able to understand the magnitude of the catastrophe that would accompany nuclear war, advocated disarmament and collaboration with the Soviets to minimize the likelihood of such a war. Because of this attitude, his loyalty to America became a subject of discussion on the floor of the U.S. House of Representatives. He became a prime target for the House Committee on Un-American Activities. Condon's travails during this period were portrayed in detail in Passaglia's history. Here we only note in passing that Condon found them distracting in the extreme as he managed the Bureau and attempted to represent its interests effectively before Congress.

On August 10, 1951, as NBS marked its semicentennial with festivities and technical conferences, Condon announced his intention to resign his directorship. His active public and scientific lives were far from over, but he felt that he had become as much a liability to NBS as he was an asset. President Harry Truman had no reservations about the value of Condon's service; in a letter reluctantly accepting his resignation, Truman praised Condon's scientific standing, his loyalty, and his many accomplishments.

Allen Varley Astin

After Edward Condon resigned, effective September 30, 1951, Secretary of Commerce Charles Sawyer asked the National Academy of Sciences to provide the names of several possible successors to the NBS directorship. One of the people so identified was Allen V. Astin, an Associate Director of NBS who had been designated Acting Director after Condon's resignation. Sawyer submitted Astin's name to President Truman, who appointed Astin in May 1952; the Senate confirmed the appointment on June 12, 1952.

Astin was then but 48 years old, although he had more than 20 years' service at the Bureau. His childhood in Utah had been marked by meager family circumstances that may have been responsible for his strong streak of self-discipline. He worked his way through the undergraduate physics curriculum at the University of Utah, won a scholarship to New York University, and completed M.S. and Ph.D. degrees there. He was awarded a postdoctoral fellowship at the Johns Hopkins University in 1928.

Astin came to NBS directly from Hopkins in 1930. His post was that of a Research Associate on behalf of the Utilities Research Commission of the State of Illinois. Because of the depression, jobs were scarce; however, Astin's work was well received and the Bureau soon was able to hire him full-time to work on a Navy aircraft project.

Allen V. Astin, fifth Director of NBS, photographed in a moment of contemplation in his office on the 11th floor of the Gaithersburg Administration building.

Astin's hiring proved to have been a smart move for the Bureau. His work was fruitful to NBS in the areas of electronics, weather and—after the start of World War II—military ordnance. He became chief of the Electronics and Ordnance Division in 1948. Three years later he was named Associate Director of NBS with oversight responsibility for many transferred-fund projects.

Quiet and reserved, more an emotional twin to Briggs than to Condon, Astin was extremely capable as a manager. That quality was a lucky thing indeed, for it fell to Astin to work through the re-deployment of the Bureau away from war work, and to face a wearing public controversy over battery testing. The reputation of NBS as a rock-solid scientific laboratory and an objective authority on measurement standards was considerably enhanced by the quality of its war work and by the intense scrutiny it survived during the battery-testing ordeal, known as "the AD-X2 incident."

Throughout the whole of his service as Director, Astin remained calm, steadfast in his defense of Bureau objectivity and procedures (which, during the AD-X2 incident, he personally reviewed in detail), and determined to maintain NBS as an effective scientific institution.

The interested reader is urged to follow in Passaglia's history the stories of the shift of NBS attention from work on WW II projects and the intriguing tale of the AD-X2 incident.[32]

The post-War reorganization, requiring the divestiture of many of the NBS staff as various war projects were transferred bodily to other agencies, was a substantial administrative challenge and thus carries its own fascination. During 1953, Secretary of Commerce Sinclair Weeks transferred Bureau personnel working on the proximity fuze project to the Army Ordnance group, where the operation was renamed the Diamond Ordnance Fuze Laboratory. In the same year, the NBS guided missile division at Corona, CA, was transferred *in toto* to the Navy Department. During the next year the Institute for Numerical Analysis, located on the campus of the University of California at Los Angeles, was transferred to the university. Within the space of one year NBS lost 2000 of its 4800 employees.[33]

The battery-testing controversy, which began in 1948, was replete with congressional hearings, newspaper headlines, and charges of Bureau bias against the "little guy." It had the makings of a literary thriller. Astin was relieved of his directorship at one point because of congressional pressure, for " . . . paying insufficient attention to the needs of the marketplace." Astin was reinstated only after public outcry from the NBS scientific staff and from many leaders of the U.S. scientific community. Despite its unblemished record of service to American technology and standards—so recently underscored by outstanding service on WW II military projects—the agency was bullied for many months by the Congress at the behest of one Jess Ritchie, an overly ambitious businessman who attacked the integrity of NBS testing procedures for the benefit of his company.

Ritchie did not want to be told, as he had been many times by Bureau testing personnel, that his storage-battery additive, labelled AD-X2, was of no demonstrable value to a battery's working life.[34]

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[32] Elio Passaglia, op. cit. Other material on this topic is contained in the following references: Elio Passaglia, "Science: Evidence, Truth and Integrity," *NBS Special Publication 690,* January 1985; "Battery AD-X2," *Hearings before the Select Committee on Small Business, United States Senate, 83rd Congress, March 31, June 22, 23, 24, 25, and 26, 1953,* U.S. GPO, 1953; Samuel A. Lawrence, *The Battery Additive Controversy,* Inter-University Case Program Series ICP No. 68, University of Alabama Press, 1962.

[33] See, for example, Elio Passaglia, *Science: Evidence, Truth and Integrity,* NBS Special Publication 690, January 1985, p. 23.

[34] The efficacy of a battery additive is difficult to prove because of the variety and sporadic nature of battery failure mechanisms. NBS test personnel therefore utilized a statistical approach to the testing of such additives. Ritchie much preferred an anecdotal test procedure, one battery at a time.

On June 22, 1953, Jess M. Ritchie demonstrated the battery additive AD-X2 before the Senate Select Committee on Small Business. (AP/Wide World Photos).

In order to force the Bureau to recommend his product, Ritchie organized a high-pressure campaign through individual members of the Congress to call into question the Bureau's procedures and objectivity. Despite Ritchie's charges, the NBS testing was done with great care. Astin himself reviewed the battery-testing procedures and the statistical analyses of the results. The study was conducted strictly by the book.

In early 1953 President Dwight Eisenhower appointed Sinclair Weeks as his new Secretary of Commerce. In turn, Weeks appointed Craig R. Scheaffer, a former president of the Scheaffer Pen Company, to the position of Assistant Secretary for Domestic Affairs. Supervision of NBS was among Scheaffer's duties. Neither Weeks nor Scheaffer was especially tolerant of governmental interference with business.[35] In any case, Ritchie's campaign soon took hold.

Weeks was very conscious of the "heavy burden" that government typically placed on the backs of businessmen; Scheaffer was more than willing to do his part to remove it. Scheaffer recommended that Astin be relieved of his post. Weeks, perhaps unaware of the apolitical heritage of Astin's position, agreed. Astin was called "downtown" and asked to resign, which he did.

[35] Samuel A. Lawrence, "The Battery Additive Controversy," #68 in *The Inter-University Case Program*, (University, AL: University of Alabama Press, 1962), p. 18 ff.

Was that the end of the AD-X2 story? Not quite. There came another campaign, this one mounted by America's scientific establishment. It was enthusiastically abetted by a national press that was critical of what it perceived as a failure of backbone at the Department of Commerce. Leading scientists from several national scientific organizations insisted that the firing of Astin would cripple the ability of NBS to perform its mission—no longer would the Bureau staff be able to undertake testing duties free of political pressure. The senior staff of the Bureau also weighed in with demands for Astin's reinstatement. Hundreds of them threatened to resign if Astin's resignation were to be accepted. This action would have seriously damaged the Bureau's ability to pursue its technical projects—many of them requested by other government agencies.

Ultimately—following an agonizing period of meetings and hearings during which political gears were forced into reverse—Astin was again endorsed as NBS Director by Secretary Weeks. On September 18, 1953, Craig Scheaffer resigned his office. Gradually the AD-X2 matter receded from the public view. NBS emerged from the AD-X2 battle with flying colors and renewed vigor. The agency's methods and integrity had been examined publicly and found to be more sound than nearly anyone outside the organization had ever realized.

Reinstated as Director, Astin continued in office for another decade and a half. His leadership—calm and quiet, but effective—was felt throughout NBS. Technical accuracy, absolute objectivity, and scientific merit remained the norm for Bureau projects.

Having led the NBS for nearly 18 years, including some of the most trying times the agency had ever endured, Allen Astin made known in 1967 his intention to retire in 1969, when he would reach the age of 65. He had served his government and his agency well. His personal involvement in research on proximity fuzes during World War II had contributed to the formation of the Harry Diamond Ordnance Fuze Laboratory. His devotion to high-quality technical work had helped to bring to NBS an outstanding staff, grounded in modern science, in nearly all technical areas. And he had led the Bureau through the stressful period of relocation of its major facilities to Boulder and Gaithersburg.

Astin's personal, scientific, and leadership qualities were recognized by numerous awards. Of these awards, we list only a few. He was the 1947 recipient of His Majesty's Medal for Service in the Cause of Freedom, from England; the Office of the Legion of Honor, from France; the U.S. President's Certificate of Merit in 1948; in 1952 the Department of Commerce Gold Medal Award for Exceptional Service; and the Rockefeller Public Service Award in 1963. He was elected to membership in the National Academy of Sciences in 1960.

At age 65 Astin felt that he was entitled to take a break. No one questioned his decision.

Astin had in mind as his successor a Bureau man who could be expected to raise still higher the level of NBS technical excellence: Lewis Branscomb, a bright, young, Harvard-trained atomic physicist and a proven administrator. However, between Astin's retirement announcement and the appointment of the next director there loomed the 1968 presidential election, already clouded by the unpopular Vietnam War and destined to be further darkened by ugly civil strife. The results of that election would have a definite impact on Branscomb's selection and tenure, as we shall see.

THE STATE OF NBS IN 1968

In 1968 the National Bureau of Standards occupied an enviable position in the firmament of Federal agencies. A heavyweight contributor to military research and development during two world wars, a highly respected authority on standards of measurement, renowned for the ability of its staff to solve tough scientific and technical problems, NBS was a sparkling asset to the national government.

Let us glance inside this wonderful machine and see what kept it ticking so well when Cyrus Smith left his post as Secretary of Commerce and Lyndon Johnson left the Presidency of the United States.

NBS Facilities

The physical plant of NBS had never been in better shape than it was in 1968. New facilities in Boulder, Colorado, and in Gaithersburg, Maryland, many of them designed especially for complicated projects, provided the Bureau staff with seemingly endless technical capabilities.

The Bureau had begun life in the Coast and Geodetic Survey building at New Jersey Avenue and B Street, in southeast Washington, DC. It was not an environment well-suited to breakthrough standards research; 14 people, including the night watchman, occupied the designated space in the modest building. Such a tiny agency could provide only minimal standards services to the Nation.

One of the initial projects of its founding Director, Samuel Stratton, was to obtain larger and better facilities for the new agency. Stratton relieved the immediate space problem by acquiring two buildings standing near the Coast and Geodetic Survey offices. He also sought a larger, permanent home for the Bureau. In this endeavor he had the assistance of the first Visiting Committee. They quickly selected an 8-acre wooded site about 3 1/2 miles from the White House along Connecticut Avenue, at the end of Washington's trolley line.[36]

This setting provided NBS with its main laboratories for more than 60 years. Periodic expansion of the duties and staff of the Bureau was accommodated by acquiring adjoining land for new laboratory construction; purchases in 1913, 1918, 1920, 1925, 1930, and 1941 gradually increased the size of the Bureau site from its initial 8 acres to just over 70 acres. Until the construction of a new site at Gaithersburg, however, there never was an administration building to house the Director, his staff, and the central service activities.[37]

The Bureau occupied many small, special-purpose sites during its decades of service.[38] These sites included both occasional and semi-permanent or permanent laboratory space acquired for a variety of purposes:

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[36] See MFP, p 62.

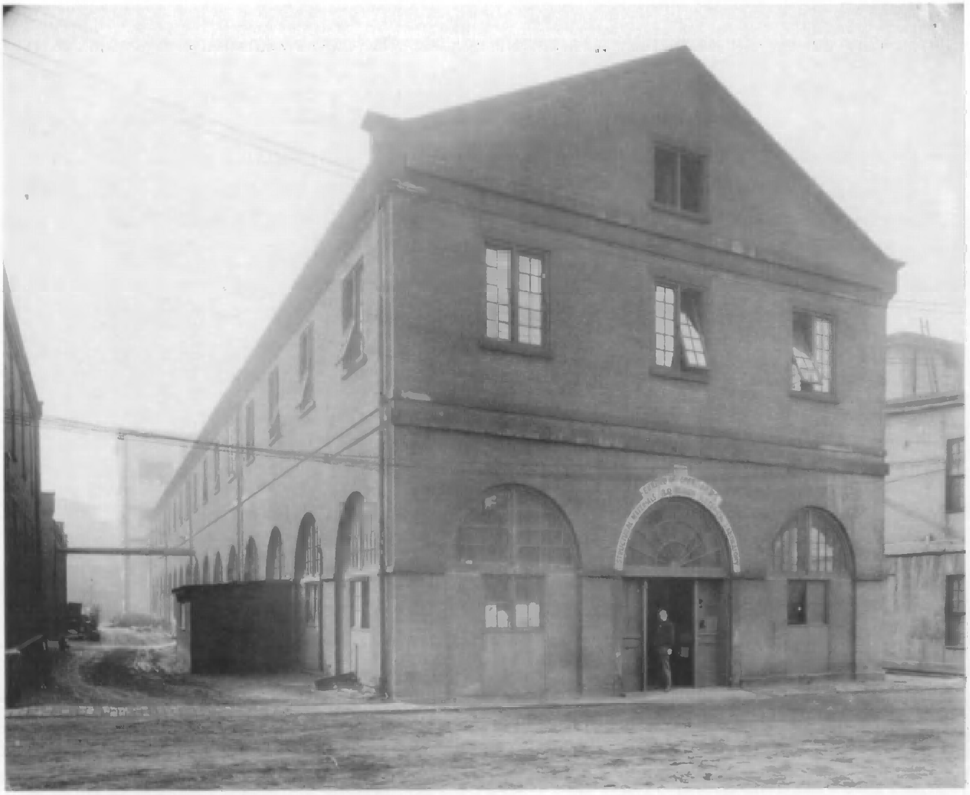
[37] Robert S. Walleigh, "The Gaithersburg Site," in *NBS/NIST: A Historical Perspective,* NIST Special Publication 825, April 1992, p. 49.

[38] See MFP, App. J.

Aerial view of the Bureau of Standards campus in Washington, D.C., circa 1922.

1. The study of structural materials occurred in:
   - Allentown, Pennsylvania.
   - Atlantic City.
   - Denver.
   - Kansas City.
   - Northampton, Massachusetts.
   - Pittsburgh.
   - Permanente, Riverside and San Jose, California.
   - Seattle.
2. Railroad-car testing was done in Clearing, Illinois beginning in 1928, to serve the needs of the Nation's railroads.[39]

[39] "NBS Railroad Track Scale Project—What and Why," *NBS Standard,* Vol XV, No. 9, September, 1970, pp. 1, 3. In 1981, this program, involving two calibration personnel, two specially equipped railway track scale test cars, and a depot in Clearing, Illinois, was transferred to the Federal Grain Inpsection Service.



In 1910, the Secretary of the Interior transferred the staff and equipment of the Geological Survey's structural materials laboratories to the Bureau of Standards. These included a Pittsburgh laboratory where cements for navy yard and dry dock construction, as well as clays, ceramics, lime, steel, and other structural materials were tested. This photograph of the Pittsburgh laboratory was taken in 1913.

3. Radio field stations girdled the globe:

- Anchorage and Point Barrow, Alaska.
- Antarctica.
- Kitt Peak Observatory in Arizona.
- Australia.
- Bolivia.
- Brazil.
- California.
- Canada.
- Canary Islands.
- Canton Islands.
- Chile.
- Colombia.
- Nearly 20 sites in Colorado.
- Ecuador.
- Greenland.

- Guam.
- Hawaii.
- Iceland.
- Illinois.
- India.
- Japan.
- Kenya.
- Malagasay.
- Malaya.
- Maryland.
- Minnesota.
- Missouri.
- Morocco.
- Nebraska.
- New Jersey.
- New Mexico.
- New Zealand.
- Nigeria.
- Okinawa.
- Oklahoma.
- Panama Canal Zone.
- Peru.
- Philippines.
- South Africa.
- Sweden.
- Puerto Rico.
- Trinidad.
- Virginia.
- West Indies.
- Wyoming.

4. A lamp inspection station was established in Brookline, Massachusetts.
5. The Institute for Numerical Analysis was created in Los Angeles.
6. Electronics testing was performed in LaPlata, Maryland, and Tuckerton, New Jersey.
7. Aircraft landing equipment was tested in Arcata, California.
8. The Joint Institute for Laboratory Astrophysics was established at the University of Colorado in Boulder.
9. The Clearinghouse for Federal Scientific and Technical Information was placed in Springfield, VA.
10. A laboratory for electronic research and development, including the development of guided missiles, was established in Corona, California.

The so-called "field stations"—some small, some large—tended to come and go as the Bureau responded to its commitments. For many years, though, the sun did not set on the NBS "empire."

By the time Edward Condon became its director in 1945, the Connecticut Avenue facilities had become overcrowded and seriously outdated or run-down. More than 100 buildings dotted the site, some constructed for special projects during the First World War. Bureau personnel occupied space in a haphazard manner—the staff of one technical division was quartered in 17 different buildings.[40] Personnel from the Public Buildings Administration, a Federal housekeeping agency, who were asked to evaluate the condition of NBS property during the mid-1950s, found many buildings that could only be described as decrepit. There were few records of the locations of the utilities for the various buildings—information that was essential to even attempt repairs for them. No funds had been provided for maintenance of the Connecticut Avenue site for years, and the buildings showed it.

[40] Robert S. Walleigh, "The Gaithersburg Site," p. 49 in *NBS/NIST: A Historical Perspective,* NIST Special Publication 825, Karma A. Beal, editor, April 1992.

The NBS Visiting Committee had frequently made Congress aware that the work of the Bureau was hampered by the limitations of its main facility on Connecticut Avenue; Congress' own assessment in 1947 supported that claim. Congress responded to this case of clearly documented need with a decade of cogitation and study.

Finally, in 1957, the Congress decided to permit the acquisition of a new principal location for the Bureau in Gaithersburg, Maryland. Strangely enough, by that time the ice had been broken by the creation of a major laboratory in Boulder, Colorado, as we shall see.

Congress' decision to relocate the main Bureau facility was only partly motivated by the obvious crowding and decrepitude of many of the Connecticut Avenue buildings. Another consideration at that time was the desire to disperse vital governmental activities in case there should be a nuclear attack on Washington. A third motivation was the substantial need for special laboratories that couldn't be located "in town" because of space or technical requirements.

A priority that influenced the selection of the new principal site was that of continuing to work on vital tasks during the course of a move. Although many specialized projects could not be undertaken at all in the old laboratories, many other activities were in progress despite the cramped quarters; some of those would suffer if the move entailed a long down-time.

The Boulder Site

Congress dithered over a move of the main NBS laboratory complex for a decade.[41] However, not all of the Bureau's assigned tasks could wait that long. Radio science was one of these. As matters turned out, cryogenic engineering was another.

The field of radio research included a whole set of projects that awaited a better environment. The area around the Connecticut Avenue site, no longer a quiet residential location, teemed with traffic, commerce, and the attendant vibration and electrical noise. Washington, DC, like any large city, was deluged by radio and other electromagnetic signals. High-power commercial stations broadcast their messages widely. Just as pervasive were radio communications networks run by police, air and ground transportation services, colleges, hospitals, and a multitude of other entities. Radio quiet and long sight-lines, essential for effective development of new standards for radio communication, no longer were available in the Nation's capital.

The Central Radio Propagation Laboratory (CRPL), organized as a division of NBS in 1946 to consolidate and broaden the work of the wartime Interservice Radio Propagation Laboratory, was the focus of the arguments for a new site. The military Joint Chiefs of Staff had urged Commerce Secretary Henry Wallace in 1945 to establish within the Bureau a central source for the dissemination of information on

[41] Wilbert F. Snyder and Charles L. Bragaw, *Achievement in Radio: Seventy Years of Radio Science, Technology, Standards, and Measurement at the National Bureau of Standards* Natl. Bur. Std. (U.S.) Special Publication 555, October 1986. The Boulder move is described in Ch XIX. The transfer of the Central Radio Propagation Laboratory to the Environmental Science Services Administration, later known as the National Oceanic and Atmospheric Administration, is discussed in Ch. XX.

radio transmission and for conducting research on radio propagation. In turn, Wallace, early in 1946, asked the Director of NBS to create a Central Radio Propagation Laboratory. Edward Condon, then NBS Director, established the CRPL as Division 14 of the Bureau as of May 1, 1946. The activities formerly conducted by the Radio Section of the Electricity Division were transferred to the new division. J. Howard Dellinger was named Chief of the CRPL; his deputy was Newbern Smith.

At the first meeting of the Radio Propagation Executive Council—formed specifically to advise the CRPL staff on its programs—Dellinger noted the inadequacy of existing Connecticut Avenue facilities and described plans to erect a new building there. But these plans changed when the laboratory leaders realized in 1948 that they really needed a location with less interference and more open space, as well as access to a larger variety of terrain than could be found locally.

Once the decision was reached to seek a new location for radio work, three criteria for choosing it were developed. The new site had to be free, or nearly free, of electromagnetic interference for radio communications; it had to feature long lines of sight; and it must be near a good university-level electrical engineering department. Boulder, Colorado, Charlottesville, Virginia, and Palo Alto, California, seemed to be suitable choices. Boulder's location, with tall mountains on the west and flat plains on the east, offered the prospect of excellent sight lines; moreover, it was favored by Director Condon. The Boulder Chamber of Commerce clinched the choice with an offer of some 200 acres of land—purchased with money raised by public subscription—to be given to the Federal government for the site.

Persuaded by the endorsement of the Joint Chiefs of Staff and the gift of a site, Congress endorsed the relocation of NBS radio research to Boulder.

As soon as the Boulder site was selected, planning for a new radio building began. The chosen design utilized reinforced concrete to produce a solid, long-lasting structure. A central spine was to be flanked by an auditorium and a library near the front, and by six perpendicular wings in the rear. The structure was to be set into the sloping land south of Boulder, with Green Mountain and the Flatiron rock formation behind it.

Construction on the Boulder site began in 1951—but, surprisingly, not for the radio laboratories!

Even before the Central Radio Propagation Laboratory mounted its crusade for a new environment—during the latter days of World War II—the hydrogen bomb had entered the national picture, though only in the form of highly secret calculations and experiments. Later, in 1949, the U.S. Atomic Energy Commission (AEC) became aware that the U.S.S.R. weapons program had caught up in the international arms race by producing an "atomic" bomb—one utilizing the principle of a neutron-induced chain reaction to propagate nuclear fission throughout a mass composed mainly of ^{235}U. Fearful of losing America's lead in munitions, the Defense Department and AEC leaders decided to mount a crash program to produce a still more powerful bomb, the "Super" thermonuclear weapon.

Aerial view of the National Bureau of Standards Boulder, Colorado laboratories and the nearby Rocky Mountains.

Declassified reports indicate that the Superbomb concept originated in discussions between Enrico Fermi and Edward Teller during the development of the fission bomb that was used during the summer of 1945 to bring World War II to a close in the Pacific theater.[42] Essentially, the idea behind the Superbomb was to use the enormous heat and pressure generated by a fission bomb to initiate nuclear fusion in hydrogen, unleashing potentially 1000 times the energy of a fission bomb. In fact, it appeared that the fusion of deuterium (^{2}H) nuclei with other deuterium nuclei, or the fusion of tritium (^{3}H) nuclei with deuterium nuclei, might provide even higher reaction rates than would the fusion of two ordinary (mass-1, ^{1}H) hydrogen nuclei. A workable bomb, it was thought, might be assembled using large amounts of liquid hydrogen, liquid deuterium, or liquid tritium—a highly radioactive isotope—in conjunction with a fission-bomb "detonator."

[42] F. G. Brickwedde, E. F. Hammel, and W. E. Keller, "The History of Cryogenics in the USA," Chapter 11 in *History and Origins of Cryogenics*, R. Scurlock, ed. (Oxford: Oxford University Press, 1992).

Thus it happened in 1950 that liquid hydrogen and expertise in cryogenics—both in large quantities—were wanted by the Atomic Energy Commission, and quickly. Seeking an appropriate laboratory where such Cold War weapons could be located, the AEC considered the new Boulder site chosen by NBS. Not only did the Bureau possess considerable experience in cryogenics, but the newly acquired location at once offered relative isolation from congested areas, yet relative proximity—only 400 miles!—to the Los Alamos laboratory.

The Bureau was well known to the AEC and highly respected for its "can do" spirit on many WW II projects. Furthermore, at its Connecticut Avenue site NBS housed a cadre of highly qualified low-temperature physicists and engineers including Ferdinand G. Brickwedde (Chief of the Heat and Power Division), Russell B. Scott (Chief of the Cryogenics Section), John R. Pellam, Emanuel Maxwell, and W.E. Gifford.[43] In fact, Brickwedde's work at NBS on the properties of liquid hydrogen had led Harold C. Urey to collaborate with him in 1931-32 on work that established the very existence of deuterium as an isotope of hydrogen.[44]

The presence of Brickwedde, Scott, and their colleagues in the NBS low-temperature laboratory, plus the favorable location of the Boulder site, appeared to the AEC to be just the ticket for the creation of a large supply of liquid hydrogen within the confines of a versatile cryogenic engineering laboratory. The laboratory would be safely isolated, yet part of the NBS complex. The AEC suggested to Congress that a cryogenics laboratory should be established immediately at the NBS/Boulder site. The recommendation was quickly approved.

Work on a monster hydrogen liquefier began immediately in the Washington cryogenics laboratory. Brickwedde assembled a team comprising himself, Scott, and Gifford from the NBS Cryogenics Section and he added Victor J. Johnson, a low-temperature engineer from the Naval Research Laboratory, also located in Washington. Within one year's time the team had designed and built a hydrogen liquefier expected to produce 350 liquid liters per hour—10 times the capacity of the largest plant previously in use.

It was because of this intense effort in cryogenics that, instead of an advance team from the Central Radio Propagation Laboratory, the first NBS staff to inhabit the Boulder location was a group of low-temperature experts—sometimes called "cryogenists"[45] but, more often, "cryogenicists"—under the direction of Russell Scott. The group included Gifford, Johnson, Dudley Chelton, Bascom Birmingham, Robert B. Jacobs, Peter C. Van der Arend, Richard Kropschot, and Robert L. Powell.

The hydrogen liquefier occupied a large building—about 1,300 square meters (14,000 square feet) in floor area—whose principal external distinguishing feature was a set of large ventilators that helped to change the air in the entire building every

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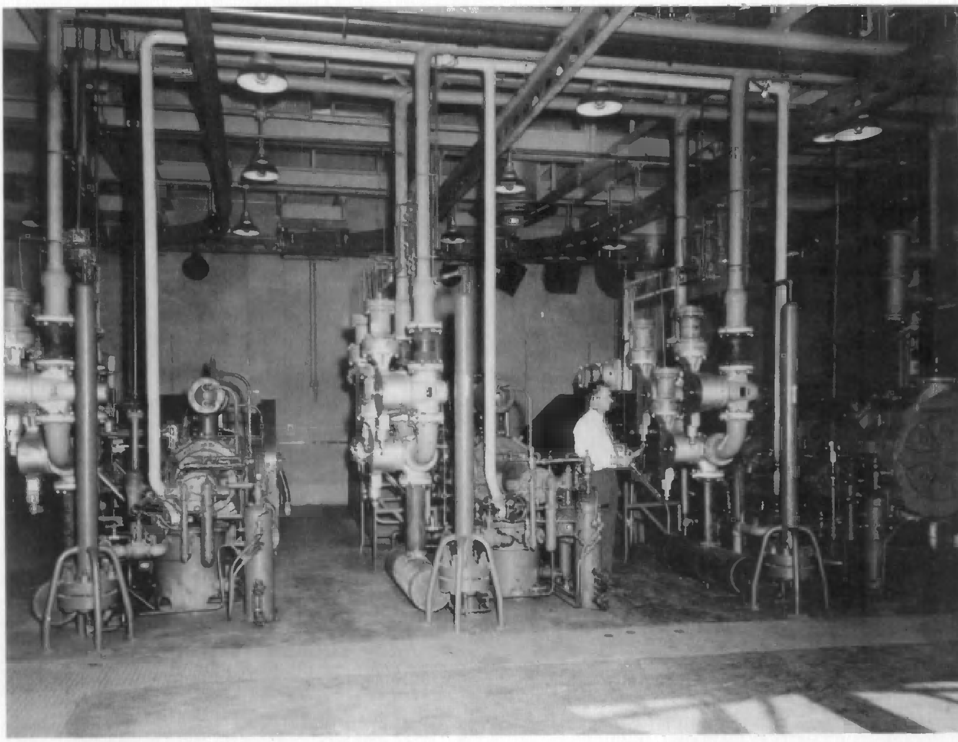
[43] See Brickwedde, Hammel, and Keller, op. cit.

[44] This work helped Urey to earn the 1934 Nobel Prize in chemistry. A concise but readable account of the work can be found in Daniel J. Kevles, "The Physicists: The History of a Scientific Community in Modern America" (Cambridge, Massachusetts: Harvard University Press, 1971) pp. 225-226.

[45] From the Greek "cryo" and "–geny," the creation of low temperatures.



Victor J. Johnson in front of a bank of air-operated selector valves connecting hydrogen compressors to hydrogen liquefying systems in the Boulder Cryogenic Engineering Laboratory.

two minutes, a very desirable safety feature. As part of the hydrogen-liquefier project, a second liquefier capable of producing 450 liters of liquid nitrogen per hour was also built. The liquid nitrogen was used to pre-cool gaseous hydrogen prior to its liquefaction. The whole plant was heavily instrumented to provide information for eventual optimization of the liquefaction process.[46]

The hydrogen liquefier was the first installation in an extensive cryogenics laboratory that gradually took shape at the NBS/Boulder site.[47] Besides the liquefier building, the cryogenics complex included an even larger—1,860 square meters—main laboratory building and a half-dozen smaller, special-purpose buildings.

The rapidly expanding cryogenics group initiated engineering studies of fundamental phenomena such as the exothermic ortho-para conversion process in hydrogen, augmented by a multitude of projects on the production, handling, transport, and instrumentation of cryogenic fluids and solids.

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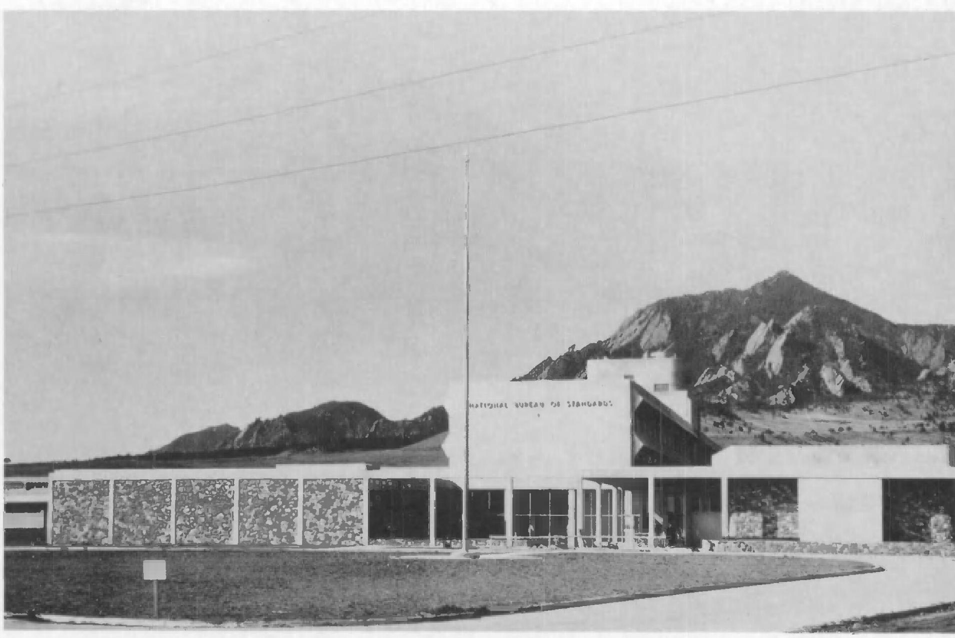
[46] Russell B. Scott, Cryogenic Engineering (Princeton, NJ: Van Nostrand, 1959).

[47] Snyder and Bragaw, *Achievement in Radio*, p 720; Robert A. Kamper, "History of the Boulder Laboratories," p. 43 in *NBS/NIST: A Historical Perspective*, Karma A. Beal, editor, NIST Special Publication 825 (Washington, DC: U.S. Government Printing Office, 1992).

We shall have much more to say about low-temperature science at Boulder as our history continues. However, we should note here that, with the success of the 1951 "George" experiment in the AEC's "Greenhouse" thermonuclear-fusion test series, the principle of thermonuclear ignition was proved. With the "Mike" shot at Eniwetok at the end of 1952, the great explosive force of the "Super"—the equivalent of about 10 megatons of TNT, dwarfing the kiloton yields of fission bombs—was demonstrated. The thermonuclear project involved very substantial advances in cryogenic engineering—not just at NBS but by a whole consortium of laboratories. However, the cryogenics staff of the Bureau played a vital part in proving that America could harness the energy of the stars through the use of isotopes of hydrogen in liquid form.

Construction of the main radio laboratory building began in 1952. On September 14, 1954, President Eisenhower led a distinguished group to Colorado to dedicate the new Boulder NBS laboratories.

The detailed history by Snyder and Bragaw provides evidence aplenty of the mushrooming demand for radio services that accompanied the opening of the new laboratories. As just one example, the Air Force asked for a whole group of new calibration and advisory services in radio while the Boulder expansion was still under study. Planners estimated that an additional facility costing $5 million should be added to the projected building expenditures just to satisfy the new Air Force needs.



Administration Building for the National Bureau of Standards Boulder, Colorado laboratories.

By 1968, the Boulder complex included the large Radio building, a Cryogenics building, a hydrogen-liquefier building, a plasma-physics building, and about a dozen other structures. In addition to these facilities on the main site south of town, Bureau scientists assigned to the Joint Institute for Laboratory Astrophysics shared with their University of Colorado colleagues a new building on the CU campus. It was completed only in 1966 with funds from the National Science Foundation and the university. Appendix D includes a map of the NBS/Boulder site.

The Gaithersburg Site

The move of the main laboratories of NBS away from its outgrown home on Connecticut Avenue was eased considerably by the success of the Boulder enterprise. There was no question that a move to new and substantially larger quarters was necessary if the Bureau was to continue to meet its responsibilities to the nation's technical enterprise. The only cause for concern appeared to lie with the potential disruption of ongoing projects that might accompany a move. The Visiting Committee advocated retention of the Connecticut Avenue campus as late as 1957, at the same time citing the pressing need for immediate relief for certain projects from the conditions existing at the old site.

Finally fully aware that NBS—a valuable national resource—could hardly prosper in the cramped, outmoded Connecticut Avenue site, Congress in 1956 decided to permit the main laboratories to take the same step taken earlier on behalf of radio science and cryogenics; an entirely new campus.

At once, defining questions needed answering: Where should NBS relocate? How much money would relocation cost? How should the Bureau plan the new facilities? Could a move take place without interrupting or destroying the continuity of the Nation's physical standards?

Responsibility for overall planning of the move was given to Robert Walleigh, NBS Associate Director for Administration, an engineer by training and a Bureau employee since 1943. Walleigh went to work immediately on the task.[48]

Where should NBS relocate? At least 20 miles from the White House, according to the criterion of dispersing government facilities to reduce the potential for damage by nuclear attack. Not much farther than 20 miles, by the practical criterion that unbearable staff attrition might accompany a move to a distant place. Of some 100 sites recommended for study by a task group composed of NBS personnel and members of the Public Buildings Service (a division of the General Services Administration), a 550-acre expanse of farmland near Gaithersburg, Maryland, was chosen by Director Astin with the advice of Walleigh and other planners.

Relocation to nearby Maryland—a short automobile ride from the Van Ness site—mitigated the fear of interrupting Bureau services during the move. The staff simply could—and did—carry certain critical instruments in their own vehicles to minimize downtime and the likelihood of damage.

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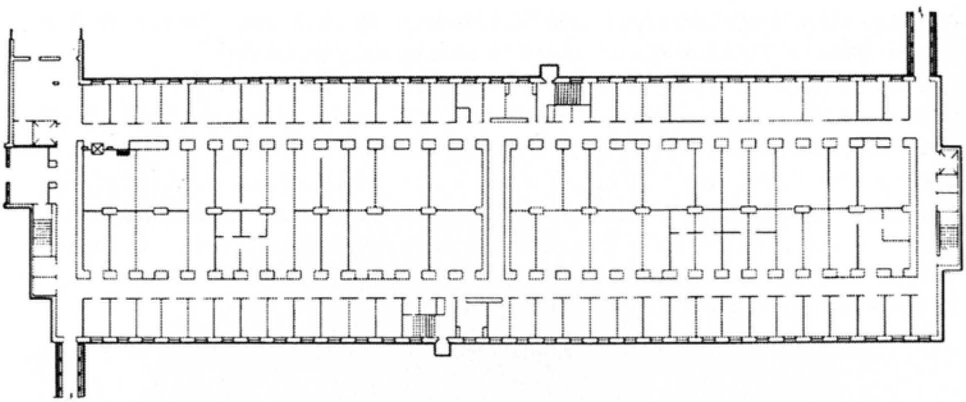
[48] Robert S. Walleigh, "The Gaithersburg Site," in *NBS/NIST: A Historical Perspective,* NIST Special Publication 825, April 1992, pp. 49-55. See also the NBS Annual Report for 1966, Miscellaneous Publication 283, April 1967; and the NBS Technical News Bulletin for November 1966.

On October 24, 1961, a red oak was planted at the new, as yet undeveloped Gaithersburg, Maryland site in honor of Director Emeritus Lyman J. Briggs. Briggs shoveled the first dirt on the tree while William R. Stevenson held it in place and Director Allen V. Astin stood by.

How much money would relocation cost? Asked this question on short notice by Congress, the NBS management consulted the General Services Administration. GSA personnel performed a quick estimate of the cost of constructing a single building with no special facilities and came up with the number $40 million, lower than the eventual cost by nearly a factor of four. The unrealistic GSA estimate would haunt NBS management for years to come.

How should the Bureau plan the new laboratory facilities? An architectural firm with experience in designing laboratory space for the Bell Telephone Laboratories, for the E.I. DuPont de Nemours Co., and for the Ford Motor Co. was engaged. An NBS Gaithersburg Planning Committee was selected to work with the architects and the technical staff. A laboratory planning committee composed of senior, active Bureau staff members began thinking about the optimum design of new laboratory space. A wide range of possibilities—from specially designed laboratories in a single building to a group of buildings containing simple, cinder-block rooms to permit maximum flexiblity—was considered by the planners. Ultimately, a combination of connected general-purpose laboratory buildings, plus separate special-purpose structures, was chosen. Use of cinder-block construction, however, was not approved for the buildings.



Floor plan of general-purpose laboratories at the National Bureau of Standards in Gaithersburg, Maryland. Experimental spaces were located in the central portions of the buildings, offices along the exterior walls.

Minimizing the effects of electromagnetic interference, a constant problem at the Van Ness site, was tackled by Clarence J. Saunders. Saunders, a Bureau veteran of many years' standing, assisted Walleigh in planning the electrical grounding and shielding systems.[49]

Further emphasis on the importance of better facilities for NBS, had any been needed, came from outer space! When the Soviets launched Sputnik I on October 4, 1957, they inadvertently intensified the desire of the U.S. Congress to improve America's technological capabilities. Suddenly, science became a more important national enterprise than it had been before the little beeper orbited the earth.[50]

Planning of the new laboratories was thorough. Each project leader was permitted to suggest modifications to a standard modular design used in the general-purpose laboratories so that the space could meet special requirements. Special buildings were planned to house one-of-a-kind activities; Walleigh was adamant that no poorly constructed or temporary buildings should be allowed on the site.

Construction of the facilities comprising the Gaithersburg complex began in 1961. Appendix D provides information on the progress of construction through 1990. Although most of the construction was completed within 7 years, a new major laboratory building was under construction even as this history was written. Most of the structures shown on the accompanying map were built during the initial construction period.

The overall plan for the Gaithersburg complex called for a central electrical power station and a central air-cooling facility. Both services would be available for all

[49] "The importance of electromagnetic compatibility at NBS," *NBS Standard,* Vol XV, No. 3, March 1970, pp. 1, 4.

[50] See, for example, pp. 421-423 in *Hearings Before a Subcommittee of the Committee on Appropriations, House of Representatives, 85th Congress, Second Session* USGPO (1958).

buildings *via* underground supply lines. Laboratory buildings would be furnished with cooled, dried air which would be heated in each building as needed.[51]

The first of the laboratory buildings to be built on the Gaithersburg site was the Engineering Mechanics building. It would house calibration equipment for load cells, force measurements, proving rings, creep measurements, "deadweight" machines, and dynamic materials testing. The needs of NASA and the Department of Defense for calibrations of high-thrust rockets were critical, so construction—at the intersection of Center Drive and South Drive—was begun as soon as possible in 1961. The building took two years to complete. The pressing need for large-force calibrations led the staff to begin work several months prior to completion.

The National Bureau of Standards Engineering Mechanics Building in Gaithersburg, Maryland. It was built to house a one-million-pound dead-weight tester.

Construction of the Radiation Physics building was started during 1962. At the same time, the Supply and Plant and the Instrument Shop service buildings were begun. The following year, a Nuclear Reactor facility was begun near the Radiation Physics building. When occupied in 1964 and 1965, respectively, these two laboratories provided

[51] This plan worked well. The only hitch developed because typical general-purpose laboratory electronic equipment, expected to consist largely of hot vacuum tubes, instead incorporated relatively cool electrical transistors, thus placing unexpectedly large demands on the laboratory re-heat systems.

the core of a Center for Radiation Research. The capabilities that were thus created soon placed NBS in the forefront of research and standards in these areas. The Radiation Physics structure incorporated an electron linear accelerator and a number of other radiation-producing machines and sources to support a wide range of research and standards capabilities. The NBS research reactor—since upgraded from 10 megawatts to 20 megawatts—quickly became a national resource, with programs of dosimetry, activation analysis, isotope production, and fundamental studies involving cold neutron fluxes and materials analyzers.[52]

Visitors to the new Bureau facility in Gaithersburg usually first saw the Administration Building as they approached the site; eleven stories high, it towered over all the other buildings. Most administrative functions of the Bureau were located there. Integral with it were two auditoriums, the main library, the central computer, a large cafeteria, sundry lecture rooms and other smaller facilities including a bank, a barber shop, and a gift shop. Construction of the administration-building complex was begun in 1962; it was first occupied in 1965.

A tree, reputed to be a direct descendant of the legendary apple tree that prompted Sir Isaac Newton to propose his law of universal gravitation, was planted in the library courtyard at the Gaithersburg site. The NBS Administration Building appears on the right-hand side of the photo.

[52] Reactor Radiation Division: Annual Progress Report, NBS Technical Notes 567 (1970), 714 (1971), 758 (1972), 813 (1973), 860 (1974), 896 (1975), 939 (1976), 969 (1977), 995 (1978), 1117 (1979), 1142 (1980), 1160 (1981), 1178 (1982), 1190 (1983), 1207 (1984), 1217 (1985), 1231 (1986), and 1257 (1988).

Seven general-purpose laboratory buildings—some of them built with three stories above ground and one below, others without basement space—were connected to the Administration Building by a central hallway two stories high. These buildings were named for scientific and technical disciplines involved in Bureau work—Metrology, Physics, Chemistry, Materials, Polymers, Technology (initially known as Instrumentation) and Building Research. Each of these except the one devoted to Building Research was constructed with peripheral offices separated by corridors from central laboratory spaces. This design eased considerably the problem of stabilizing laboratory temperatures, since sunlight—with its variable heating rate—was excluded from the laboratory space.

The Building Research laboratory was constructed with a view to testing structures on a large scale. Sections of bridges, piers, walls, and other structural components could be subjected to mechanical or thermal stresses in a variety of modes—indeed, one project featured a test of the efficiency of the thermal insulation in an entire modular home.

Construction of all the general-purpose laboratories was begun in 1963, and all were occupied by the end of 1966.

A pair of small, special-purpose buildings devoted to the study of low-level magnetism were built behind the Nuclear Reactor building. Construction was begun in 1964, and they were first occupied in February 1968. These buildings had the interesting distinction of having been constructed without the use of ferromagnetic materials—no steel nails, no iron reinforcing rods, no steel conduit for electrical wires.

The Sound building, dedicated to the study of acoustic phenomena, featured a large anechoic chamber and a reverberation chamber as well. It was begun in 1965 and occupied early in 1968. It was located between West Drive and Gate C.

During 1966, construction of the Hazardous Materials building, the Concreting Materials building, and the Industrial building was begun. Like the Sound building, these were good examples of separate, special-purpose buildings on the Gaithersburg site built to accommodate specific technical projects. One of these projects was a study of the properties of a mixture of liquid sodium and potassium, used as the primary coolant for certain nuclear reactors because of the low neutron-capture cross-sections of these two elements. This mixture was extremely dangerous to handle; it could combine explosively with several ordinary materials. The Hazardous Materials building was built to isolate such projects. The building was placed on the southern edge of the grounds, well away from the general-purpose laboratories. It was first occupied during 1968. The Concreting Materials building took two years to complete; its service life also began during 1968. The Industrial building, containing special equipment for the study of paper making and textiles, also was completed and occupied during 1968.

The Fluid Mechanics building was built across South Drive from the Engineering Mechanics building. Begun in 1967, it was completed and occupied two years later. Specialized studies of the flow characteristics of a variety of fluids could be accomplished on a routine basis in this building.

Although the Bureau's fire-studies program was among its oldest endeavors, work on a Fire Research building was begun only in October, 1973, in response to a national outcry for more effort in fire prevention. The Fire Research building was occupied in April 1974 and dedicated on June 25, 1974. However, it was regarded as complete only during October, 1975. Like the Hazardous Materials building, it was placed somewhat away from the general-purpose laboratories for added safety. In the Fire Research laboratories, entire rooms full of furniture could be heavily instrumented and then burned in order to observe the nature, progress, and noxious products of fires typical of all types of residential and commercial buildings.

An unusual circumstance permitted interesting studies of the cost savings that could be realized by retrofitting an ordinary home with modern thermal insulation. The Bowman House, an existing rural residence which NBS had more or less inadvertently purchased along with the rest of the new grounds, was used for the insulation study by the Building Research Division. The useful life of the building was extended in a uniquely satisfying manner when it was given over to an on-site child-care program after completion of the thermal study.

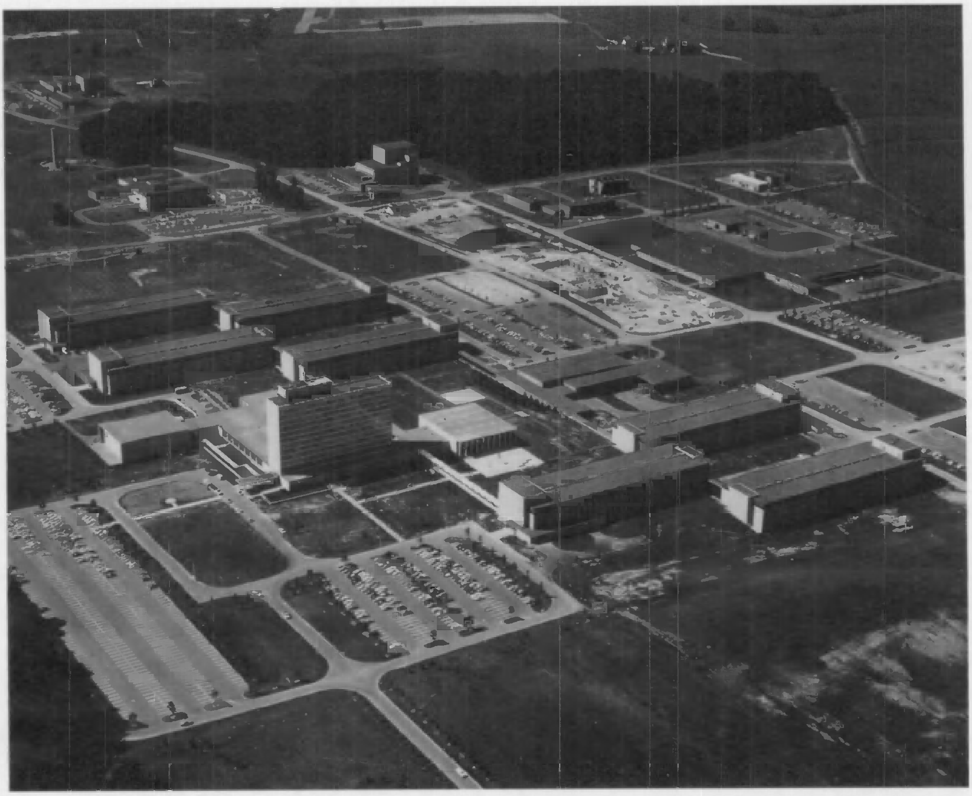
As each building was completed, the occupying groups measured the new space against plans they had prepared prior to the construction. In fact, many—if not all—had designated one or more staff members to monitor the progress of the construction. These people planned and tracked the placement of group property in the new space, with special emphasis on the well-being of experimental apparatus. Nearly everyone moving into the new quarters felt that metrology and science at the Bureau were about to move up a notch.

Although many buildings were constructed on the Gaithersburg site, its large area still provided a park-like setting. The extensive grounds had been requested by the Bureau planners to provide a buffer against the electrical and mechanical disturbances that plagued the old site. Together with an absence of heavy industry near the site, achieved through an agreement with the Montgomery County government, the encircling open space proved effective in forestalling the encroachment of both types of interference as the nature of the surrounding area changed from rural to urban. The use of steel in the construction of the walls of most of the buildings played a role as well in shielding sensitive experiments against electromagnetic interference.

From the beginning of the Bureau's occupation of the Gaithersburg site, a small herd of deer (originally approximately five in number) inhabited the area inside the boundary fence. The protection of the fenced Bureau grounds allowed these few animals to increase steadily to a very noticeable herd of several hundred. The deer lent a sylvan beauty to the site, but the price of that beauty was the ravaging of many decorative plants that contributed to its extensive landscaping.[53] Canada geese, too, proved a mixed blessing. Attracted by the large expanse of grass and two ponds placed on the grounds as emergency water sources,[54] they inhabited the grounds on a

[53] Among the plantings on the Gaithersburg site were nearly all of the azaleas from the Van Ness NBS grounds. These plants were quickly destroyed by the deer.

[54] Robert S. Walleigh, personal recollection.



Aerial view taken in 1966 of the new National Bureau of Standards laboratory complex in Gaithersburg, Maryland.

year-round basis. Like the deer, they found NBS a hospitable landlord. It was not unusual to see a nesting goose outside a window that featured predictions of hatching dates and other information on a placard. Unfortunately, the unrestricted goose population made for messy sidewalks and roadways.

The official dedication of the Gaithersburg laboratories took place in November 1966, after about 90 percent of the staff had moved to the new site. Left behind were several groups, including the Fluid Meters, Hydraulics, and Aerodynamics Sections—the last to move to the Gaithersburg site, in 1969—and the Office of Vehicle Safety, which remained in the old Industrial Building until it was transferred to the Department of Transportation in 1972.

A Symposium on Technology and World Trade was one of the events that took place during the dedication of the NBS Gaithersburg laboratories in November 1966. Vice President Hubert Humphrey addressed symposium attendees at a banquet held at the Department of State. Seated to the left of the dais was Professor Marshall McLuhan of the University of Toronto, well-known for his explorations of the relationship between technology and culture.

Organization and Staffing

In 1968, as Allen Astin prepared to hand over the directorship of NBS to his successor, he supervised a staff of over 3000 full-time employees, divided among the many scientific disciplines of the Bureau—in physics, chemistry, materials, mathematics, and engineering. The staff also included administrators, technicians, and clerical workers as well as other support personnel such as firefighters, police, a medical unit, and buildings-and-grounds workers. The most noticeable change in the composition of the Bureau staff during the previous 15 years had been the growth in the number of administrators, arising from increasing demands for planning and documentation.

The reader should recall that nearly all the staff and projects devoted more or less entirely to military work during World War II had been transferred as whole units to defense organizations by 1954, substantially reducing the size of the Bureau population from its previous high of nearly 4800. A further reduction occurred in 1965, when the entire Central Radio Propagation Laboratory—approximately 650 people—and a group of 15 staff members from the Sound Section were transferred from NBS to the

Medical staff serving the Bureau Gaithersburg site during the mid-1960s. Chief of the staff was physician George H. L. Dillard.

Environmental Science Services Administration (ESSA) in order to bring the Nation's predominantly environmental programs into a single agency. Renamed the Institute for Telecommunication Sciences and Aeronomy, the old CRPL joined the Weather Bureau and the Coast and Geodetic Survey to form ESSA. The CRPL staff continued to occupy their previous quarters until 1967, becoming temporary tenants of the Bureau. Thus departed from NBS the group that, more than any other, had precipitated the acquisition of its Boulder site.

A chart showing the numbers of people employed by the Bureau during its first 90 years of existence is presented in Appendix E. The influence of war work as well as other events that affected the level of NBS staffing show clearly in this graph.

The reassignment of so many staff members during the post-WWII period—nearly 40 percent of the Bureau's permanent force—was not seen by NBS management as a blow to its influence or importance. Instead there was a sense of refocusing of the efforts of the agency on its central mission of providing measurement standards and scientific and technical support for the needs of the Nation—leaner and cleaner, so to speak. Many projects remaining at NBS were related to the mission of the Defense Department and its contractors, but these now mainly took the form of solving scientific, technical, or metrological problems, not primarily the development of weapons hardware.

The pared-down (and partially rebuilt) permanent staff of NBS as of June 30, 1968, numbered 3,519, of which about one-third held academic degrees (509 physicists, 279 chemists, 261 engineers, 56 mathematicians, and 133 in assorted other disciplines). One-sixth of the permanent staff were located in the Boulder laboratories.[55]

Major Organizational Units

A hierarchy of three "institutes" was created by Allen Astin in 1964 in order to reduce the number of technical organizations reporting to the Director. Seventeen division chiefs had reported directly to Astin, but by 1968 the entire Bureau staff was represented by only five major organizational units.

The Institute for Basic Standards, placed under the leadership of Ernest Ambler, incorporated most of the old-line standards and calibration divisions in Gaithersburg, as well as all of the staff at the Boulder site.

The Institute for Materials Research, with John D. Hoffman as director, was composed of five materials-oriented divisions and the Office of Standard Reference Materials.

The Institute for Applied Technology, directed by Lawrence M. Kushner, comprised some 16 divisions whose activities ranged from computer science to engineering standards.

In 1968, the four NBS divisions concerned with the theory and application of ionizing radiation were formed into a Center for Radiation Research, with Carl O. Muehlhause as Acting Director. By 1971, the Center had been incorporated into the Institute for Basic Standards.

The Office of the Associate Director for Administration was supervised by Robert S. Walleigh. This group provided accounting, personnel, supply and other Bureau-wide services to the staff.

Nearly all of the permanent Bureau staff—and most of the part-timers—worked in one or another of these five major units.

The institute and center directors were "... responsible for the development and direction of research programs and central national services essential to the fulfillment of a broad segment of the Bureau's mission."[56] They also provided general supervision to the division chiefs, as well as guidance on overall space and financial matters. Although final Bureau management authority resided in the five units identified above, the division management level still provided the backbone of the Bureau's scientific

[55] *1968 Technical Highlights of the National Bureau of Standards: Annual Report, Fiscal Year 1968,* Natl. Bur. Stand. (U.S.) Special Publication 308, November 1968.

[56] *1964 Technical Highlights of the National Bureau of Standards: Annual Report, Fiscal Year 1964,* Natl. Bur. Stand. (U.S.) Miscellaneous Publication 264, December 1964.

and technical effort. Day-to-day direction of the staff, equipment and space needs of individual scientists, and the first level of personnel evaluation and counseling took place within the divisions.

"Matrix Management" Comes to the Bureau

Since 1904 the Bureau had utilized the principles of sharing project responsibility among its technical units. A major fire that year in Baltimore, followed by a smaller one on the grounds of NBS itself, showed an abysmal lack of standardization in the firefighting apparatus of the Nation.[57] Called upon to improve the situation, staff members throughout the Bureau contributed to the design of standard hose connectors and other equipment items and to the education of firefighters regarding their use. Because of the continuing national need for fire research, the fire program of the Bureau continued to flourish to the present day.

With the creation of programs in Standard Reference Data and Standard Reference Materials in the mid-1960s, cooperation across the boundaries of technical division lines became more formalized, leading to a new type of management. In both the SRD and the SRM programs, the managers directly supervised small staffs to "market the product"—standard data and standard samples, respectively. The actual generation of the "product" was mostly in the hands of scientists located elsewhere in the NBS organization or, occasionally, outside NBS altogether. Encouragement (and frequently, money) provided the incentive that caused the desired work to be accomplished.

The inauguration of an administration-wide initiative on *Program Planning and Budgeting* during Lyndon Johnson's presidency provided a surge of effort throughout the Federal government to understand and apply the idea of program-based management interlocking with a discipline-based staff.

The system whereby a given employee might owe allegiance to, say, the Analytical Chemistry Division and simultaneously participate as a member of a Standard Reference Data project came to be known as "matrix management." In one form or another it was in use for decades; during the 1960s and 1970s use of the name became more prevalent.[58]

To the analytical minds of NBS managers, the name matrix management was well-chosen because of its similarity to the mathematical matrix, which is composed of rows and columns. Individual rows of the management matrix, for example, might each denote a technical division within NBS and individual columns might define program responsibilities for particular members of that division. A given column could be identified, say, as the Office of Standard Reference Data; a checkmark at the intersection of the OSRD column and a particular division's row would indicate that one or more of the division staff contributed to the work of the OSRD, either "for free" or as a grantee. Such a matrix management diagram was useful mainly as a tracking device, showing the reach of particular programs across Bureau disciplinary lines.

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[57] MFP, p. 82.

[58] See, for example, Kenneth Knight, editor, *Matrix Management* (New York: PBI-Petrocelli Books, 1977).

In most cases, the "program" or "office" involved in matrix management included no laboratory space, but only a responsibility to produce certain results on behalf of an outside organization or a congressional mandate. Sometimes "program" results were simply accounts of work done in pursuit of a division goal that happily fit into the program's objective. In other cases, the program manager, by the judicious insertion of money into one or more of the laboratory units, could focus a division's technical work on a desired program objective. This type of administrative work demanded a nice mix of technical ability and administrative cooperation.[59]

The Standard Reference Data program, under Edward Brady, and the Standard Reference Materials program, under W. Wayne Meinke, were two of the major managed programs at NBS in 1968. Many other such programs followed, as we shall see.

The matrix management system, whenever it involved funds from other government agencies or from organizations outside the government, could provide needed financial support beyond that available directly from the NBS congressional appropriation, and *ipso facto* could show the relevance of Bureau work to the collaborating organization. Both of these characteristics were good, but the level of such funding often was subject to change without notice, which was bad. Bureau managers were often hard-pressed to avoid staff disruption resulting from rapidly varying funding levels.

Equal Employment Opportunity

From earliest times, employment at NBS was not governed by distinctions based upon race, gender, or other incidentals. The natural tendency of Bureau technical managers was to hire the best person available for a given position so as to produce the best possible results. The unintended result of this tendency was to perpetuate the *status quo.* In 1964, passage of the Civil Rights Act, which mandated the formation of an Equal Employment Opportunity structure, impacted Bureau hiring policies as it did in nearly all Federal agencies.

The first formal steps toward an EEO structure were taken in 1965 by Director Allen Astin, with a plan for a two-person NBS Equal Employment Office and specific attention to the hiring, training, and promotion of minorities.[60] In 1968 Astin ordered the formation, within the Personnel Division, of an advisory committee to review progress in hiring minorities.[61] The committee, consisting of Donald G. Fletcher, Karl E. Bell, and Robert F. Bain, was to receive any complaints of incidents of discrimination occurring on the Bureau grounds.

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[59] H. Steffen Peiser recalls a suggestion by Irl C. Schoonover, then Deputy Director of NBS, that the sole function of program managers be the awarding of funds, with no project management to be exercised.

[60] Memorandum to Secretary of Commerce John T. Connor from A.V. Astin, "NBS plan for expanding equal employment opportunities," December 15, 1965. (NIST RHA, Director's Office, Box 381, Folder Nov. 1–Dec. 31, 1965.)

[61] Memorandum from Director Astin to NBS Deputy Director; Associate Director for Administration; Institute Directors; Director, Center for Radiation Research; and Division Chiefs, "Reaffirmation of Equal Employment Opportunity Policy and Practices," May 16, 1968. (NIST RHA, Director's Office, Box 386, Folder Chrono File May 1–June 30 1968.)

In that same year, Astin and his peer at the National Institutes of Health, James A. Shannon, advised the Montgomery County, Maryland, County Council of their desire to see a positive stance on equal access to county housing. The Council quickly responded by enacting a Public Accommodations Ordinance forbidding discrimination in housing and public places. A Montgomery County Commission on Human Relations was created to deal with complaints of discrimination in the community.[62]

One of Astin's last acts as Director was to refine the Bureau's EEO system. The EEO Committee was expanded to nine members selected from divisions throughout NBS: Harvey E. McCoy, Nina Knight, and Charles W. Anderson (Administrative Services Division); Avery T. Horton (Inorganic Materials Division); Donald G. Fletcher (Product Evaluation Division); Jon T. Hougen (Atomic Physics Division); Elizabeth L. Tate (Library Division); Karl E. Bell (Personnel Division); and Joyce J. Grimes (Physical Chemistry Division).

At the same time, an Affirmative Action Plan was developed for the Bureau. This plan identified recruitment, training, publicity, and incentive awards as areas where NBS could improve its utilization of minority employees. In addition to the committee and the plan, a new Civil Service program for the resolution of grievances was adopted by the Bureau.[63]

Avery Horton, named Chairman of the EEO Committee, took his committee responsibilities seriously. A chemist with an active interest in the properties of crystals,[64] he nevertheless spent considerable time in an effort to ensure fair treatment for minorities, both in the Bureau and in the community. At one point, distressed by the refusal of a local barber to cut his hair, Horton filed and won a discrimination lawsuit against him. This suit helped to end the segregation of commercial public facilities in Montgomery County.[65]

Part-Time Employees, Guest Workers and Visitors

In addition to the full-time staff members at NBS in 1968, there were 353 part-time, summer,[66] Youth Opportunity Corps, intermittent, and temporary workers. In addition, 147 research associates and guest workers, including many from foreign countries, were part of the Bureau staff. The research associates represented 31 different organizations—trade associations and individual firms—whose activities involved measurements and standards at a level where they needed to have one or more people working at NBS.

[62] Memorandum to All Employees from A. V. Astin, "Equal Opportunity," July 12, 1968 (NIST RHA), Director's Office, Box 386, Folder Chrono File 7-1-68–8-31-68.

[63] "NBS Moves to Insure Equal Opportunity For All Employees," NBS Standard, June 1969, p 1.

[64] See, for example, R. Brooks, A. T. Horton, and J. L. Torgesen, "Occlusion of mother liquor in solution-growth crystals," *J. Crystal Growth 2*, pp. 279-283 (1968).

[65] Karl E. Bell recollects that Horton and the barber eventually became friendly to the extent that Horton, an amateur cabinetmaker, refurbished the man's barbershop.

[66] For a personal insight into the summer-student program, see "NBS Summer Programs," *NBS Standard*, Vol XV, No. 9, September, 1970, pp. 7-8.

The Bureau had actively welcomed visits from foreign scientists and engineers for many years. Most of these visitors came from other national standards laboratories or from international agencies with strong interests in standards, such as the International Bureau of Weights and Measures, the United Nations, the North Atlantic Treaty Organization, the International Atomic Energy Agency, and the International Standards Organization. Visitors from countries whose standards programs were still developing often came with the dual objectives of studying the NBS organization and management techniques and of participating in scientific projects; among other countries, Mexico, Iran, South Korea, Saudi Arabia, and Taiwan sent this type of visitor. Visitors from countries with advanced efforts in metrology usually came as full partners in continuing research programs. During 1968 some 700 foreign scientists visited NBS; 24 other foreign scientists representing 16 different countries had guest status.[67]

Post-Doctoral Research Associates

Included in the full-time-permanent category in 1968 were 42 postdoctoral research associates assigned to the Bureau through a joint program of the National Research Council, the National Academy of Sciences, and the National Academy of Engineering. In part, the selection process included approval by the potential mentor of a plan for a scientific or engineering project to be accomplished at NBS. Each of the successful candidates received an opportunity to work at NBS with a world leader in metrological science. But the Bureau received enormous benefits as well; the influx of vigorous young scientists, trained in up-to-the-minute scientific methods in the Nation's best graduate schools, brought a flood of new ideas and techniques that permeated the NBS laboratories. The program was important, too, because it provided an opportunity for NBS managers to appraise in detail the quality of potential future staff members.[68]

In the following paragraphs, we list the names of the 1968 postdoctoral associates, officially called "NRC-NBS Postdoctoral Research Associateships recommended by the NAS-NRC." We list as well their graduate schools and (in parentheses) their NBS mentors:

- Donald W. Alderman, Cornell University (Robert J. Mahler, head of solid state electronics in the Radio Standards Physics Division in Boulder).
- Michael J. Bielefeld, University of Pennsylvania (Jon J. Spijkerman, Analytical Chemistry Division).
- Edith F. Borie, University of North Carolina (Leonard C. Maximon, Radiation Theory group, Center for Radiation Research).

[67] Ronald B. Johnson, Executive Officer for the Institute for Materials Research during that period, kindly points out that the term "Guest Researchers" was much preferred by many visiting scientists over the less-elegant "Guest Worker" title commonly used in Bureau personnel reports.

[68] An informative account of the the origin and early history of the postdoctoral program at NBS is given by Joseph Hilsenrath, "The National Academy of Sciences-National Research Council's Postdoctoral Research Associateship Program," NBS/GCR-85/500, September 1985.

- Arnold M. Denenstein, University of Pennsylvania (Chester H. Page, chief of the Electricity Division).
- Gabriel L. Epstein, University of California, Berkeley (Joseph Reader, Atomic Physics Division).
- Benjamin Gibson, Stanford University (Michael Danos, Radiation Theory group, Center for Radiation Research).
- Roger A. Hegstrom, Harvard University (Jon H. Shirley, Time and Frequency Division, Boulder, and Richard P. Reed, Cryogenics Division, Boulder).
- John W. Knoeck, Iowa State University (John K. Taylor, head of microchemical analysis in the Analytical Chemistry Division).
- Hassell M. Ledbetter, University of Illinois (Richard P. Reed, Cryogenics Division, Boulder).
- William R. Ott, University of Pittsburgh (Wolfgang L. Wiese, head of plasma spectroscopy in the Atomic Physics Division).
- Stephen J. Pierce, University of California, Santa Barbara (Morris Newman, head of numerical analysis in the Applied Mathematics Division).
- LeRoy W. Schroeder, Northwestern University (John J. Rush, Reactor Radiation Division).
- Stuart K. Searles, University of Alberta, Canada (Pierre J. Ausloos, head of radiation chemistry in the Physical Chemistry Division).
- Stanley E. Stokowski, Stanford University (Ludwig H. Grabner, Inorganic Materials Division).
- Donald D. Thornton, Syracuse University (Billy W. Mangum, Heat Division).
- Edward F. Zalewski, University of Chicago (Richard A. Keller, Physical Chemistry Division).

Of the 1968 postdoctoral group, Ledbetter, Ott, Schroeder, and Zalewski (one-fourth of the group) became permanent Bureau researchers.

From the beginning of the postdoctoral program in 1955 until 1969 there were a total of 173 of these awards. Alumni of the program were prominent among NBS leaders in scientific and management programs at NBS. Names of subsequent postdoctoral research associates are listed in Appendix F.

Professional Advancement, Education, and Awards

From the time of its move to Connecticut Avenue, NBS possessed some of the characteristics of a technical university. Many Bureau scientists and engineers were motivated to give extra effort as much by the desire to learn as by the desire to take home an extra-large paycheck. In areas of front-line research, NBS staff members and their university colleagues enjoyed very close professional relationships, belonging to the same organizations, attending the same conferences, publishing in the same journals and competing for the same types of professional recognition. In addition, there was a steady flow of teacher-student interactions among the technical staff of the Bureau, both in Boulder and Gaithersburg.

In 1968, the NBS Graduate School program was already in its 60th year; four new diplomas were added that year to the 344 graduate degrees awarded to Bureau staff members since its inception.[69]

Staff development was not limited to graduate-level training, however. Educational programs were also in place for more than 600 undergraduates, technicians, secretaries, and other non-technical staff, fulfilling the twin goals of keeping up with current technology and providing Bureau employees with an avenue for personal advancement. Instruction, often by outside consultants, was available both on-site and in conjunction with local schools, not only for the Gaithersburg facility but also for Boulder personnel.

Most of the technical divisions scheduled periodic seminars, colloquia, or staff meetings—often on a weekly basis—on subjects related to division projects. These technical meetings, held in small conference rooms maintained in the Administration building and in each of the technical buildings, generally were led by local staff or by visiting experts. Advertised on local technical bulletin boards, they usually attracted interested participants from outside the Bureau—other government scientists, professors from area universities, visitors from far-off places, and, increasingly, personnel from small-scale, high-technology industries developing on the "doorstep" of NBS.

Technical meetings provided a good mechanism whereby new projects could be explored, current ones could be exposed to scrutiny by peers, and completed work could be publicized. In addition, frequent lectures were offered in the major auditoriums. The "Red" auditorium, seating about 700, and the "Green" auditorium, seating about half that number, were the largest Gaithersburg halls, while the Radio Building Auditorium hosted the largest meetings at the Boulder site. These lectures provided large technical audiences—from NBS and elsewhere—with talks of general interest.

High-quality work by the staff of the NBS was recognized every year by awards from outside groups, from the Federal government and from the Bureau itself. More than 30 NBS staff members were recognized in 1968 by external professional groups, including the following:

- Samuel N. Alexander, the Harry Good Memorial Award of the American Federation of Information Processing Societies.
- Melvin R. Meyerson, the George Kimball Burgess Award of the Washington Section of the American Society for Metals.
- Robert D. Stiehler, Award of Merit of the American Society for Testing and Materials.

[69] *1968 Technical Highlights of the National Bureau of Standards: Annual Report, Fiscal Year 1968,* NBS Special Publication 308, November 1968.

- Allen V. Astin, the Commendation Plaque of the National Conference on Weights and Measures, and the Distinguished Alumni Award of the University of Utah Alumni Association.
- F. Cecil Brenner, the Notable Services Award of the Apparel Research Foundation.
- Lewis M. Branscomb, the Career Service Award of the National Civil Service League.
- Robert D. Cutkosky, the Scientific Achievement Award of the Washington Academy of Sciences.
- Jon T. Hougen, the Coblentz Society Award.
- Malcolm W. Jensen, the Commendation Plaque of the National Conference on Weights and Measures.
- W. Wayne Meinke, the American Nuclear Society 1968 Special Award for Industrial Applications of Radiation Techniques.
- Morgan L. Williams, the Bissell Award of the Washington Section of the American Welding Society.

In 1968 the Department of Commerce honored eight Bureau staff members with the Department of Commerce Exceptional Service Award (the "Gold Medal"). Those honored were:

- Louis Costrell, for radiation physics instrumentation.
- Henry J. Kostkowski, for radiation thermometry.
- Lawrence M. Kushner, for research management.
- David R. Lide, Jr., for molecular structure studies.
- Kurt E. Shuler, for chemical physics.
- Carl O. Muehlhause, Harry H. Landon, Jr., and Robert S. Carter, a group award for nuclear radiation research.

The Department of Commerce also awarded silver medals for Meritorious Service to:

- David W. Allan, for atomic frequency and time standards.
- Clarence N. Coates, Jr., for legislative programs.
- William C. Cullen, for materials durability studies.
- John R. Cuthill, for alloy physics.
- James R. DeVoe, for radiochemical analysis techniques.
- Samuel B. Garfinkel, for radioactivity standards.
- Kurt F. J. Heinrich, for x-ray spectrometry.

- Frank L. McCrackin, for ellipsometry studies.
- Harvey Marshak, for low-temperature nuclear orientation.
- William C. Martin, Jr., for atomic spectroscopy.
- Hans J. Oser, for studies in systems dynamics.
- James F. Schooley, for superconductivity.
- W. Reeves Tilley, for technical communication.
- William W. Walton, for building research.
- Andrew W. Weiss, for plasma spectroscopy.
- Harold F. Wollin, for weights and measures.
- William R. Shields and Thomas J. Murphy, a group award for studies in analytical mass spectrometry.

Department of Commerce Superior Service (Bronze Medal) Awards went to 12 Bureau members:

- Richard M. David, for radiation chemistry.
- Herbert H. Garing, for instrument construction.
- Elizabeth L. M. Henley, for administrative systems.
- Albert E. Ledford, Jr., for molecular energy level work.
- Katherine S. Lunsford and Minnie R. Massie, a group award for thermometry calibration.
- Cornelius H. Pearson, for thermophysical properties.
- Ruth L. Peterson, for spectroscopy.
- Marion S. Roberts, for employee development techniques.
- Wilbert F. Snyder, for radio standards engineering.
- Earl S. Williams, for electrical instrumentation.

The Bureau itself that year presented the Eugene C. Crittenden Award to eight staff members for superior performance by support personnel:

- James Hester, for electrical services.
- John Hydro, Jr., for glassblowing.
- Harman L. Lantz, for floor care.
- Grace S. Lederer, for procurement services.
- Susan B. Mayers, for cleaning services.
- John L. Michalak, for structural testing.
- Arthur Pittman, Jr., for payroll services.
- Lawrence Schneider, for precision instruments.

The 1968 NBS Samuel Wesley Stratton Award was given to David R. Lide, Jr. for his outstanding work in the field of microwave spectroscopy.

The Edward Bennett Rosa Award, recognizing outstanding achievement in the development of standards of practice in the measurement area, was presented to W. Wayne Meinke for his efforts with the Standard Reference Materials program.

In Appendix G we list the recipients of major awards given from 1968-1993 by the Department of Commerce and by NBS/NIST.

Cash awards, grade-level promotions or certificates for outstanding work were presented to other high-achieving employees by most NBS divisions.

Mens Sana in Corpore Sano

The history of recreational activities at the Bureau has long been closely intertwined with the history of the Standards Employees Benefit Association (SEBA). Perhaps the first participation in organized sports at NBS was the Interdepartmental Tennis League; tennis teams from the Bureau competed with other agency teams as early as the 1920s. Eventually, SEBA sponsored many intramural activities for Gaithersburg employees, including the following:

- Chorus.
- Slow-pitch softball.
- Fast-pitch softball.
- Women's softball.
- Football.
- Golf.
- Tennis.
- Basketball.
- Bowling.

The Gaithersburg site also saw considerable noon-time and after-hours intramural and extramural athletics, including volleyball, basketball, softball, bicycling, and jogging.

Recreational activities for the Boulder employees of NBS were substantially less well-organized, but no less enthusiastic. The Boulder Laboratories Employee Association (BLEA) occasionally sponsored picnics, softball, and other group events; however, most sports and other hobbies were organized informally.

According to the recollection of Robert A. Kamper, cycling, running, hiking, fishing, rock and mountain climbing, and skiing in the nearby mountains attracted many of the Boulder staff. It was not unusual for Bureau individuals or groups to "take to the hills" for a day's recreation in any manner favored by the weather. Kamper also recalled a period of time during the early 1970s when musicians from the Bureau joined in annual treks up the mountain with symphonic instruments to perform in the Altissimo Music Festival—a fine combination of art and athletics.

During the early 1990s, James D. Siegwarth and B. James Filla, assisting paleontologist Robert Bakker in his search for the remains of dinosaurs, discovered a previously unknown species. Professor Bakker named the species Nisti, in honor of his volunteer colleagues, thus gaining for the Boulder laboratory the distinction of being the only Federal agency with a dinosaur named for it.

Advisory Committees

Following the practice introduced at its founding (Sect. 1.3), NBS programs and equipment were monitored annually by a Visiting Committee of outside technical experts appointed by the Secretary of Commerce. The Secretary often sought the advice of the senior Bureau management on new appointments to the Visiting Committee. Over the years, the Visiting Committee was a strong advocate for the NBS/NIST programs as well as a critical observer of the state of Bureau facilities, equipment, and output. Its reports offered strong encouragement to the Department to shore up weaknesses or to enter new areas of research. The membership of this important group is given in Appendix H.

In 1968 the Visiting Committee was chaired by Robert Sproull, Vice President of the University of Rochester. Other members of the committee included Norman Ramsey, Professor of physics at Harvard University; Emanuel R. Piore, Vice President and Chief Scientist of IBM Corp; Elmer W. Engstrom, President of RCA; and Paul C. Cross, President of the Mellon Institute.

In addition to the NBS Visiting Committee, technical evaluation panels annually reviewed the work of many technical divisions of NBS from 1959. The President of the National Academy of Sciences appointed members of the panels that advised the divisions of the Bureau's Institute for Materials Research and the Institute for Basic Standards. Similarly, the President of the National Academy of Engineering appointed panels for the divisions of the Institute for Applied Technology. The committees prepared formal reports for the use of the National Research Council, but perhaps more important was the guidance that they gave informally to the division leadership.

Budget

The NBS budget often resembled the heroine in the serial thriller "The Perils of Pauline." The draft of the budget document, with its carefully drawn plans and requests for their support, lurched from crisis to crisis, with painful injury or death imminent from moment to moment. This resemblance was particularly apt in 1968, when Congressman John J. Rooney of New York served as Chairman of the Subcommittee on Departments of State, Justice, and Commerce, The Judiciary, and Related Agencies Appropriations, a unit of the House Committee on Appropriations. Mr. Rooney's subcommittee held annual hearings on the NBS budget, and there was no doubt who was in charge. For the entire duration of his chairmanship, 1963 to 1974, the appropriations hearings featured a running Rooney-against-the-bureaucrats sideshow that makes fascinating reading but could only have been a nightmare for NBS management.[70]

[70] The text of the hearings is contained in bound records published by the U.S. Government Printing Office.

The difficulties that NBS encountered in balancing its commitments against its budget, like the budgetary problems of many another federal agency, arose from the dichotomy that is characteristic of the U.S. Congress: Congressional authorization *vs* Congressional appropriation.

Continuing oversight of NBS programs resided in 1968 in the House Committee on Science and Astronautics and its Subcommittee on Science, Research, and Development, along with its Senate counterpart, the Senate Commerce Committee and its Subcommittee on Science and Technology. Most of the assignments given to the Bureau by Congress originated in these subcommittees, whose members were generally familiar with its staff and the capabilities of the agency. The members of these subcommittees were, in general, supportive of NBS. They felt that the Bureau gave good value for the Congressional dollar, and they were willing to entrust new projects to it through the authorization process.

Once a particular project was outlined by the authorizing committees for NBS, however, the House Appropriations Committee could decide whether the proposed project was worthy of funding to pay for personnel, facilities, and operations needed to execute it. The wherewithal to perform either existing or new projects at the Bureau necessarily came from the House Committee on Appropriations, Subcommittee on Departments of State, Justice, and Commerce. Not infrequently, the authorizing committee and the appropriations committee did not see eye to eye on the necessity of a given task or on the suitability of NBS to perform it, let alone its proper funding level. Thence came trouble, with the Bureau cast in the hapless role of the shuttlecock in a game of Congressional badminton.

A typical NBS budget document began life at least one year before funds were expected from it. Its beginning was generally peaceful and straightforward, as befitted the nature of its scientific authors: plans were laid for continuing and new projects, based upon technological needs or scientific opportunities as foreseen by NBS in consultation with the Congressional oversight committee; justifications were written for any foreseeable changes necessary in Bureau space, personnel, or operational costs to accomplish them; and prospective sources were identified for funding—typically Congressional appropriations, other Federal agency funds, calibration fees, or sales of standard reference materials.

Aggregation of these ideas from throughout the Bureau resulted in the preparation of the first draft of a budget document. The document generally incorporated requests arising from arcane scientific projects—in 1968, such a project involved collecting data on the energy content and behavior of nuclear particles—side by side with requests arising from the most practical technical needs, exemplified in 1968 by NBS participation in technical committees of the American Standards Association.[71]

The basic budget document then entered the first phase of its perilous journey to reality—examination by the Department of Commerce, where fiscal and political pressures of a type unknown within NBS made all the difference. Endowed with different

[71] Now known as the American National Standards Institute.

viewpoints, with substantially different training, and with stimuli markedly different from those felt by the originators of the budget draft, the DoC examiners typically added to and subtracted from the document until it reflected an entity that they could vigorously defend in the dangerous second phase—review by the Bureau of the Budget (later known as the Office of Management and Budget).

In the BoB review, other pressures—frequently a desire to restrain spending throughout the Executive Branch—and different politics came into play, resulting in a new draft that all too often only vaguely resembled the original budget document. On the bright side, this budget, once prepared, generally was supported by *the President of the United States.*

The greatest peril to the document usually—but by no means always—occurred during the hearings of the House Appropriations subcommittee that enjoyed jurisdiction over the Bureau's finances. The scientific content of the budget draft often faded into insignificance in comparison with wrangling over issues totally unrelated to NBS activities. Logic became twisted or, not infrequently, abandoned completely. Political motives usually dictated the fate of portions of the document. In the meantime, other Federal agencies were learning of their own budgetary destinies, which in turn might determine whether they could participate financially in planned cooperative projects with NBS staff members.

Finally, a joint conference of House and Senate members could further adjust the NBS budget. The result of this lengthy process was that the President often signed a budget document for the Bureau that was barely recognizable as the offspring of the original draft.

Not uncommon was a disappointing situation wherein no budget at all was passed, months after the beginning of a new fiscal year. In these cases the process had broken down, with Congress so involved with other activities that it did not complete one of its most basic tasks. The usual solution in that case was known as a "Continuing Resolution," which could be translated roughly by the instruction "Do what you did last year at the same (or a lower) level of spending."[72] In this event, of course, the NBS leadership had to make educated guesses as to what should be done about very desirable new projects or tasks that Congress had ordered NBS to perform. During "continuing resolution" years, Congressionally requested projects usually were undertaken by reassigning existing staff, space and equipment. New projects proposed by NBS usually were deferred.

During any budget cycle, it was not unusual for a congressional authorizing committee to formally ask ("mandate") the Bureau to perform specific tasks that one or another member deemed desirable at the time.[73] Sometimes the instructions for the

[72] Poor as it was, the continuing-resolution option was preferable to the alternative—temporarily closing the doors of NBS for want of authorization to continue operations.

[73] The Congressional request might have been made of the Secretary of Commerce, asking him to utilize his "scientific resources" for a particular task, an instruction that often resulted in an assignment for NBS.

assigned tasks were included in legislation that was not part of the appropriations process; such legislation may or may not have authorized reimbursement to the Bureau for the costs involved in fulfilling the requested work. Any such "unfunded mandates" usually caused the Bureau management to generate staff, space, and funds for the work by deferring or abandoning other work. Congressionally mandated work at NBS in 1968 included the following:

- In December 1967 the 90th Congress amended Public Law 88-164 (15 U.S.C. 1191; 67 Stat 111), originally passed on June 30, 1953, and known as the *"Flammable Fabrics Act."* The amendment, PL 90-189 (81 Stat 568), authorized the Secretary of Commerce (and thus NBS) to (1) conduct research into the flammability of products, fabrics, and materials; (2) conduct feasibility studies on the reduction of flammability in such items; (3) develop flammability test methods; and (4) offer training on flammability issues. The Act authorized $1.5 million to pay the costs of all its provisions during FY 1968, with $2.25 million authorized in each of the following two years.

- The *Fire Research and Safety Act* of 1968 (PL 90-259, 82 Stat 34, passed in January 1968) amended the Organic Act of NBS to authorize the Bureau to undertake a wide-ranging program in fire research and information dissemination. It authorized $5 million in funding through June 30, 1970.

- The *Standard Reference Data Act* of 1968 (PL 90-396, 82 Stat 339, passed on July 11, 1968) gave the Secretary of Commerce authorization for the "... collection, compilation, critical evaluation, publication, and sale of standard reference data." The sum of $1.86 million was authorized for expenditure on this task through June 30, 1969. Authorization also was given for the recovery of costs through sales of data. The Bureau was permitted to copyright data publications as well; this privilege was unique among Federal agencies. The provisions of this act enlarged and formalized an activity that had been under way for many years in conjunction with the Nation's chemistry, physics, and engineering communities, the Federal Council for Science and Technology, and the President's Science Advisory Committee.[74]

The overall financial support of NBS in 1968 amounted to slightly over $65 million. Of this amount, almost $33 million was appropriated by Congress to fund Bureau operating programs; this sum was augmented by $28.4 million received for work done on behalf of other Federal agencies, for other outside groups, or as payment for calibrations, standard reference materials, or other services. Congress also provided nearly $4 million to be used for plant and facilities support and for new construction.[75] In Appendix I we provide a chronological display of the regular congressional and

[74] The acts containing these mandates are recorded in Appendix A.

[75] *Annual Report for 1968* (NBS Special Publication 308, November 1968) p. 162.

special appropriations for NBS/NIST as well as funds provided by other government agencies for the period 1968-1993.

One can only hope that the eventual funding level of Bureau requests for support from Congress rested upon firmer ground than is indicated by the 1968 hearings of Congressman Rooney's subcommittee.[76] Mr. Rooney routinely reacted to the very detailed, heavily justified budget request of Director Astin as if Astin were part of a conspiracy to raid the U.S. Treasury for nefarious purposes. Perhaps more aggravating, in frequent side comments Rooney seemed at pains to denigrate the highly trained scientific staff of the Bureau. It has been said that Rooney's comments were intended to portray for his constituents an image of fiscal responsibility on the part of one who controls public purse strings. Nevertheless, one finds these congressional barbs disturbing—in part because they took place in a "game" in which only one team was allowed to "play," but also because of the possibility of real damage to the Nation's scientific enterprise under the pretext of fiscal responsibility.

Publications By NBS Staff

It can be argued that the most important output of many an NBS scientific project was a number—the quantitative result of a careful measurement, expressed in the appropriate unit. The number might describe the frequency of an atomic transition, the temperature of a phase transition, the spacing of a crystalline lattice, or the breaking-strength of an aerospace material, to be compared with measurements made in a similar project elsewhere or to be used in defining a new standard of measurement.

However, the national technical community probably valued most highly—perhaps more than NBS calibration results, *Standard Reference Materials,* or service on technical committees—the publications that described Bureau work. Even when a long-awaited number such as those mentioned above had been communicated by the quickest means available, its significance had to be documented by a carefully recorded exposition of the experimental techniques that produced it, along with its uncertainty. The intention of most Bureau publications was to provide information of such quality that the results described therein could be duplicated elsewhere even if the originating laboratory was destroyed or abandoned. The aim of the Bureau was to make these publications as widely available as the technical public desired.

In 1968 the NBS staff published its scientific and technical results in many different outlets. The effort to communicate the results of the Bureau's research, development, and service work was a vigorous one, producing as many as 1000 items each year. Titles of most of these publications were printed in the *NBS Annual Report* series, prepared for the use of the NBS Visiting Committee and for distribution to the Department of Commerce and other interested parties. Abstracts of publications originating

[76] Hearings Before a Subcommittee, 90th Congress, First Session, Part 3, Department of Commerce.

in 1968-69 were printed in *NBS Special Publication 305, Supplement 1,* issued under the editorial leadership of Betty L. Oberholtzer in December 1970.[77] This series was continued through 1997 with annual or biennial supplements.

Individuals who wished to consult Bureau publications generally had two options: they could subscribe to any of the Bureau periodicals or purchase, from the Government Printing Office, copies of listed Bureau publications; or they could visit one of the many technical libraries that possessed the publications and consult them there. Besides libraries in large cities and at educational institutions, a class of "Depository Libraries" in various states and U.S. possessions routinely received and stored NBS publications. This large network of outlets made the results of Bureau projects available on a wide basis indeed.

Editorial Review

The mechanism for oversight of Bureau publications was modified by Director Astin in 1965. Responsibility for enforcing Bureau policies in its publications was transferred to the Associate Director for Technical Support. Technical review of NBS publications resided in the Washington Editorial Review Board (WERB), which was the oldest committee at the Bureau,[78] and in three Boulder Editorial Review Boards representing the Central Radio Propagation Laboratory; the Radio Standards Laboratory and the Cryogenics Division; and the Laboratory Astrophysics Division.[79]

All publications written by NBS staff members and any publications to be printed on the authority of NBS were reviewed by one or more peers of the author. The usual process involved an *Editorial Record* form which accompanied each manuscript on its way to becoming an NBS publication. The administrative superior of the author was expected to review the draft, often with the assistance of a colleague in the originating

[77] The last comprehensive record of NBS staff publications—referencing all the publications since its founding—was prepared while Edward Condon was the director. NBS Circular 460, published in August 1948, contained a listing of Bureau publications from 1901 to June 30, 1947. Papers published before 1942 were listed by title only; later entries included abstracts.

A supplement to Circular 460 was printed in May 1958—it updated the earlier document with abstracts of papers published from July 1947 through June 1957.

In April 1961 Betty L. Arnold of the Office of Technical Information and Publications edited Miscellaneous Publication 240, "Publications of the National Bureau of Standards, July 1, 1957 to June 30, 1960." For the first time, titles of articles written by NBS staff members for publication in outside journals were included in the listing.

A supplement to MP 240 prepared by Betty L. (Arnold) Oberholtzer was issued in April 1967. It contained abstracts of in-house publications from July 1960 through June 1966 and titles of outside publications from 1960-65.

The Special Publication 305 series was commenced in April 1969, again prepared by Oberholtzer. The initial volume covered the period 1966-67.

As this history was written, the NIST administration contemplated discontinuing the paper catalog in favor of a computerized "on-line" edition.

[78] Personal recollection of W. Reeves Tilley, former chief of the Office of Technical Information and Publications.

[79] Although each of the institute directors was given the authority to create its own editorial review board by NBS Administrative Bulletin 65-24 (superseding NBS Admin. Bull. 63-3), the Washington directors decided to create a single Washington Editorial Review Board with membership from each of the institutes.

section. The chief of the author's division supervised a separate review before sending the approved manuscript to the appropriate ERB for final review and disposition (except that the Laboratory Astrophysics Division ERB conducted its own final review). Occasionally the process was truncated if a particular lower-level reviewer was known to be especially knowledgeable on the topic and thorough in reviewing. The ERB final reviewer, besides judging the technical merit of the draft, also sought to ascertain that no Bureau policies would be violated by the publication.

The Bureau review and publication procedures appeared cumbersome and, to some, even paranoid. However, they served to keep the technical and editorial levels of NBS publications as high as the levels anywhere in science; editors of periodicals, conference proceedings, and books found few outright errors, half-digested ideas, or ambiguous expressions in Bureau writing. The members of the ERBs were among the most experienced of Bureau scientists, whose recommendations could not be taken lightly.

In 1965, the Chairman of WERB was Chester H. Page. Other members were Roger G. Bates, Randall S. Caswell, Vernon Dibeler, Myron G. Domsitz, Churchill Eisenhart, D. McIntyre, Robert D. Elbourn, W. Reeves Tilley, and John E. Carpenter. Carpenter served as Secretary to the Board.

The Chairman of the Central Radio Propagation Laboratory ERB was Douglas D. Crombie. J. Krantz was the Secretary. The membership included Edwin L. Crow, Kenneth Davies, Martin T. Decker, Mark T. Ma, George C. Reid, D.V. Row, James R. Wait, and Bernard Wieder.

David M. Kerns chaired the Radio Standards Laboratory ERB. Members included Vincent D. Arp, Edwin L. Crow, Glenn F. Engen, Thomas N. Gautier Jr., Richard C. Mockler, Robert C. Powell, Balfour B. Stewart, and Robert W. Zimmerer. Ms. Krantz was the Secretary of this board also.

The three-person Laboratory Astrophysics Division ERB was headed by Lewis Branscomb. Peter L. Bender and Sidney Geltman served as members.

By 1968, the Central Radio Propagation Laboratory was no longer part of NBS, having been assigned to the Environmental Science Services Administration. NBS/JILA papers were then monitored by the Laboratory Astrophysics Division ERB, and the Radio Standards Laboratory ERB reviewed all other papers originating in NBS/Boulder.

In 1969 Edward Brady was appointed Chairman of WERB. When asked in 1987 about the usefulness of the ERB system, Brady said:

> I think [the NBS Editorial Review Board] is enormously valuable to the Bureau. To have a peer review inside the Bureau before anything goes out adds another level of technical quality control that has been exceedingly helpful in guaranteeing that the material put out by the Bureau is high quality and not something foolish or something incorrect.[80]

[80] Edward L. Brady, Oral History, August 17, 1987.

NBS Journal of Research

The premier NBS technical periodical in 1968 was the *Journal of Research of the National Bureau of Standards.* It was issued in three parts. *Section A, Physics and Chemistry,* edited by Charles W. Beckett with assistance from Donald D. Wagman and John M. Richardson, was issued bimonthly. *Section B, Mathematical Sciences,* edited by Morris Newman with assistance from Frank W. Olver and John R. Edmonds, and *Section C, Engineering and Instrumentation,* edited by Martin Greenspan with the assistance of G. Franklin Montgomery, R.V. Smith, and A.F. Schmidt, were issued quarterly. Typically, archival descriptions of completed projects, with extended discussions of equipment, procedures, analytical techniques, and significance of the results in the respective fields, made up the majority of papers published in the *Journal of Research.*

Technical News Bulletin

Information concerning Bureau activities in research, development, cooperative projects with other scientific or technical groups, and publication notes was available during 1968 in the *Technical News Bulletin* (TNB). Feature articles in this periodical were selected from a *Summary Technical News Service* prepared specifically for the editors of hundreds of scientific, technical, and trade magazines.[81] They provided information on both the technical nature of the work and its relevance to the public at large.

The TNB was intended for industrial readers working in strongly technical areas. In 1968 this periodical was issued monthly. The Editor was W. Reeves Tilley. William K. Gautier was the Technical Editor, the Managing Editor was Richard W. Seward, and Carla Messina was the Visual Editor.

The January 1968 issue of the TNB, a fairly typical example, contained short articles describing fire safety studies of apartments, the results of an investigation into static fatigue of glass, and the properties of slush hydrogen that were of particular importance to the aerospace industry. It also contained notes on coming technical conferences and a report on the 13th General Conference on Weights and Measures. Other features included standards and calibration news, developments in the National Standard Reference Data and Standard Reference Materials programs, and titles of new NBS publications.

During 1973, Director Richard W. Roberts "restructured" the *Technical News Bulletin,* converting it to a "public relations" document with a new name: *"Dimensions."*

[81] The *Summary Technical News Service* articles were synopses of NBS archival papers. They were prepared in the Office of Technical Information and Publication by physical science editors Sharon L. Butrymowicz, Robert T. Cook, Donal K. Coyle, Jack R. Craddock, Carol R. Naas, Arthur Schach, and Don E. Webb. Circulation of the articles greatly increased public understanding of the work of the Bureau.

Non-Periodical NBS Publications

The Bureau offered nine non-periodical publication outlets in 1968. These outlets and the types of communication intended for publication therein were:

- *NBS Monographs,* " . . . major contributions to the technical literature on various subjects . . . ";
- *NBS Handbooks,* " . . . recommended codes of engineering and industrial practice developed in cooperation with interested industries, professional organizations, and regulatory bodies";
- *NBS Special Publications,* " . . . proceedings of . . . national and international conferences sponsored by NBS, precision measurement and calibration volumes, NBS Research Highlights . . . ";
- *NBS Applied Mathematics Series,* " . . . mathematical tables, manuals, and studies";
- *National Standard Reference Data Series,* " . . . quantitative data on the physical and chemical properties of materials . . . ";
- *NBS Building Science Series,* " . . . research results, test methods, and performance criteria . . . ";
- *NBS Technical Notes,* " . . . communications and reports of limited or transitory interest. Often . . . final reports of work sponsored at NBS by other Government agencies";
- *NBS Product Standards,* " . . . developed cooperatively with interested Government and industry groups, and used voluntarily"; and
- *Federal Information Processing Standards Publications (FIPS),* " . . . the official source of information in the Federal Government regarding (1) uniform Federal information processing standards . . . and (2) data elements and codes standards in data systems . . . "

Publication in Non-NBS Media

Although NBS publications clearly offered a multitude of avenues for the promulgation of results of work by Bureau staff members, there were excellent reasons for publishing certain results in outside journals, in books, or—on rare occasions—in newspapers.

The most cogent reason for publication in an "outside" venue was the desire to reach a specific audience as directly as possible. Thus a discussion of "Tests of the Born approximations: differential and total 2^3S, 2^1P, and 2^1S cross sections for excitation of He by 100 eV to 400 eV electrons," by John Arol Simpson and Stanley R. Mielczarek of the Atomic Physics Division and their colleague L. Vriens, a guest worker from the University of Utrecht in The Netherlands, was published in the journal *Physical Review* because that journal provided a principal forum for atomic physics topics. Similarly, Ernest E. Hughes' description of a simple method for the determination of the absolute concentration of oxygen in the atmosphere was published in the journal *Environmental Science and Technology* in order to reach a high percentage of the environmental scientists who might find such measurements helpful. And a 50-page study of the smoke and gases produced in the burning of materials typically used in aircraft interiors, performed by Daniel Gross, Joseph J. Loftus, Thomas G. Lee, and Vannie E. Gray of the Building Research Division, was published as an individual monograph by the Federal Aviation Agency to expeditiously bring the work to the attention of the air-transportation community.

Conference proceedings, specialized books or book chapters, and voluntary standards publications also were frequent vehicles for the scientific exposition of NBS authors who wanted to reach specific audiences.

In many cases, material written by Bureau authors was requested by outside groups who wished to make use of the expertise of particular NBS staff members. Textbooks, technical encyclopedias, instructional literature, and data compilations—all of these coaxed NBS writing away from NBS-based publications.

Not infrequently, questions of scientific priority led Bureau authors to publish their findings in journals that specialized in rapid communication. *Physical Review Letters, Chemical Physics Letters,* and Nature were examples of such journals. In Appendix J we provide a comprehensive listing of the publications of NBS and NIST.

NBS Technical Work in 1968

The quality of the National Bureau of Standards as an effective technical agency can best be judged by the range and significance of its scientific and engineering work. Here the historian's problem is an oversupply of the fabulous. Development and calibration of ingenious and wonderfully capable tools and standards for measurement; study of light from the stars; heat from the earth; water from ancient ice; transportation; communication; manufacturing; sales; medicine; agriculture; and space travel—all these activities and many others engaged the inquiring minds of NBS scientists and engineers over the years. The challenge for the historian is not that of finding fascinating topics to illustrate the significance of Bureau work, but to refrain from creating an indigestible catalog of scientific and technological exploits.

In the following sections we take a whirlwind tour through the Bureau's technical divisions as they were constituted in 1968. This tour provides an identity for each division, illustrating the type of work in which it was engaged as Director Allen Astin left NBS. The discussion also is meant to help the reader follow the relevance and origins of technical work that will be described in subsequent chapters.[82]

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[82] Most of the information given here was obtained from the NBS Annual Reports, from material provided to the Senate Committee on Commerce at the time of its hearings on the nomination of Lewis Branscomb as NBS Director (Senate Committee on Commerce, *Nominations–1969: Hearings before the Committee on Commerce,* 91st Cong., 1st Sess., Dr. Lewis M. Branscomb, 31 July 1969: pp. 86-93), or from publication records of the period 1965-68.

In 1968, Bureau projects exhibited variety not only in the breadth of the their science and engineering, but in the composition of the work groups that produced them. In many—perhaps most—cases, a project was in the hands of one or two people who patiently pursued a technical goal, sometimes over a period of many years. Other efforts were undertaken by small groups of scientists or engineers, frequently assisted by one or more technicians. A few projects involved large numbers of NBS staff members, sometimes coordinating massive efforts with colleagues scattered throughout the world. Part of the unique nature of the institution resided in the flexibility of its approach to its tasks.

NBS Organizational Charts

There may not exist a governmental agency that does not circulate—at least among its own staff—an *Organizational Chart* showing the relationships that connect its component groups. It is only natural that this should be so, since the chart quickly establishes relative rank and helps to identify responsibilities within the agency. Yet the information conveyed by an organizational chart generally is of the most rudimentary kind—little of the depth of the agency's activities is to be found within a given entry. And seldom is an inkling given of the number of staff members represented by the listed organizational units.

NBS was always a dynamic entity—the more so during times of major change, when whole groups joined or disappeared from the agency. An updated organizational chart was issued at least twice a year, almost always with some changes from the previous edition.

For our technical tour of the Bureau, we utilize the chart issued on June 14, 1968, only months before Allen Astin retired. We here identify only a skeletal portion—approximately 60 organizational units including the division level—of the more complete listing given in Appendix K.

In Appendix K we also provide a chronological progression of the evolving NBS/NIST through 1991 as portrayed by its changing organizational charts.

Office of the Director (Allen V. Astin, Director, NBS).

The Director was responsible for the policies of the Bureau and for the development and execution of its programs. Besides the Deputy Director, Irl C. Schoonover, several other individuals reported directly to Astin. These included an assistant for metric study, Alvin G. McNish; a legal advisor, Allen J. Farrar; a senior research fellow, Churchill Eisenhart; and the heads of the following offices:

Office of Industrial Services (George S. Gordon, Chief).

The OIS examined the need for joint industry-NBS research activities; recommended methods by which NBS research results could best be utilized in industry and commerce; promoted cooperative research with industry for the solution of technical problems; and maintained the Research Associate Program.

The Research Associate Program was by then a 50-year-old Bureau activity. In 1968 it included 61 scientists and engineers. These visitors worked on a full-time basis at NBS on projects of mutual interest to their own organizations—industrial corporations, technical trade associations, professional societies, and other Federal agencies—and the Bureau. The salaries of Research Associates were paid by the sponsoring organizations. The OIS performed an outreach function to encourage and facilitate participation in the program, providing industrial groups with information about NBS and its projects.

Office of Engineering Standards Liaison (A. Allan Bates, Chief).

This office provided administrative liaison between the Bureau and engineering standards bodies, both domestic and international; evaluated Bureau engineering standards activities; and developed policy in this area. In keeping with his responsibilities, Bates published in 1967 a short note on engineering codes for the building industry.[83]

Office of Public Information (A. Victor Gentilini, Chief).

This office prepared press releases for the news media.

Office of Academic Liaison (Shirleigh Silverman, Chief).

The major responsibilities of this office were to keep the academic world and other government agencies aware of the types of work being done at NBS and to facilitate cooperative research with them. In pursuit of these goals, Silverman presented, at a symposium on biological science, a paper on the role of bioengineering in interdisciplinary research.[84]

Office of Program Development and Evaluation (Robert D. Huntoon, Chief).

This office was newly created in 1968 to provide the Director with guidance on programs, including in its recommendations relative priorities and information on the changing needs of U.S. science and industry.

Papers by Huntoon, for the journal *Science*[85] and for the journal *Physics Teacher*[86] provided insightful discussions of the principles of a *National Measurement System* for

[83] A. A. Bates, "Building code viewpoints," *J. Bldg. Res. Inst.* 4, No. 1, 48 (Jan. 1967).

[84] S. Silverman, *Reflections on bioengineering,* Bioengineering—An Engineering View, pp. 103-106 (San Francisco: San Francisco Press, Inc., June 1968).

[85] R. D. Huntoon, "Status of the National Standards for physical measurement," *Science* **150**, No. 3693, 169-178 (Oct. 8, 1965).

[86] R. D. Huntoon, "The basis of our measurement system," *Phys. Teacher* **4**, No. 3, 113-120 (March 1966).

physical quantities and helped define the intent of the new office. The concept of a national measurement system for each of the different measurement units was new at that time, part of an effort originating with Allen Astin to refine and publicize the mission of NBS.

Office of the Deputy Director (Irl C. Schoonover, Deputy Director, NBS)

Apart from providing daily assistance to Director Astin and acting on his behalf when necessary, the Deputy Director also supervised several administrative units. The Office of International Relations, the Office of Technical Information and Publications, the Library Division, the Instrument Shops Division, and the Measurement Engineering Division all reported directly to him.

Office of International Relations (Ladislaus L. Marton, Chief).

The OIR provided services to ease the path to NBS for visitors from other countries, as well as assisting NBS staff traveling abroad. Marton, famous for his scientific work in electron microscopy, not only served as Chief of the OIR in 1968, but he was still publishing technical papers at 67 years of age.[87] Before Astin left office, however, he relieved Marton of his OIR responsibility, replacing him with H. Steffen Peiser. Peiser, born in Europe and educated at Cambridge University in England, was—like Marton—a natural choice to represent NBS to its foreign peers. Besides his cosmopolitan upbringing and a flair for language, he was an expert crystallographer, he had lectured in physics at the university level, and he possessed the virtue of tact in abundance.

Office of Technical Information and Publication (W. Reeves Tilley, Chief).

Tilley supervised a section devoted to the staging of special events for NBS, publications-oriented sections that included editorial, redacting, photographic, and illustration capabilities, and a computer-assisted-printing section. His groups rendered assistance to all Bureau staff members in preparing their work for publication. In addition, they prepared motion pictures on Bureau projects, scheduled tours, interacted with the technical press, arranged conferences, and responded to queries from the public.

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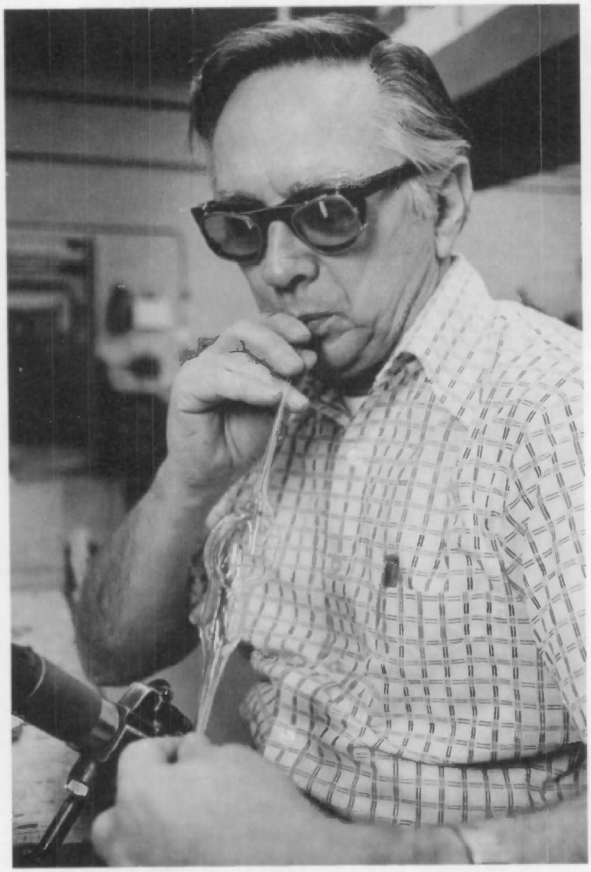
[87] L. Marton, "Progress in electron physics during the last 20 years," pp. 17-25 in Proc. Third Czechoslovak Conf. Electronics and Vacuum Physics, Prague, Czechoslovakia, Sept. 13, 1965 (Czechoslovak Academy of Sciences, Prague, 1967). A biography of Marton was written by Charles Süsskind, "L. L. Marton, 1901-1979," *Advances in Electronics and Electron Physics, Supplement 16,* p. 501 (Academic Press, Inc, 1985). Marton retired from NBS in July, 1970, after 24 years of service to the Bureau. Among his many awards was the Department of Commerce Gold Medal, presented in 1955. Marton was a member of the Royal Society of Belgium, the Graduate Faculty of Maryland, and (during 1962-63) the University of Paris. He was the author of several books on electron physics and microscopy.

Library Division (Elizabeth L. Tate, Chief).

Besides conventional library services, the Library Division provided bibliographic, reference, and translation services, and it served as a focal point for legislative materials and information issued by other Federal agencies.

Instrument Shops Division (Frank P. Brown, Chief).

Staffed by experienced machinists, draftsmen, and other shops experts, the Instrument Shops designed, constructed, and repaired high-precision instruments and auxiliary equipment for the use of Bureau scientists.



Allan M. Houck worked in the National Bureau of Standards instrument shops for over two decades. Most of those years were spent in the glassblowing shop where Houck was called on by Bureau scientists to manufacture custom glassware to very close tolerances.

Butch Robinson, mechanic in the National Bureau of Standards instrument shops, selected an arbor and a collet from the shops' instrument crib for use in fabricating one-of-a-kind scientific apparatus.

This group was mirrored by a shops division at the Boulder site.

Measurement Engineering Division (G. Franklin Montgomery, Chief).

The MED provided consultations in the area of measurement technology, including electronics, optics, thermometry, and mechanical systems.

Office of the Associate Director for Administration (Robert S. Walleigh, Associate Director for Administration).

In 1964 the Associate Director for Administration had been given new and manifold responsibilities, all dedicated to the objective of keeping the Bureau running smoothly. Walleigh managed the NBS buildings, plants, and other non-scientific facilities, in addition to supervising several administrative functions. The effectiveness of Walleigh as an administrator had led Astin to entrust him with the management of this large and complex domain.

Patent Advisor (David Robbins).

David Robbins provided assistance with patent searches, advice on patent-related record-keeping, and information on disclosure processes for the NBS staff. He also provided similar assistance to other Commerce employees. In addition to these activities, Robbins recently had prepared a note on a semi-automatic editing machine.[88]

Accounting Division (James P. Menzer, Chief).

This division housed the central NBS fiscal records. It also was the focus of the Bureau's accounting activities—billing, payments, test administration, and financial reports.

Administrative Services Division (George W. Knox, Chief).

George Knox supervised the distribution of Bureau mail, janitorial services, the guard force, safety, emergency planning, transportation, and special services such as the maintenance of the Bureau's lecture rooms and lecture equipment. It also maintained an NBS records holding area.

Budget Division (James E. Skillington, Jr., Chief).

Skillington advised NBS managers on the preparation, review, and presentation of the budget. He was responsible for maintaining fiscal balance between income and expenses for all NBS programs.

Personnel Division (George R. Porter, Chief).

The Personnel Division was the center for recruitment, placement, and classification of employees, as well as employee development. It also provided the focus for employment policies such as evaluation and promotion criteria.

Plant Division (Hylton Graham, Chief).

Personnel of this division repaired and improved the buildings and grounds at the Gaithersburg site and served as a focal point for similar work at other NBS locations.

Supply Division (George B. Kefover, Chief).

George Kefover had supervisory responsibility for property records and procurement and acted as the contracting officer for the Bureau.

Management & Organization Division (John T. Hall, Chief).

John Hall was responsible for maintaining management policies, for employee training and development, for preparing and circulating management announcements, and for creating management records and forms.

[88] D. Robbins, editor, *Disclosure on: Autoeditor—a semi-automatic copy-editing apparatus*, NBS Technical Note 440, April 1968.

Institute for Basic Standards (Ernest Ambler, an expert in cryogenic physics, was newly appointed in 1968 as Director, IBS).

The main responsibility of the IBS was to provide a central national basis for a complete system of physical measurements, internally consistent and in harmony with international standards. A second task was to develop, maintain, and disseminate standards to facilitate measurement of physical quantities in America's technical activities. The IBS also was called to provide measurements of critically needed physical properties.

The measurement of physical quantities was an important and continuing preoccupation Standards. The concerns of this Institute included development and maintenance of standard units of measurement[89] as well as the application of these standards to particular problems of technical importance. In this section we provide a few examples to characterize the efforts of the IBS.

Henry L. Mason, internationally renowned for his research on the application of computer technology to scientific problems, filled the post of *Coordinator for Measurement Services* until the fall of 1968. Mason reviewed the work of IBS calibration services, focusing especially on the quality of the data analysis that supported the various services. He acted as a point of contact between calibration personnel and NBS statisticians, often helping the services to improve the presentation of their results.

During 1968, an Office of Measurement Services was created within IBS to increase the visibility of the function that Henry Mason had performed. Joseph M. Cameron was appointed Acting Chief. Cameron had received the Department of Commerce Gold Medal Award for Exceptional Service in 1963 for "outstanding success in winning acceptance of statistical engineering as a research tool in physical science and engineering." His interest in that topic had not waned; in 1969 Cameron published a note for the journal *Technometrics* on the role of the statistical consultant in scientific work.[90]

Office of Standard Reference Data (Edward L. Brady, Chief).

The staff of this office coordinated the critical evaluation of the quality of sets of data that were basic to the success of a great variety of national scientific, technical, and engineering projects. In 1968, long-time efforts in this area were formalized by Congress in Public Law 90-396 (82 Stat 339), *The Standard Reference Data Act.* Among the long list of organizations cooperating with NBS on this project were the Chemical Abstracts Service of the American Chemical Society, the American Institute of Physics, the Engineers Joint Council, the Atomic Energy Commission, the Department of Defense, and the National Aeronautics and Space Administration.

[89] These standards were embodied in the International System of Units (SI), defined by the 11th and the 12th General Conferences on Weights and Measures in Paris.

[90] J. M. Cameron, "The statistical consultant in a scientific laboratory," *Technometrics* **11**, No. 2, 247 (1969).

The relatively small staff of the OSRD included: Stephen A. Rossmassler, whose responsibility lay in the area of atomic and molecular data; Lewis H. Gevantman, chemical kinetics and mechanical properties; Howard J. White, Jr., colloid and surface chemistry, thermodynamics, and transport data; Herman M. Weisman, information services; Joseph Hilsenrath, design of information systems; and David T. Goldman, nuclear data. Their efforts were multiplied many times over by assistance from NBS experts and from other technical organizations.

After completion of baccalaureate and masters degrees in chemistry at the University of California at Los Angeles, Brady joined one of the major laboratories of the atomic bomb project at the University of Chicago in 1942. His war-time work included a stint at the forerunner of the Oak Ridge National Laboratory, where he helped design and operate the first large-scale high-level-radioactivity facilities for the U.S. nuclear program. Following World War II, he completed doctoral studies in nuclear physics at the Massachusetts Institute of Technology, then in succession held positions in nuclear science at the *General Electric Knolls Atomic Power Laboratory*, with the *U.S. Atomic Energy Commission*, and with the *General Dynamics Corporation*. When NBS established the *National Standard Reference Data System* in 1963, Brady was recruited to head the program. He retained a personal interest in the NSRDS activity until his death in 1987, although he accepted an appointment as *Associate Director of NBS for International Affairs* in 1978, in which post he was successful in creating agreements with the USSR and China on the exchange of scientific information.

Brady described the work of the NSRDS in an *NBS Technical Note* and for the *Journal of Chemical Documentation.*[91] In the Technical Note, he identified numerous projects supported by the NSRDS, as well as the scientists involved in the research.

Data Needs and Compilations

One example of the types of work done under the NSRDS program was that of gathering information. Herman M. Weisman and his colleague Gerda B. Sherwood used the results of a questionnaire sent by the American Chemical Society to its members, asking about their needs and resources for critically evaluated property data on a variety of materials. Using this information, they prepared a list of data compilations. Some 16,000 replies, analyzed for the NSRDS, revealed a high level of need and, surprisingly, a number of compilation activities previously unknown to the system.[92]

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[91] Edward L. Brady, editor, *STATUS REPORT: National Standard Reference Data System,* NBS Technical Note 448, June 1968. See also E. L. Brady, "The National Standard Reference Data System," *J. Chem. Doc.* 7, No. 1, pp. 6-9 (1967).

[92] H. M. Weisman and G. B. Sherwood, "Annotated accession list of data compilations of the NBS Office of Standard Reference Data," *NBS Technical Note 554,* September, 1970, 196 pp.

An excellent example of the encouragement offered by NSRDS to outside groups to prepare much-needed technical information is provided by *NBS Technical Note 482,* compiled by Ben W. Roberts of the General Electric Research and Development Center in Schenectady, NY.[93] This compilation, based on an earlier effort published in the journal *Progress in Cryogenics,*[94] brought up to date the most important superconductive properties of hundreds of elements, compounds, and alloys. It also included more than 700 references to original data papers, review articles, and books, thus collecting in one handy publication a great deal of information of interest to experimentalists and theoreticians alike.

National Standard Reference Data Series

The initial publications of the NSRDS took the form of *National Standard Reference Data Series* publications, issued serially whenever contributions were ready. One publication in the NSRDS series, Section 2 of NSRDS-NBS 3, prepared by Charlotte E. Moore of the Atomic Physics Division, was devoted to the analysis of optical spectra of Si I.[95] Another contribution, a critical analysis of the literature on the heat capacity of the noble metals and an evaluation of their thermodynamic properties for temperatures between 0 K and 300 K, was prepared by George T. Furukawa, William G. Saba, and Martin L. Reilly of the Heat Division.[96]

A third contribution to the NSRDS series during this period was made by Lester Haar of the Heat Division, who evaluated the thermodynamic functions of ammonia as an ideal gas.[97]

Walter J. Hamer of the Electricity Division prepared NSRDS tables of theoretical activity coefficients for strong electrolytes in water solutions based upon seven different widely used expressions for these coefficients.[98]

Critical Reviews

An 80-page discussion of the excitation of atoms by electron impact was presented by Stephen J. Smith of JILA and his colleague Benjamin L. Moiseiwitsch of the Queen's University of Belfast, Northern Ireland.[99] This critical review was divided into

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[93] B. W. Roberts, *Superconductive Materials and Some of Their Properties,* NBS Technical Note 482, May 1969.

[94] B. W. Roberts, "Superconductive Materials and Some of Their Properties," *Progress in Cryogenics 4,* pp. 160-231 (1964).

[95] Charlotte E. Moore, *Selected Tables of Atomic Spectra: A. Atomic Energy Levels—Second Edition. B. Multiplet Tables: Si I.,* National Standard Reference Data Series-U.S. National Bureau of Standards, NSRDS-NBS 3, Section 2, November 30, 1967.

[96] George T. Furukawa, William G. Saba, and Martin L Reilly, *Critical Analysis of the Heat-Capacity Data of the Lierature and Evaluation of Thermodynamic Properties of Copper, Silver, and Gold from 0 to 300 °K,* NSRDS-NBS 18, April 1968.

[97] Lester Haar, *Thermodynamic Properties of Ammonia as an Ideal Gas,* NSRDS-NBS 10, August 1968.

[98] Walter J. Hamer, *Theoretical Mean Activity Coefficients of Strong Electrolytes in Aqueous Solutios from 0 to 100 °C,* NSRDS-NBS 24 December 1968.

[99] B. L. Moiseiwitsch and S. J. Smith, *Electron Impact Excitation of Atoms,* NSRDS-NBS 25, August 1968.

theoretical discussions of excitations in hydrogen, helium, neon, argon, mercury, the alkali metals, oxygen and nitrogen, followed by an analysis of experimental work on most of the same elements. It contained more than 200 references to original papers and more than 60 tables of data.

Data Centers

David Garvin and Henry M. Rosenstock provided information on data centers for chemical kinetics and mass spectrometry for the *Journal of Chemical Documentation.* In their discussion, they compared the methods of operation of the centers, including the methods of evaluation and retrieval.[100]

Stephen A. Rossmassler described the NSRDS center for atomic and molecular properties for a symposium on the compilation of data on chemical and physical properties.[101]

The NBS Alloy Data Center, formed to stimulate cooperation among groups generating physical-property information on well-characterized alloys and to aggregate the data in one location, was described in some detail by Gesina Carter with the assistance of Lawrence H. Bennett, John R. Cuthill, and Daniel J. Kahan.[102] Not only did the Center utilize an automated retrieval system, but its staff also maintained an up-to-date bibliography.

Handbooks

During 1968 NBS Handbook 101 *OMNITAB, A Computer Program For Statistical and Numerical Analysis* went into its second printing. Originally prepared for the Heat Division by Joseph Hilsenrath, Guy G. Ziegler, Carla G. Messina, Philip J. Walsh, and Robert J. Herbold the handbook described *OMNITAB,* a general-purpose digital computer program that enabled the average scientist to use computers in analyzing data and performing other calculations even though he or she was not familiar with the usual programming languages. The occasion of the second printing was used to make corrections and clarifications in the original text and to add an illustrative appendix by David Hogben. Hilsenrath and Alfred E. Beam, a colleague from the University of Maryland (and a former NBS staff member), published a full description of a multiple-precision version of OMNITAB.[103] The new program, labeled *PRECISE,* mitigated the loss of precision that ordinarily resulted from round-off operations in numerical computing.

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[100] D. Garvin and H. M. Rosenstock, "Two National Bureau of Standards data centers—chemical kinetics and mass spectrometry," *J. Chem. Doc.* **7**, No. 1, 31-34 (Feb. 1967).

[101] S. A. Rossmassler, "The National Standard Reference Data System program in atomic and molecular properties" (Proceedings of a Symposium on Compilations of Data on Chemical and Physical Properties of Substances, 152nd National Meeting, Am. Chem. Soc., New York, NY, Sept. 12, 1966), *J. Chem. Doc.* **7**, No. 1, 15-18, February 1967.

[102] Gesina C. Carter with L. H. Bennett, J. R. Cuthill, and D. J. Kahan, *The NBS Alloy Data Center: Function, Bibliographic System, Related Data Centers, and Reference Books,* NBS Technical Note 464, August 1968.

[103] Alfred E. Beam and Joseph Hilsenrath, *PRECISE: A Multiple Precision Version of Omnitab,* NBS Technical Note 446, June 1968.

Computerized Data Programs

With colleague Robert C. McClenon, Hilsenrath also described a new general-purpose program for manipulating formatted data.[104]

Also described during this period was a group of five utility computer programs written in the Fortran language to make overall changes in existing data sets.[105]

Applied Mathematics Division (Edward W. Cannon, Chief).

The origin of an applied mathematics unit at NBS dated to 1946, when Director Edward Condon hired Churchill Eisenhart, one of the first mathematicians to graduate from Princeton University in the specialty of statistics.[106] Condon realized the value of creating at the Bureau the capability to apply the rigor of statistics to scientific measurements, which generally feature data sets much smaller than were suited to the generation of ordinary statistical manipulations, and he knew from personal experience that Eisenhart shared his view. To create such an applied mathematics group, Eisenhart hired Lola Deming, Helen Herbert, Joseph M. Cameron, and William J. Youden.[107] This group became the nucleus of a Statistical Engineering Laboratory.

In 1963 Eisenhart was appointed Senior Research Fellow and was assigned to the Office of the Director. He retired from NBS in 1983 with many honors for the high quality of his work.

The Applied Mathematics Division staff utilized the methods of mathematics and statistics to assist in the development of new measurement techniques and to evaluate the results of measurement. The staff also performed a variety of other research and service functions.

The work of the division was separated into sections on operations research, led by Alan J. Goldman; statistical engineering, headed by Joseph M. Cameron until he was reassigned to head the Office of Measurement Services, then placed under the leadership of Joan Rosenblatt; numerical analysis, under Morris Newman; and systems dynamics, under the guidance of Hans J. Oser.

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[104] Robert C. McClenon and Joseph Hilsenrath, "A General-Purpose Program for Manipulating Formatted Data Files," *NBS Technical Note 444,* August 1968.

[105] Carla G. Messina and Joseph Hilsenrath, "EDPAC: utility programs for computer-assisted editing, copy-production, and data retrieval," *NBS Technical Note 470,* January 1969.

[106] Ingram Olkin, "A Conversation With Churchill Eisenhart," *Statistical Science,* Vol. 7, No. 4, pp. 512-530 (1992).

[107] The hiring of Youden illustrates a strength of NBS—its attraction as a fine place to work. Eisenhart state in his oral history that he was reluctant to approach Youden, a well-known statistician then employed by Rand Corporation at a salary of perhaps $15,000 per year, about coming to work at the Bureau, where the *Director's* salary was only $9,000. When approached, however, Youden confessed to a long-term desire to be associated with NBS and paid little mind to the pay cut. Youden was a productive applied mathematician at NBS until his death in 1971.

The Statistical Engineering section served an unusual purpose for all the Bureau staff: it offered direct assistance in statistical analysis. Those scientists who needed to evaluate uncertainties of measurement in the preparation of SRMs, those who were assessing the results of fundamental measurements, and other Bureau staff involved in the analysis of data could receive assistance from section personnel in the often-arcane generation of accurate statistical values. Volume 1 of *NBS Special Publication 300,* edited by Harry H. Ku, provided much-valued guidance with sections entitled The Measurement Process, Design of Experiments in Calibration, Interlaboratory Tests, Functional Relationships, and Statistical Treatment of Measurement Data.[108] Certain examples for this text came from actual NBS calibration work.

Information Theory

With the collaboration of S. Kullback of the George Washington University, Ku utilized an information-theory approach to the problem of interaction in multi-dimensional contingency tables, including illustrative examples.[109]

The division staff applied their efforts to problems arising in other government agencies as well as NBS. Division personnel conducted fundamental mathematical research in several areas.

Consumer Trends

In an investigation supported by the Department of Commerce Office of High-Speed Ground Transportation, J. M. McLynn, Alan J. Goldman, Philip R. Meyers, and R. H. Watkins analyzed mathematically how the "market"—a group of consumers—might divide its buying among competing products.[110]

Data Retrieval

An intensive study of the usefulness of multiple-access computer-retrieval methods for searching the scientific citation literature was performed by Franz L. Alt and Russell A. Kirsch.[111] It was hoped that the study, which involved a group of NBS physicists and citations in some 25,000 physics publications, would help to refine such methods in the future.

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[108] "Precision measurement and calibration. Selected papers on statistical concepts and procedures," *NBS Special Publication 300; 1*, H. H. Ku, editor, February 1969, 436 pp.

[109] H. H. Ku and S. Kullback, "Interaction in multidimensional contingency tables; an information theoretic approach," *J. Res. NBS, 72B,* No. 3, 159-199 (1968).

[110] J. M. McLynn, A. J. Goldman, P.R. Meyers, and R. H. Watkins, "Analysis of a market split model," *J. Res. NBS, 72B,* No. 1, pp. 43-60 (1968).

[111] F. L. Alt and R. A. Kirsch, "Citation searching and bibliographic coupling with remote on-line computer access," *J. Res. NBS 72B,* No. 1, pp. 61-78 (1968).

Responsibilities of Other IBS Divisions

Each division of IBS except the Applied Mathematics Division shared a variety of specialized functions. Among these were the following:

- Develop and maintain U.S. standards of physical measurement, including multiples and sub-multiples as appropriate, and develop transfer standards and standard instruments.
- Calibrate instruments in terms of the national standards and provide other needed services to promote the accuracy and uniformity of physical measurements.
- Provide advisory services to other government agencies and to U.S. science and industry on basic measurement problems.
- Correlate with other nations the standards and definitions in measurement science.
- Determine values for relevant fundamental physical constants.
- Conduct experimental and theoretical studies of physical phenomena that might be relevant to the creation of new measurement methods or standards.

Meeting these requirements required each division to maintain a staff of highly capable scientists, as well as world-class calibration personnel and facilities. It is a testament to the competence of Bureau management that, for the most part, these goals were reached.

Electricity Division (Chester H. Page, Chief).

The Electricity Division grouped its activities into sections on resistance and reactance, headed by Chester Peterson; electrochemistry, under Walter J. Hamer; electrical instruments, led by Francis L. Hermach; high voltage, under F. Ralph Kotter; and absolute electrical measurements, headed by Forest K. Harris.

As listed in the *NBS Special Publication 250,* Electricity Division personnel provided a number of calibration services to the public and to other governmental organizations, including the following types:[112]

- Electrical resistance, inductance, capacitance, and emf.
- Electrical instruments.
- Voltage ratios and high-voltage measurements.
- Dielectric constants and dissipation factors.
- Magnetic induction, hysteresis, permeability, core loss, and fluxmeters.

[112] *Calibration and Test Services of the National Bureau of Standards*, NBS Special Publication 250, May 1968. NBS Special Publication 250 constitutes a series of documents announcing and describing the many Bureau calibration services. The series was begun in November 1963.

Special Publication 300

In 1968 there were published two volumes of NBS Special Publication 300, a multi-volume compendium on specialized topics in the area of high-precision measurement and calibration. These volumes were used as reference sources by metrologists throughout the world. Replacing a similar series published in the 1950s as *NBS Handbook 77,* SP 300 was intended to present up-to-date reprints of papers in a dozen standards areas.

One of the SP 300 volumes, No. 3, covered the field of electricity; it was edited by Francis L. Hermach and Ronald F. Dziuba.[113] Nearly 500 pages long, it contained reprints of 45 papers and nearly as many abstracts of papers dealing with standard cells and Zener diodes, resistors and resistance-measurement equipment, capacitors, inductors, ac-dc transfer standards, transformers and inductive voltage dividers, high voltages, dielectrics, magnetic measurements, and general papers on electrical standards. The interested reader could find in its pages information on, or at least references to, most contemporary electrical standards work.

Electric Charge

One of the electrical measurement quantities to which NBS contributed significantly was electric charge. The classical method used in determining values of the unit of electric charge, at that time known as the Faraday, involved the electrolytic deposition of silver from an aqueous solution of silver nitrate. However, many other methods were used as well. A summary of values obtained by five different methods, converted to the contemporary unified ^{12}C international scale of atomic weights, was given by Walter J. Hamer. He compared the values of the Faraday as determined by Norman Craig and James I. Hoffman using silver deposition, iodide oxidation, oxalate oxidation, silver dissolution, and the omegatron instrument. A recommended value of $(96{,}487.0 \pm 1.6)$ coulombs/gram-equivalent, using the dissolution of silver in aqueous solutions, proved most reliable. The results varied by as much as one part in 10,000.[114]

Later (see Sect. 4.5.1), Richard S. Davis and Vincent E. Bower, using improved methods, would bring measurements of the Faraday to a new level of accuracy—better than 1 ppm.

At present, the SI unit of electric charge is the coulomb.[115]

[113] *Precision measurement and calibration. Selected NBS papers on electricity—low frequency,* F. L. Hermach and R. F. Dziuba, editors, NBS Special Publication 300, Volume 3, December 1968, 498 pp.

[114] W. J. Hamer, "Résumé of values of the Faraday," *J. Res. Nat. Bur. Stand. (U.S.),* **72A**, No. 4, 435-439 (1968).

[115] See, for example, Barry N. Taylor, "Guide for the use of the International System of Units (SI)," *NIST Special Publication 811, 1995 Edition,* April 1995, p. 50.

Capacitance Standards

The quality of the standard for capacitance improved noticeably at that time as a result of a collaboration between the National Measurement Laboratory (NML) of Australia and NBS. A.M. Thompson and D.G. Lampard of NML initiated the work with a new theoretical discussion of capacitance. They followed their advance by developing new practical standards and measurement techniques in a long-term collaboration with Robert D. Cutkosky, John Q. Shields, and Lai H. Lee of the NBS Electricity Division.

Cutkosky and Lee reported development of an improved, transportable 10 pF capacitor during a 1965 meeting of the Consultative Committee for Electricity at the International Bureau of Weights and Measures in Paris.[116] Later, Cutkosky reported a new value for the absolute farad obtained with the new tools;[117] it stood as the world's best for a decade.

Voltage Standards

The Bureau's voltage standard in 1968 resided in a bank of saturated standard cells. The NBS realization of the volt was derived from intercomparisons of these cells, so that the methods used in performing the intercomparison were significant. In an example of the usefulness of the statistical capabilities of the staff of the NBS Office of Measurement Services, Joseph Cameron of that office collaborated with Woodward G. Eicke in designing procedures for monitoring the NBS collection of standard cells.[118]

Zener diodes, much easier to maintain than electrochemical cells, were calibrated at the Bureau as secondary-level voltage standards. Eicke and Henry H. Ellis prepared for long-term study a group of these diodes of normal voltage 8.1 V to 9.2 V. During the study, the devices were maintained within 0.02 °C of 25 °C. The authors tracked the stability of the group of devices over a 3 year period. The level of voltage stability of the diodes over the period ranged from 3 ppm to 10 ppm, as reported during a meeting of the Consultative Committee for Electricity at the International Bureau of Weights and Measures in Paris.[119]

The problem of comparing ac voltages to dc standard voltages at high accuracy became more significant as advances in operational amplifiers and inductive voltage

[116] R. D. Cutkosky and L. H. Lee, *An improved transportable ten picofarad capacitor*, Proceedings of the 11th Session of the Consultative Committee for Electricity, May 10-12, 1965 (BIPM, Paris, France).

[117] R. D. Cutkosky, "New NBS measurements of the absolute farad and ohm" *IEEE Trans. Instrum. Meas. IM-23*, No. 4, 305-309 (1974).

[118] W. G. Eicke and J. M. Cameron, *Design for the surveillance of the volt maintained by a small group of saturated standard cells*, NBS Technical Note 430, October 1967.

[119] W. G. Eicke and H. H. Ellis, *On long-term stability of Zener reference diodes*, Proceedings of the 11th session of the Consultative Committee for Electricity, May 10-12, 1965 (BIPM, Paris, France).

dividers achieved linearity and day-to-day stability levels better than 100 ppm. Francis L. Hermach conceived the idea of using thermal converters for ac/dc comparisons; he performed careful studies to elucidate the frequency dependence of the devices. Earl S. Williams and Hermach assembled a group of thermoelements which they examined at audio frequencies at currents from 5 mA to 20 mA. They found that they could evaluate the ac-dc differences with uncertainties of about 2 ppm. Inserting these thermoelements into circuits with a range of series resistors to create thermal voltage converters, they were able to measure voltages in the range 0.5 V to 500 V with uncertainties less than 10 ppm.[120]

A new method for self-calibration of inductive voltage dividers was described by Wilbur C. Sze. Characterized as a "boot-strapping" injection method, the new technique was suggested for determining both in-phase and quadrature deviations. Advantages of the new technique over earlier methods were discussed as well.[121]

Metrology Division (Theodore R. Young, Acting Chief).

The Metrology Division consisted of three branches. One of these specialized in optical techniques under the leadership of Louis E. Barbrow. It was composed of sections in photometry led by Charles A. Douglas, another in image optics and photography under Calvin S. McCamy, and a third in colorimetry and spectrophotometry headed by Isadore Nimeroff. A second branch, in length metrology, was headed by Young himself. It consisted of a section on length led by John S. Beers, and another on engineering metrology headed by Arthur G. Strang. A third branch, in mass and volume metrology, was headed by Paul E. Pontius.

Calibration and testing services provided by the staff of the Division included the following services listed in *NBS Special Publication 250*:

- Photometry.
- Image Optics and Photography.
- Spectrophotometry.
- Length.
- Engineering Metrology (length and diameter, end standards, step gages, threads and gears, spherical diameters, internal diameters and ring gages, master gears, calipers, flatness, straightness, optical reflecting planes, roundness, surface texture, angles, mass, volume, and density).

[120] F. L. Hermach and E. S. Williams, "Thermal converters for audio-frequency voltage measurements of high accuracy," *IEEE Trans. on Instr. and Meas.* **IM-15**, No. 4, pp. 260-268 (1966).

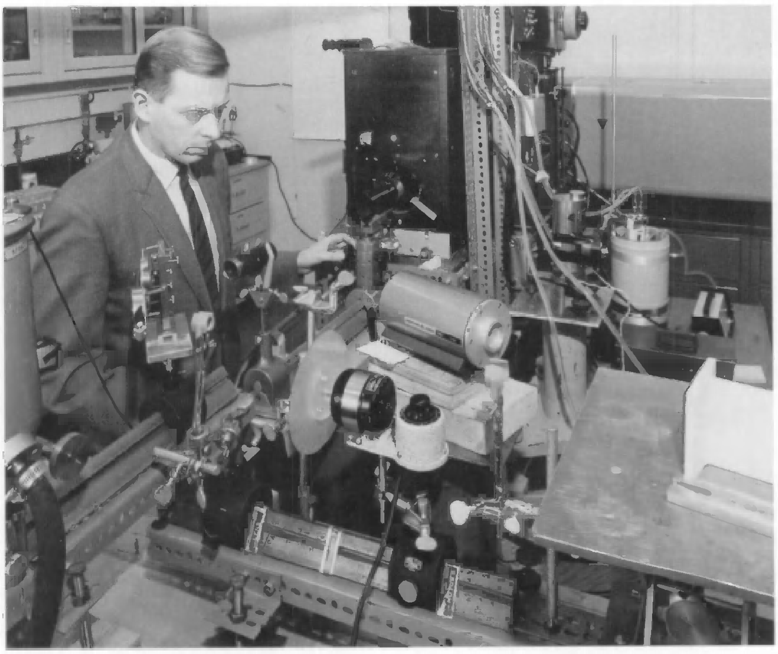
[121] W. C. Sze, "Comparator for calibration of inductive voltage dividers from 1 to 10 kHz," *ISA Trans.* **6**, No. 4, 263-267 (Oct. 1967).

International Comparison of Laser Wavelengths

Laser wavelength calibrations, undertaken jointly by scientists at NBS, at the National Physical Laboratory in England, and at the Physikalisch-Technische Bundesanstalt in Germany, showed agreement among stabilized helium-neon lasers at the level of 5 parts in 10^8 in wavelength. Bureau scientists involved in this type of measurement included Klaus D. Mielenz and Karl F. Nefflen of the Metrology Division.[122]

Mass Measurement

With the assistance of Joseph Cameron of the Office of Measurement Services, Paul E. Pontius reviewed the procedures for accurate mass measurement.[123] Included in



Klaus D. Mielenz aligned the apparatus used at NBS to measure laser wavelengths as part of an international study. Light from a standard ^{86}Kr lamp (extreme left) was brought to a common focus along with a helium-neon laser beam. The beams were then recollimated to illuminate an interferometer (upper center). The ring pattern produced by the interferometer was photographically recorded by a spectrograph. Finally a computer was used to calculate the laser wavelength relative to the ^{86}Kr standard.

[122] K. D. Mielenz, R. B. Stephens, K. E. Gillilland, and K. E. Nefflen, "Measurement of absolute wavelength stability of lasers," *J. Opt. Soc. Am.* **56**, No. 2, 156-162 (1966).

[123] P. E. Pontius and J. M. Cameron, "Realistic uncertainties and the mass measurement process. An illustrated review," *NBS Monograph 103*, August 1967.

this discussion was the idea of incorporating a laboratory standard in the calibration routine as an unknown, to provide a check on the quality of the calibration process; this technique became the basis for *Measurement Assurance Programs.*

Line Standards

The use of a 633 nm helium-neon laser as a light source for an automatic fringe-counting interferometer made possible an improved calibration technique for line standards, leading to uncertainties less than 0.1 ppm. The advance was made through a collaborative effort involving Kitt E. Gillilland, Herbert D. Cook, Klaus D. Mielenz, and Robert B. Stephens.[124]

Microfilm Storage

In a continuing study of problems related to the storage of microfilm, performed in part at the request of the U.S. Library of Congress, Chester I. Pope reported on the effects that the details of the film processing procedures could cause later in storage. [125] Pope and his colleague Calvin S. McCamy had recently published several discussions on this topic.[126] During this period McCamy also reviewed photographic standardization and research at NBS for the journal *Applied Optics.* [127]

Color

Deane B. Judd, soon to retire after an illustrious scientific career at NBS, wrote an extensive summary work on color vision and colorimetry for the second edition of the *Handbook of Physics,* a comprehensive tome originally prepared during the years 1948-1958 under the editorship of Edward Condon, then Director of NBS, and Hugh Odishaw.[128]

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[124] K. E. Gillilland, H. D. Cook, K. D. Mielenz, and R. B. Stephens, "Use of a laser for length measurements by fringe counting," *Metrologia* **2**, No. 3, 95-98 (1966).

[125] C. I. Pope, "Blemish formation in processed microfilm," *J. Res. NBS* **72A**, No. 3, 251-259 (1968).

[126] C. S. McCamy, "Inspection of processed photographic record films for aging blemishes," *NBS Handbook 96* (Washington, DC: USGPO, 1964). See also,

C. S. McCamy and C. I. Pope, "Summary of current research on archival microfilm," *NBS Technical Note 261* (Washington, DC: USGPO, 1965).

[127] C. S. McCamy, "Photographic standardization and research at the National Bureau of Standards," *Appl. Opt.* **6**, No. 1, 27-30 (1967).

[128] D. B. Judd, "Color vision and colorimetry," Chapter 4 in *Handbook of Physics,* Second Edition, Part 6, Optics, E. U. Condon and H. Odishaw, editors, McGraw-Hill, NY, 1967, pp. 6-65 to 6-77. Judd retired after 42 years at NBS in October 1969. At that time, he held the honorific position of Senior Research Scientist. Among many awards for his scientific achievements were the Department of Commerce Gold Medal (1950), the Frederic Ives Medal of the Optical Society of America (1958), the Gold Medal of the Illuminating Engineering Society (1961), and the NBS Stratton Award (1965).

Another substantial work on colorimetry, *NBS Monograph 104,* written by Isadore Nimeroff, was published in January 1968.[129] The monograph superseded *NBS Circular 478,* dating from 1950, which had been reprinted several times but had become obsolete in many respects. Parts of the original text were retained where they were correct and useful. Aspects of the topic included the involvement of the eye in defining color, early color standards, colorimetry by comparison, colorimetry by material standards, and color scales.

As part of a continuing investigation into color vision, Gerald L. Howett reported the results of a study of the variation in the shape of spectral absorptance curves obtained using pigment solutions of varying concentration. He discussed his results in terms of the current theory of color vision.[130]

An NBS research associate from IBM Corp., Carl F. Shelton, determined the photo-excitation, spectral-emission properties of 10 phosphor samples issued as standards by NBS.[131] Radiation was observed at 253.7 nm and 365 nm.

Thermal Properties

Temperature-dependent properties of materials received attention from several NBS divisions. Bruce D. Rothrock and R. Keith Kirby completed the development of an apparatus for the measurement of thermal expansion of refractory materials at temperatures to 1600 °C.[132] The apparatus consisted of an optical comparator and a controlled-gradient vacuum furnace; it provided results estimated to be accurate within 50 ppm.

Kirby also completed measurements of the thermal expansion of a single crystal of TiO_2 (rutile) over the range 100 K to 700 K, using an Abb-Pulfrich interferometer to obtain the results in terms of the tetragonal symmetry of the crystal.[133]

Mechanics Division (Edward C. Lloyd, Acting Chief).

The Mechanics Division consisted of sections involved in measurements of sound, headed by Martin Greenspan; engineering mechanics, under Lafayette K. Irwin; and rheology, led by Robert S. Marvin. Lloyd himself supervised a branch for mechanical measurements: its sections included pressure measurements, also headed by Lloyd; vacuum measurements, under Stanley Ruthberg; vibration studies, led by Roscoe L. Bloss; and humidity measurements, headed by Arnold Wexler. A branch on fluid mechanics consisted of sections on fluid meters, led by Fillmer W. Ruegg; hydraulics, under Gershon Kulin; and aerodynamics.

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[129] I. Nimeroff, "Colorimetry," *NBS Monograph 104,* January 1968, 50 pp.

[130] G. L. Howett, "Variation of absorptance-curve shape with changes in pigment concentration," *J. Res. NBS* **72A**, No. 4, 309-340, 1968.

[131] Carl F. Shelton, "Spectral Emission Properties of NBS Standard Phosphor Samples Under Photo-Excitation," *NBS Technical Note 417,* March 1968.

[132] B. D. Rothrock and R. K. Kirby, "An apparatus for measuring thermal expansion at elevated temperatures," *J. Res. NBS* **71C**, 85-91 (1967).

[133] R. K. Kirby, "Thermal expansion of rutile from 100 to 700 °K," *J. Res. NBS* **71A**, 363-369 (1967).

The division offered several calibration and test services, which were listed in *NBS Special Publication 250*:

- Acoustics.
- Vibration.
- Humidity.
- Engineering Mechanics (hardness, load cells, proving rings, and elastic force).

Arnold J. Mallinger inspected a proving ring before its calibration as a force standard in a deadweight machine at the National Bureau of Standards.

- Fluid Meters.
- Hydraulics.
- Aerodynamics.
- Pressure and Vacuum.
- Railroad Track Scales.

Humidity

The construction and use of a new adiabatic saturation psychrometer were described by Lewis Greenspan and Arnold Wexler.[134] The instrument was intended for use in atmospheric humidity measurements, but was tested for use in other vapor-gas combinations. Its uncertainty in humidity measurements was evaluated as +0.2 % of the reading. The new device was expected to be especially valuable in the fields of air conditioning and the chemical process industries.

Pressure

In an investigation of potential pressure-scale reference points, Peter L. M. Heydemann reported the use of a dead-weight piston gage to determine the pressure of the bismuth I–bismuth II transition at about 25.3 kbar (approximately 2.6 GPa).[135] He used two samples of different purity; the less-pure sample yielded a transition pressure about 1 % higher, well outside the estimated measurement uncertainty of 0.2 %.

In support of the use of the vapor pressure of carbon dioxide at 0 °C as a pressure-scale reference point, Daniel P. Johnson and his student, J. L. Edwards of The George Washington University in Washington DC, developed a dynamic method to determine that value.[136] The method involved the use of a controlled-clearance piston gage. The value obtained, 34.8516 bar, differed by as much as three parts in 10,000 from earlier measurements. The authors cautioned that the quality of the pressure measurements, the temperature environment, and the sample preparation were all of comparable importance to the success of the measurement.

Fluid Flow

A study of high-order correlations in turbulent fluid fields was reported by Philip S. Klebanoff and his associate François N. Frenkiel, a physicist at the David Taylor Model Basin in Carderock, Maryland.[137] Wishing to extend the analysis of turbulence that was found, for example, in air or water flow, in sea waves, or in acoustic noise, the authors constructed a grid of 0.5 cm diameter bars with a mesh size of 2.5 cm. They placed the grid in the NBS wind tunnel and recorded the turbulence thereby created in a 15 cm/s air flow some 50 diameters downstream from the grid. They pointed out the indications of non-Gaussian probability distributions in the experimental results, and they obtained several relations between correlation coefficients for these distributions.

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[134] L. Greenspan and A. Wexler, "An adiabatic saturation psychrometer," *J. Res. NBS* **72C** (Engineering and Instrumentation), No. 1, 33-47 (1968).

[135] P. L. M. Heydemann, "The Bi I-II transition pressure measured with a dead weight piston gage," *J. Appl. Phys.* **38**, No. 6, 2640-2644 (1967).

[136] J. L. Edwards and D. P. Johnson, "A dynamic method for determining the vapor pressure of carbon dioxide at 0 °C," *J. Res. NBS* **72C** (Engineering and Instrumentation), No. 1, 27-32 (1968).

[137] F. N. Frenkiel and P. S. Klebanoff, "Higher-order correlations in a turbulent field," *Phys. Fluids* **10**, No. 3, 507-520 (1967).

Gravity

Douglas R. Tate used the "free fall" method to measure the acceleration of gravity at a reference point in the Engineering Mechanics building in 1965; the value obtained was 980.1018 cm/s^2. In a 1968 *NBS Monograph,* No. 107, he described the experimental apparatus used, the techniques employed, and the data analysis on which the value was based.[138] Gradient techniques were utilized to transfer the measurement to another reference point in the gravity room of the Department of Commerce building in Washington, DC. That value was determined to be (980.1048 $\pm$ 0.0005) cm/s^2.

Force Measurement

Richard A. Mitchell provided an analysis of the various methods used to optimize the shape of proving rings and other elastic ring-type force transducers.[139] The intent of the project was to minimize the weight of the rings without losing the flexibility needed for the device.

Heat Division (Ralph P. Hudson, Chief).

The Heat Division consisted of sections on heat measurements, led by Defoe C. Ginnings; cryogenic physics, headed temporarily by James F. Schooley; equation of state, under Max Klein; statistical physics, led by Melville S. Green; temperature, under Harmon H. Plumb; and radiation thermometry, headed by Henry J. Kostkowski.

The division listed several calibration services in *NBS Special Publication 250*:

- Temperature (Liquid-in-glass, Thermocouple, and Resistance Thermometers).
- Cryogenic Resistance Thermometers.
- Radiation Thermometers and Standard Lamps.
- Radiometers.

Special Publication 300

In the notes on the Applied Mathematics and Electricity Divisions we called attention to *NBS Special Publication 300,* a multi-volume compendium on precision measurement and calibration. In 1968 Volume 2, *Temperature,* was published.[140] This 500-page volume was edited by James F. Swindells, former chief of the Temperature Section. Topics presented in the 30-some papers reprinted in the volume included the

[138] D. R. Tate, "Acceleration due to gravity at the National Bureau of Standards," *NBS Monograph 107,* June 1968, 24 pp.

[139] R. A. Mitchell, "Analysis of n-degree elliptical elastic rings of nonuniform cross section," *J. Res. NBS* **72C** (Engineering and Instrumentation), No. 2, 139-160 (1968).

[140] J. F. Swindells, editor, "Selected NBS papers on temperature," Volume 2 in *NBS Special Publication 300, Precision Measurement and Calibration,* August 1968, 520 pp.

expression of uncertainties, temperature scales, resistance thermometry, thermoelectric thermometry, liquid-in-glass thermometry, optical pyrometry, and spectroscopic thermometry. Most of the thermometry research that undergirded the International Practical Temperature Scale of 1968 was represented in this volume. A bibliography covering the period 1953-65 was appended to it.

Cryogenic Temperature Scales and Cryogenic Physics

A provisional temperature scale for the range 14 K to 20 K was put forth by Harmon H. Plumb and George Cataland in 1966. The scale relied upon the relationship between the saturated vapor pressure of liquid hydrogen and the temperature as determined by acoustic isotherms in helium gas.[141] This work also provided information on the second virial coefficient of ^{4}He in the same temperature range; the values were derived and published in a collaborative effort with Marjorie E. Boyd and Sigurd Y. Larsen of the Statistical Physics Section.[142]

A temperature scale for even lower-temperature use was described by Ralph P. Hudson, the division chief, and Robert S. Kaeser. By measuring the internal energy of cerous magnesium nitrate (CMN) as a function of its entropy, using magnetic cooling and gamma-ray heating, they were able to deduce the thermodynamic temperature, correlate it with the paramagnetic susceptibility of CMN, and thus to develop a scale that extended from 0.002 K to 2 K.[143]

As part of a study of the behavior of paramagnetic materials at low temperatures, Billy W. Mangum and Jack H. Colwell reported measurements of the heat capacity of neodymium and praseodymium chlorides in the range 0.3 K to 4 K. They interpreted the results in terms of the linear Ising model of paramagnetism.[144]

The thermodynamic properties of ammonia were studied intensively at NBS over a period of many years. The substance was used in refrigeration throughout the United States prior to the introduction of freons. During this period, Lester Haar evaluated and published values for several thermodynamic functions of ammonia as an example of a nearly ideal gas.[145]

[141] H. Plumb and G. Cataland, "Acoustical thermometer and the National Bureau of Standards provisional temperature scale 2-20 (1965)," *Metrologia* **2**, No. 4, 127-139 (1966).

[142] Marjorie E. Boyd, Sigurd Y. Larsen, and Harmon Plumb, "Second virial coefficient of He^4 in the temperature range from 2 to 20 °K," *J. Res. NBS* **72A**, No. 2, 155-156 (1968).

[143] R. P. Hudson and R. S. Kaeser, "Cerous magnesium nitrate: a magnetic temperature scale 0.002-2 °K," *Physics* **3**, No. 2, 95-113 (1967).

[144] B. W. Mangum and J. H. Colwell, "Low-temperature heat capacity of $NdCl_3$ and $PrCl_3$," *J. Appl. Phys.* **38**, No. 3, 1468-1469 (1967).

[145] L. Haar, "Thermodynamic properties of ammonia as an ideal gas," *J. Res. NBS* **72A**, No. 2, 207-216 (1968).

Using the methods pioneered during the Bureau's "free radicals" program, Stanley Abramowitz, collaborating with Nicolo Acquista of the Atomic Physics Division, studied the infrared spectra of LiF embedded in matrices of argon cooled to low temperatures by liquid hydrogen.[146] The results were interpreted in terms of the formation of dimers or possibly trimers of LiF.

Progress to date on understanding the existence of superconductivity in semiconducting $SrTiO_3$ and mixed titanates was summarized in papers written by Ernest Ambler, Jack Colwell, Earl R. Pfeiffer, and James Schooley of the Heat Division and their colleagues Hans P.R. Frederikse, William R. Hosler, and W. Robert Thurber of the Inorganic Materials Division.[147, 148] The variability in the concentration of the electrical charge carriers in $SrTiO_3$, readily controlled in sample preparation, made it a particularly interesting superconductor since the temperature of transition to the superconductive state depended upon the carrier concentration. A theoretical correlation between charge-carrier concentration and superconducting transition temperature was developed by Calvin S. Koonce and his mentor from the University of California, Marvin L. Cohen.[149] This work won for Koonce the Distinguished Young Scientist Award of 1969 from the Maryland Academy of Sciences.

The first observation of the superconducting energy gap by electron tunneling in a semiconductor, GeTe, was reported by Schooley and his colleagues Philip J. Stiles and Leo Esaki of the IBM Watson Research Center in Yorktown Heights, NY.[150] Measurements were made by cooling an Al-Al_2O_3-GeTe tunnel junction to temperatures ranging from 0.085 K to 2.5 K in an adiabatic demagnetization cryostat, then measuring the conductance dI/dV *vs* V. At temperatures above 0.5 K the structure in the conductance due to the GeTe superconductivity disappeared.

[146] S. Abramowitz and N. Acquista, "Infrared matrix spectra of lithium fluoride," *J. Res. NBS* **72A**, No.5, 487-493 (1968).

[147] J. F. Schooley and W. R. Thurber, "Superconductivity in semiconducting $SrTiO_3$," *Proceedings of the International Conference on the Physics of Semiconductors,* Kyoto, Japan, September 8-11, 1966, *J. Phys. Soc. Japan* **21**, 639-642 (1966).

[148] E. Ambler, J. F. Schooley, J. H. Colwell, E. R. Pfeiffer, H. P. R. Frederiske, W. R. Hosler, and W. R. Thurber, "Transition temperatures and critical fields of $SrTiO_3$ and mixed titanates," *Proc. Xth Intern Conf. Low Temperature Physics, Moscow, USSR, Aug 31-Sept 6, 1966,* Vol. 2B, *Superconductivity,* Paper S123, 142-148 (1968).

[149] C. S. Koonce, M. L. Cohen, J. F. Schooley, W. R. Hosler, and E. R. Pfeiffer, "Superconducting transition temperatures of semiconducting $SrTiO_3$," *Phys. Rev. 163,* 380 (1967).

[150] P. J. Stiles, L. Esaki, and J. F. Schooley, "Observation of the superconducting energy gap in a semiconductor (GeTe)," *Phys. Lett.* **23**, No. 3, 206-207 (1966).

High-Temperature Radiation Thermometry and Radiometry

A new stable and inexpensive temperature reference at 1083 °C was developed by Richard D. Lee, using NBS copper standard samples and a carefully designed furnace. The copper sample was incorporated into a blackbody-type radiation source that was capable of stability at the level of 0.01 °C.[151]

Lee and and his colleague Ernest Lewis, Jr., determined the radiance temperatures at a wavelength of 650 nm displayed by 20 different graphite electrodes used in an electric arc . All of the electrode temperatures fell in the range 3786 K to 3808 K. The estimated uncertainty of the measurements was ±2 K.[152]

Lee also wrote a major paper describing the newly developed NBS photoelectric pyrometer and its use to realize the international temperature scale with enhanced accuracy.[153] At the level of 95 % confidence, the experimental uncertainties were ±0.12 °C at 1063 °C, ±0.24 °C at 1256 °C, and ±3 °C at 3525 °C.

Albert T. Hattenburg determined the spectral radiance of the anode of a low-current graphite arc in the region 210 nm to 850 nm. In performing these measurements, Hattenburg utilized a recently developed spectroradiometer of improved accuracy.

The radiance values showed an uncertainty estimated as 1.5 % to 5 %, with the smaller uncertainty at the longer wavelengths.[154]

Donald A. McSparron, Charles A. Douglas, and Herbert L. Badger of the Metrology Division reviewed available radiometric methods for measuring the output of pulsed lasers. They recommended use of a thermopile or phototube, as well as attenuating the laser power to a value similar to the calibrating source. The total uncertainty for the measurements was estimated to be 5 %.[155]

A new tungsten-filament lamp standard for total irradiance was brought into service. It replaced the type of 50 W carbon-filament lamp that had been in use for 50 years. The new lamps were made available in 100 W, 500 W, and 1000 W units. They operated at higher temperatures than the previous standard lamps, producing sources of considerably higher irradiance. The new lamps were prepared in a collaborative effort by Ralph Stair of the Metrology Division, in collaboration with William E. Schneider, and William B. Fussell.[156]

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[151] R. D. Lee, "Construction and operation of a simple high-precision copper-point blackbody and furnace," *NBS Technical Note 483*, May 1969. 16 pp.

[152] R. D. Lee and E. Lewis, "Radiance temperature at 6500 Å of the graphite arc," *Appl. Opt.* **5**, No. 11, 1858 (1966).

[153] R. D. Lee, "The NBS photoelectric pyrometer and its use in realizing the International Practical Temperature Scale above 1063 °C," *Metrologia* **2**, No. 4, 150-162 (1966).

[154] A. T. Hattenburg, "Spectral radiance of a low current graphite arc," *Appl. Opt.* **6**, No. 1, 95-100 (1967).

[155] D. A. McSparron, C. A. Douglas, and H. L. Badger, "Radiometric methods for measuring laser output," *NBS Technical Note 418*, November 1967.

[156] R. Stair, W. E. Schneider, and W. B. Fussell, "The new tungsten-filament lamp standards of total irradiance," *Appl. Opt.* **6**, No. 1, 101-105 (1967).

Joseph C. Richmond and Gerhart J. Kneissl, collaborating with their colleagues Douglas L. Kelley and F.J. Kelly of the Institute of Applied Technology, reported new procedures for the precise determination of total normal emittance of ceramic materials at very high temperatures.[157]

Kneissl and Richmond also reported the construction and testing of an integrating sphere for use with laser light sources. Using the new equipment, they were able to measure the reflectance of a variety of refractory materials to 2150 °C, with an imprecision less than 0.05 %.[158]

Gerhart J. Kneissl obtained reflectance measurements from the laser-source reflectometer. The laser beam was alternately directed into a large integrating sphere (outside picture at left) and a small averaging sphere (left center). Reflectance values were indicated by a digital voltmeter.

[157] J. C. Richmond, G. J. Kneissl, D. L. Kelley, and F. J. Kelly, "Procedures for precise determination of thermal radiation properties," *NBS Technical Note 292*, February 1967.

[158] Gerhart J. Kneissl and Joseph C. Richmond, "A Laser-Source Integrating Sphere Reflectometer," *NBS Technical Note 439*, February 1968.

In a related work, William Fussell and Jon C. Geist measured the normal spectral emissivity of single-crystal calcium fluoride in the wavelength range 2 μm to 12 μm and the temperature range 500 °C to 600 °C.[159]

Thermodynamic Properties of Materials

Thomas B. Douglas calculated the high-temperature energies of dilute solid solutions for all 96 cases of binary alkali halides excepting cesium.[160] His results compared favorably with available experimental data.

In the area of statistical physics, Raymond D. Mountain reviewed a comprehensive calculation of the interaction of light with density fluctuations in a dense, simple fluid.[161] In the calculation, Mountain used the hydrodynamic equations of irreversible thermodynamics; he was able to confirm the results of Landau and Placzek and to develop a procedure for deriving certain correction terms as well.

Melville S. Green and his colleague Leopold S. Garcia-Colin of the Mexican National Commission for Nuclear Energy analyzed the meaning of temperature in the kinetic theory of dense gases.[162] These ideas were related to the general question of useful macroscopic variables in non-equilibrium statistical mechanics.

Critical phenomena in a variety of materials—gases, binary liquids, binary alloys, magnets, and superfluids—were compared by Jan V. Sengers and Johanna M. H. L. Sengers for the journal *Chemical and Engineering News.*[163] They found strong similarities in the thermodynamic behavior among these very different systems. It was their hope to obtain a universal equation of state for all critical anomalies.

High-Speed Measurements

A lengthy discussion on the use of the exploding-wire technique to provide information on the high-temperature properties of a variety of materials was presented by Esther C. Cassidy, Stanley Abramowitz, and Charles W. Beckett in NBS Monograph No. 109, issued in November 1968. Time-resolved measurements of electrical energy,

[159] W. B. Fussell and J. C. Geist, "Approximate normal emissivity spectra in the infrared at elevated temperatures of single-crystal and polycrystalline calcium fluoride," *Appl. Opt.* **6**, No. 1, 119-124 (1967).

[160] T. B. Douglas, "Calculated heats of dilute solid solution among the alkali halides other than cesium salts," *J. Chem. Phys.* **45**, No. 12, 4571-4585 (1966).

[161] R. D. Mountain, "Spectral distribution of scattered light in a simple fluid," *Revs. Mod. Phys.* **38**, No. 1, 205-214 (1966).

[162] L. S. Garcia-Colin and M. S. Green, "Definition of temperature in the kinetic theory of dense gases," *Phys. Rev.* **150** No. 1, 153-158 (1966).

[163] J. V. Sengers and J. M. H. L. Sengers, "The critical region," *Chem. Eng. News* **46**, No. 25, 104-118 (1968).

power, voltage and current; high-speed photographs of the explosions; and time-dependent recordings of the radiant output of the sample all were described, along with notes on the types of apparatus available.[164] This technique would later be exploited by a group led by Ared Cezairliyan for the study of refractory metals.

Computing Devices

With the collaboration of Robert C. Thompson of the Office of Standard Reference Data, Charles H. Popenoe prepared a recipe for simple modifications to a teletypewriter to facilitate its use as a remote console for a computer.[165] This work led to pioneering developments in computer-assisted typesetting, led by Joseph Hilsenrath, Robert C. Thompson, and Carla G. Messina.

Atomic Physics Division (Karl G. Kessler, Chief).

The Atomic Physics Division was composed of 6 sections: spectroscopy, headed by William C. Martin; infrared and microwave spectroscopy, under David R. Lide, Jr.; far-ultraviolet physics, led by Robert P. Madden; electron physics, under John A. Simpson; atomic physics, headed by Richard D. Deslattes; and plasma spectroscopy, under Wolfgang L. Wiese.

Atomic Spectroscopy

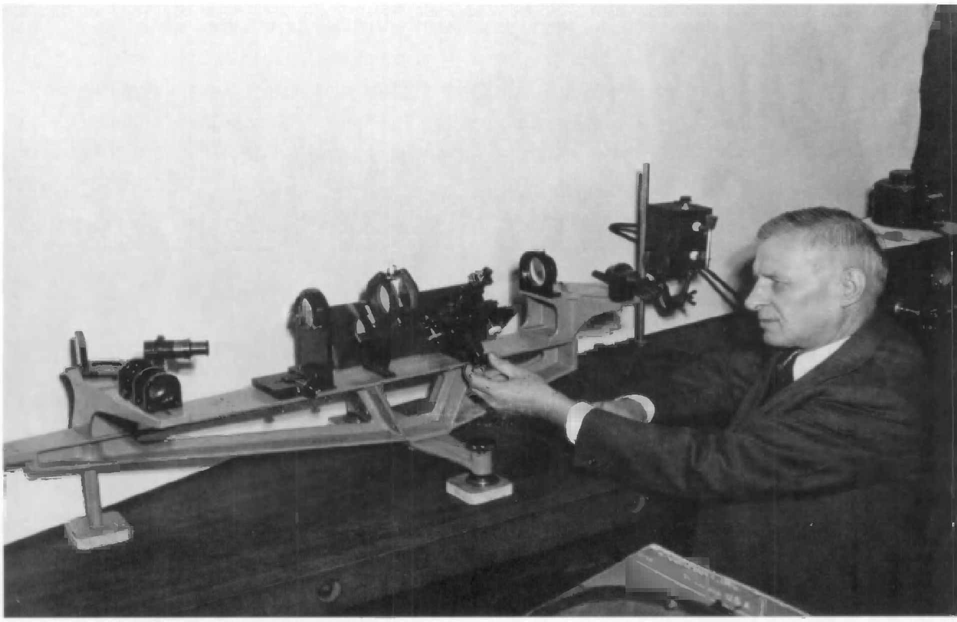
One of the most important contributions of the Bureau's Atomic Physics Division was the observation, analysis, and tabulation of spectral lines arising from the excitation of neutral and ionized atoms. William F. Meggers, a world-renowned spectroscopist, was heavily involved in this work from 1914 until the year of his death in 1966. In recognition of his painstaking and prolific contributions to the knowledge of atomic spectra during a half-century at NBS, an entire issue of the NBS Journal of Research (Vol. **71A**, No. 6, 1967) was dedicated to Meggers' work. In an introductory tribute to the work of Meggers, Division Chief Karl Kessler wrote, "More than any other man, Dr. Meggers came to be identified with this voluminous increase in our knowledge of atomic structure."

Kessler's tribute was followed by a paper describing Meggers' last work, on the second spectrum of ytterbium (Yb II);[166] Charlotte E. Moore-Sitterly, one of his long-time colleagues, edited the 148-page paper which analyzed spectra involving some 315 energy levels. In the same issue, a second Meggers work, accomplished jointly with William R. Bozman, Charles H. Corliss, and Jack L. Tech, presented a new description of the spectrum of Tc I and Tc II. Corliss and Tech also discussed the

[164] E. C. Cassidy, S. Abramowitz, and C. W. Beckett, "Investigation of the exploding wire process as a source of high temperature studies," *NBS Monograph 109*, November 1968, 53 pp.

[165] Charles H. Popenoe and Robert H. Thompson, "Accessory Equipment and Teletypewriter Modifications for Remote Computer Consoles," *NBS Technical Note 419*, February 1968.

[166] In the standard notation used in the spectroscopy of atoms, Tc II refers to the "second spectrum" of technetium, i.e., the spectrum of the singly ionized atom. In this notation, Tc I refers to neutral Tc, Tc III to doubly ionized Tc, and so on. See, for example, P. H. Heckmann and E. Träbert, *Introduction to the Spectroscopy of Atoms*, translated from the German by S. Bashkin (New York: North-Holland, 1989) p. 10.



Spectroscopist William F. Meggers adjusted interferometer for use with the ^{198}Hg lamp, which he developed in 1947. Although the 86 Kr lamp became the international standard in 1960, the ^{198}Hg lamp was frequently used for laboratory length measurements because of its relative ease of operation.

lifetimes of energy levels, oscillator strengths, and transition probabilities in neutral Fe (some of this material appeared in NBS Monograph 108, March 1968); Corliss and John B. Shumaker, Jr. of the Heat Division, measured transition probabilities in Ar I; Victor Kaufman and Jack Sugar observed a dozen spectral lines in Pr V; and Joseph Reader and Sumner P. Davis (on leave from the University of California, Berkeley) examined the fundamental energy levels of Pm I.

Spectroscopic instrumentation specifically designed for use with the NBS 180 MeV electron synchrotron was described by Robert P. Madden, David L. Ederer, and Keith Codling.[167] These instruments included a 3 m grazing-incidence spectrograph and a monochromator.

Richard Deslattes, working with William Sauder of the Virginia Military Institute, completed a study of the Zeeman effect in the annihilation of positronium.[168] With Robert E. LaVilla, Deslattes also described the spectra obtained from several

[167] R. P. Madden, D. L. Ederer, and K. Codling, "Instrumental aspects of synchrotron XUV spectroscopy," *Appl. Opt.* 6, No. 1, 31-38 (1967).

[168] W. C. Sauder and R. D. Deslattes, "Zeeman effect in positronium annihilation at low temperatures," *J. Res. NBS* **71A**, No. 5, 347-353 (1967).

chlorinated hydrocarbons, using a two-crystal x-ray spectrometer with high resolving power.[169]

John A. Simpson described the physical limitations on electron beams and the design of electron guns in one chapter of the text *Methods of Experimental Physics* and the production and use of monoenergetic electron beams in another.[170]

In collaboration with Elio Passaglia, Chief of the Metallurgy Division, and Nicholas N. Winogradoff of the Electronic Technology Division, Karl G. Kessler, Chief of the Atomic Physics Division, prepared a summary of NBS laser standards and materials projects supported by either the Advanced Research Projects Agency or the U.S. Air Force Avionics Laboratory.[171] The projects included the following: laser energy and power measurement and continuous-wave power measurements, by Donald A. Jennings;[172] laser pulse measurements, continuous-wave power measurements, and radiometric techniques at new laser wavelengths, by Donald McSparron of the Metrology Division; CO_2 laser power measurements, by Louis J. Schoen; laser power and energy measurements, properties of long-wavelength lasers, and semiconductor laser materials, by Nicholas Winogradoff; far- and near-field laser studies, by Merritt M. Birky; bulk optical properties of laser materials, by Given W. Cleek of the Inorganic Materials Division; laser characterization standards, by John L. Torgeson, also of the Inorganic Materials Division; optical evaluation of laser rods, by Fred W. Rosberry of the Metrology Division; magnetic resonance studies of laser materials, by Te-Tse Chang of the Inorganic Materials Division; laser-rod holography, by Klaus D. Mielenz and Arthur T. Funkhouser, both of the Metrology Division; and optical characterization of crystals, by Robert F. Blunt and Martin I. Cohen, both of the Inorganic Materials Division.

Office of Deputy Director, IBS/Boulder (Bascom W. Birmingham, Acting Chief).

In 1968 all the activities at the Boulder site were brought under the supervision of one manager, who in turn reported to the Director of IBS. By that time, the NBS Central Radio Propagation Laboratory already had been transferred to the Environmental Science Services Administration—another unit of the Department of

[169] R. D. Deslattes and R. E. LaVilla, "Molecular emission spectra in the soft x-ray region," *Appl. Opt.* **6**, No. 1, 39-42 (1967). On the basis of this and related atomic constants work utilizing x-rays and optical interferometry, Deslattes received the 1969 Arthur S. Flemming Award. The Flemming Award was given to outstanding government researchers under the age of 40.

[170] J. A. Simpson, "Electron guns," and "Special sources of monoenergetic electrons," in a Chapter entitled "Sources of Atomic Particles" in *Methods of Experimental Physics*, Volume *4*, "Atomic and Electron Physics," pp 84-95 (New York: Academic Press, Inc., 1967) pp. 84-95 and 124-135.

[171] K. G. Kessler, E. Passaglia, and N. N. Winogradoff, editors, "Research on laser standards and materials at the National Bureau of Standards," *NBS Technical Note 449*, June 1968, 32 pp.

[172] See, for example, D. A. Jennings, E. D. West, K. M. Evenson, A. L. Rasmussen, and W. R. Simmons, "Laser power and energy measurements," *NBS Technical Note 382*, October 1969, 64 pp.

Commerce—although the personnel involved still occupied part of the NBS/Boulder Radio Building. Five technical divisions and three administrative divisions made up the Boulder laboratories.

Administrative Services Division/Boulder (Barton F. Betts, Chief).

The Instrument Shops Division at Boulder under R. S. Perrill and the Plant Division at Boulder headed by E. A. Yuzwiak rendered services that were similar to those of their counterparts in Gaithersburg. Their personnel contracted for materials and equipment, performed mail deliveries and managed other communications activities, provided the Boulder staff with visual aids and graphics, maintained records, constructed specialized scientific equipment, and cared for buildings and grounds.

Radio Standards Physics Division/Boulder (Harold S. Boyne, Acting Chief).

This division was composed of three sections: solid state electronics, under Robert J. Mahler; quantum electronics, headed by Donald A. Jennings; and plasma physics, led by Karl-Birger Persson.

Calibration Services

Calibration of certain electromagnetic properties of materials was offered by the RSP division. These properties included the permittivity of nonmagnetic liquids and solids, the permittivity of ferrites, magnetic permeability of toroids and rods, and ferromagnetic-resonance linewidths and gyromagnetic ratios of samples of various geometric shapes.

Laser Studies

A first for the Boulder laboratories—a pulsed ruby laser—was achieved by Donald A. Jennings in 1962.[173] The laser, powered by xenon flash lamps, was "bootlegged," according to Snyder and Bragaw, since no funds had been included in the Division budget for its construction. The new instrument made accessible a whole range of experiments that had been beyond the laboratory capabilities. It was also the forerunner of many other lasers, developed at Boulder and Gaithersburg, and of laser-characterization methods.

In 1968, an HCN laser was used to observe electron-paramagnetic-resonance absorption between two ground-state levels of oxygen. The laser-based spectrometer was constructed and used by a group that included Kenneth M. Evenson, Joseph S. Wells, and Robert J. Mahler from the Radio Standards Division, Herbert P. Broida—famous

[173] Wilbert F. Snyder and Charles L. Bragaw, "Achievement in Radio: Seventy Years of Radio Science, Technology, Standards, and Measurement at the National Bureau of Standards," (Washington, DC: USGPO, 1986): p 631. Jennings received the Department of Commerce Gold Medal Award for Exceptional Service in 1970 for this work.

for his contributions to the NBS free radicals program but then on his way to the University of California at Santa Barbara—and Masataka Mizushima of the University of Colorado.[174]

Material Properties

The accurate and convenient measurement and comparison of the complex permeability of magnetic materials in the range 30 MHz to 100 MHz were discussed by A. L. Rasmussen and his colleague from the Radio Standards Engineering Division, C. McKay Allred.[175] The manner by which an admittance meter could be used for this purpose was described in some detail.

William S. Lovell and Lynn M. Thiel discussed interferometric methods for the determination of the complex dielectric constants of liquids; in addition, they pointed out sources of error in these methods.[176]

Spectroscopy Data Compilation

During 1968, Volumes IV and V of Monograph 70, *Microwave Spectral Tables,* were published by Marian S. Cord, Jean D. Peterson, Matthew S. Lojko, and Rudolph H. Haas. Volume IV, containing some 400 pages, was devoted to a compilation of literature values up to 1961 for the spectra of polyatomic molecules without internal rotation. Volume V, about 25 % larger, contained a listing of the spectral lines given in Vols. I, II, and III. Monograph 70 had been initiated as a service to the user community by Paul F. Wacker in 1964. It expanded upon the first atlas of microwave spectra, *NBS Circular 518,* published in 1952 by P. Kisliuk and C. H. Townes.

Electromagnetic Fields

In a study of the radial distribution of radiation from a cylindrical source, Earl R. Mossburg, Jr., and Matthew S. Lojko used orthogonal polynomial expansions to solve the Abel integral transform.[177]

Radio Equipment

Noting the need for regulated, low-voltage power supplies for use with transistorized circuits, John H. Rogers offered three different circuit designs for such supplies.[178] The designs differed principally in the available circuit gain.

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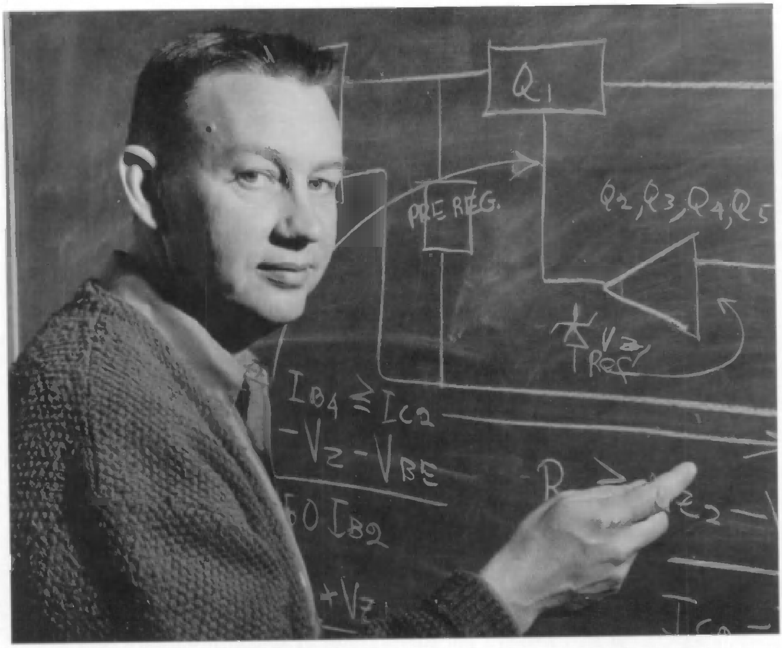
[174] K. M. Evenson, H. P. Broida, J. S. Wells, R. J. Mahler, and M. Mizushima, "Electron paramagnetic resonance absorption in oxygen with the HCN laser," *Phys. Rev. Lett.* **21**, 1038-1040 (1968).

[175] A. L. Rasmussen and C. M. Allred, "An admittance meter technique to measure the complex permeability at VHF," *J. Res. NBS* **72C**, No. 1, 81-89 (1968).

[176] W. S. Lovell and L. M. Thiel, "Interferometric Measurements of the Complex Dielectric Constant of Liquids," *NBS Technical Note 369,* August 1968.

[177] Earl R. Mossburg, Jr. and Matthew S. Lojko, "Solution of the Abel Integral Transform for a Cylindrical Luminous Region With Optical Distortions at Its Boundary," *NBS Technical Note 368,* July 1968.

[178] John H. Rogers, "Transistorized Low Voltage Regulator Circuits and Design," *NBS Technical Note 371,* September 1968.



In 1968, John H. Rogers prepared a schematic diagram from simplified design equations for low-voltage regulator circuits. The equations led to the construction of inexpensive and dependable regulator circuits.

Radio Standards Engineering Division/Boulder (Helmut M. Altschuler, Chief).

The RSED conducted research in the following areas: radiofrequency electrical standards, under C. McKay Allred; radiofrequency impedance standards, ordinarily headed by Robert C. Powell but temporarily in the charge of Cletus A. Hoer; microwave circuit standards, under M. B. Hall; and electromagnetic field standards, led by Ramon C. Baird.

Calibration Services

The division offered calibrations of radiofrequency standard instruments used for measurements of voltage, power, impedance, attenuation, phase shift, effective noise temperature, pulse properties, and electromagnetic field strengths. Karl W. Wendt and Roy E. Larson were in charge of the calibration services.[179]

George E. Schafer described for the journal Proceedings of the IEEE the system of electromagnetic measurements in the United States, using Huntoon's national measurement system as a model.[180]

[179] "Calibration and Test Services of the National Bureau of Standards," *NBS Special Publication 250,* 1968.

[180] G. E. Schafer, "A systems concept of electromagnetic measurements in the U.S.A.," *Proc. IEEE* **55**, No 6, 775-778 (1967).

AC Current Standards

In connection with the Gaithersburg Electricity Division, we already have mentioned a study of alternating current standards by Winston W. Scott, Jr. and Nolan V. Frederick of the Radio Standards Engineering Division in Boulder. In this case, however, the comparisons involved current measurements at the higher frequencies utilized in radio work. Scott and Frederick focused on state-of-the-art techniques, including thermocouple ammeters, electrodynamic ammeters, photoammeters, and air-thermometer ammeters. The study emphasized frequency ranges, current-level ranges, and convenience as much as it did the accuracy of the methods.[181]

Allan S. Risley and Howard E. Bussey reported studies indicating success with calculations on nonresonant circuits modeled using resonant-circuit theory.[182]

Measurement Techniques

Progress in an international intercomparison of electromagnetic measurements at high frequencies—from 30 kHz to 40 GHz—were reported by Myron C. Selby.[183] Besides NBS, other international organizations involved in the project included the International Electrotechnical Commission, the International Radio Scientific Union and the International Bureau of Weights and Measures. At that time, measurements of power, attenuation, and permittivity already had been compared; the new objective was to standardize both measuring equipment and measurement procedures.

In a related effort, A. Y. Rumfelt and Lyman B. Elwell reviewed bolometric, calorimetric, and other types of radio-frequency power measurements, emphasizing techniques for minimizing error from mismatch, dc substitution, and bolometer-mounting inefficiency.[184] An error analysis in the use of a Wollaston-wire element in bolometers (a device known as a barretter) was outlined as well, by Stephen Jarvis, Jr., and John W. Adams.[185]

Donald N. Homan showed how parasitic loop currents in ac bridge circuits could be suppressed by the use of coaxial choke coils.[186] This technique soon became standard practice.

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[181] Winston W. Scott, Jr. , and Nolan V. Frederick, "The measurement of current at radio frequencies," *Proc. IEEE*, **55**, No. 6, pp. 886-891 (1967).

[182] A. S. Risley and H. E. Bussey, "Interpretation of ferromagnetic resonance measurement made in a nonresonant system," *IEEE Trans. Instr. Meas.* **IM-5**, No. 4, 393-396 (1966).

[183] M. C. Selby, "International comparison of measurements at high frequencies," *IEEE Spectrum* **3**, No. 1, 89-98 (1966).

[184] A. Y. Rumfelt and L. B. Elwell, "Radio frequency power measurements," *Proc. IEEE* **55**, No. 6, 837-850 (1967).

[185] S. Jarvis, Jr. and J. W. Adams, "Calculation of substitution error in barretters," *J. Res. NBS* **72C**, No. 2, 127-237 (1968).

[186] D. N. Homan, "Applications of coaxial chokes to ac bridge circuits," *J. Res. NBS* **72C**, No. 2, 161-165 (1968).

Microwave Attenuation

Robert W. Beatty, scientific consultant to division chief Helmut Altschuler, described microwave attenuation measurements and standards in NBS Monograph 97.[187] Ramon L. Jesch and Robert M. Jickling outlined the principles of impedance measurements for coaxial waveguides.[188]

Time and Frequency Division/Boulder (James A. Barnes, Chief).

James L. Jesperson was in charge of one of the division's three sections, frequency and time dissemination research; Donald W. Halford led another, atomic frequency and time standards. Peter P. Viezbicke headed the time and frequency broadcast services.

Calibration Services

Most of the services concerning NBS time and frequency were delivered via the broadcast signals from radio stations WWV, WWVL, WWVB, and WWVH. These signals included standard radio frequencies, standard audio frequencies, standard musical pitch, standard time intervals, time of day, universal time (UT2) corrections, radio propagation forecasts, and geophysical alerts. NBS Special Publication 236, *NBS Frequency and Time Broadcast Services*, issued in 1968, provided a brief discussion of these services. However, the division also offered an in-house frequency-calibration service involving direct comparison of the user's signal source with the NBS Frequency Standard.

Alvin H. Morgan reviewed the distribution of the standard time and frequency signals in a paper prepared for the *Proceedings of the IEEE*.[189]

A New International Unit of Time

As a result of research performed over the previous several years, much of it at NBS, the 13th General Conference on Weights and Measures was able to adopt a new definition of the second. The new definition was: "The second is the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two nuclear hyperfine levels of the fundamental state of the atom of cesium-133." Heavily involved in the research that led to the new definition were James Barnes and David W. Allan.[190]

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[187] R. W. Beatty, "Microwave measurements and standards," *NBS Monograph 97*, April 1967.

[188] R. L. Jesch and R. M. Jickling, "Impedance measurements in coaxial waveguide systems," *Proc. IEEE* 55, No. 6, 912-923 (1967).

[189] A. H. Morgan, "Distribution of standard frequency and time signals," *Proc. IEEE* 55, No. 6, 827-836 (1967).

[190] J. A. Barnes and D. W. Allan, "An approach to the prediction of coordinated universal time," *Frequency*, 5, No. 6, 15-20 (1967).

Frequency Standards

David Allan also published a theoretical treatment on the statistics of frequency standards based on atomic transitions.[191] The work established a relationship between the expectation value for the standard deviation of the frequency fluctuations of short-term data samples and the infinite-duration standard deviation. It also included methods for determining the power spectral density of the frequency fluctuations, the sampling time, and the dependence on system bandwidth.

In a cooperative study involving the NBS Time and Frequency Division, the Quantum Electronics Division of Varian Associates, and the Hewlett-Packard Co, an intercomparison was completed for hydrogen and cesium frequency standards. These standards included the NBS III cesium-beam United States Frequency Standard, a cesium-beam device from Hewlett-Packard, and two hydrogen masers built by Varian Associates.[192] The group found that the level of stability exhibited by the two hydrogen masers reached 1×10^{-13} over a two-month period. The other devices showed similar levels of stability. The frequency of the atomic transition in hydrogen observed during the work, corrected to conditions of free space, zero magnetic field, and zero absolute temperature was (1420,405,751.7860 ± 0.0046) Hz.

Flicker Noise

The subject of flicker noise—random noise occurring in electrical circuits, whose spectral density is larger at lower frequencies—was treated by Donald Halford. He developed a general mechanical model for frequency-dependent noise.[193] This topic had been treated earlier by Barnes and Allan, using the method of fractional order of integration.[194]

Laboratory Astrophysics Division/Boulder (Lewis M. Branscomb, Chief).

The Laboratory Astrophysics Division served as the "home" for NBS staff members working at the Joint Institute for Laboratory Astrophysics (JILA). The brainchild of Lewis Branscomb and Richard N. Thomas, JILA was established in 1962 on the campus of the University of Colorado at Boulder. The LAD/JILA group quickly became known within NBS as a fertile source of scientific achievement in aerospace physics. The intimate connection with the graduate program of the University of Colorado provided an abundant supply of eager scientific collaborators. Branscomb was the first LAD chief.

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[191] D. W. Allan, "Statistics of atomic frequency standards," *Proc. IEEE* **54**, No. 2, 221-230 (1966).

[192] R. Beehler, D. Halford, R. Harrach, D. Allan, D. Glaze, C. Snider, J. Barnes, R. Vessot, H. Peters, J. Vanier, L. Cutler, and L. Bodily, "An intercomparison of atomic standards," *Proc. IEEE* **54**, No. 2, 301-302 (1966).

[193] D. Halford, "A general mechanical model for $|f|^{\alpha}$ spectral density random noise with special reference to flicker noise $1/|f|$," *Proc. IEEE* **56**, No. 3, 251-258 (1968).

[194] J. A. Barnes and D. W. Allan, "A statistical model of flicker noise," *Proc IEEE* **54**, No. 2, 176-178 (1966).

Laser Technology

Laser technology became one of the first major efforts in a collaboration that linked scientists from several divisions. As noted previously, Donald A. Jennings, Chief of the Quantum Electronics Section of the Radio Standards Physics Division, built the first laser at the Boulder site. John L. Hall, who came to the Bureau as a Postdoctoral Research Associate, received the Department of Commerce Gold Medal Award in 1970 for his exceptional research on lasers and their application to length metrology. Details of laser collaborations appear in later chapters.

Wolf-Rayet Stars

A small (38 participants) symposium on Wolf-Rayet stars was held at the University of Colorado June 10-14, 1968. The symposium was co-sponsored by the American Astronomical Society, the Harvard College Observatory, JILA, and the Smithsonian Astropysical Observatory. Katharine B. Gebbie and Richard N. Thomas edited the proceedings.[195] An interesting feature of the 275-page proceedings is that an enormous amount of astronomical effort up to that time had apparently produced relatively few widely held conclusions regarding an interesting group of radiating celestial objects.

Electron Scattering in Stars

The importance of Doppler noncoherence in electron scattering in particular types of stars was discussed by David Hummer and D. Mihalas in the *Astrophysics Journal.*[196]

In a study of excitation of light atoms, Robert L. Long, Jr., Donald M. Cox, and Stephen J. Smith reported an investigation of the excitation of the 2p state of atomic hydrogen by electron impact.[197] The results confirmed the existence of a substantial discrepancy between theoretical predictions and experimental findings at electron energies below 50 eV.

Branscomb, the Division Chief, described his study of photodetachment of the negative hydroxyl ion,[198] and summarized the progress in electron atomic and molecular physics over the previous two decades.[199]

[195] Katharine B. Gebbie and Richard N. Thomas, editors, "Wolf-Rayet Stars" in *Proceedings of a Symposium Held at the Joint Institute for Laboratory Astrophysics, University of Colorado, Boulder, CO, June 10-14, 1968,* NBS Special Publication 307, December 1968, 275 pp.

[196] D. G. Hummer and D. Mihalas, "Line formation with noncoherent electron scattering in O and B stars," *Astrophys. J.* **150**, No. 1, L57-L59 (1967).

[197] R. L. Long, Jr. , D. M. Cox, and S. J. Smith, "Electron impact excitation of hydrogen Lyman-α radiation," *J. Res. NBS* **72A**, No. 5, 521-535 (1968).

[198] L. M. Branscomb, "Photodetachment cross section, electron affinity, and structure of the negative hydroxyl ion," *Phys. Rev.* **148**, No. 1, 11-18 (1966).

[199] L. M. Branscomb, "Twenty years of physics: atoms, molecules, and electrons," *Physics Today* **21**, No. 5, 36-39 (1968).

Cryogenics Division/Boulder (Dudley B. Chelton, Acting Chief).

Members of the Cryogenics Division participated in nearly every major U.S. cryogenic engineering program from the time of its founding. Of particular importance to America's space effort was the division's studies of the thermodynamic properties of fluids, in the early days directed by Robert J. Corruccini.

The Division provided many services to the cryogenics community in 1968. The Cryogenic Data Center, headed by Victor J. Johnson, collected low-temperature-properties information on materials of interest to both engineers and scientists. Other division work featured research on cryogenic properties of solids—headed by Richard H. Kropschot—and fluids, under the temporary leadership of Duane L. Diller. Research on fluid-transport systems was led by R. V. Smith, and cryogenic systems research was headed by R.W. Arnett on an acting basis. Cryogenic metrology was the specialty of a group led by Douglas B. Mann. W. A. Wilson headed a group offering cryogenic technical services.

Thermal Properties

The kinetic-theory approach to transport-property calculations for dilute gases was employed by Howard J. M. Hanley and Gregory E. Childs to derive values for the coefficients of viscosity and thermal conductivity of dilute nitrogen and oxygen[200] and, in a separate *NBS Technical Note,* of dilute neon, krypton, and xenon.[201] In this context, the term 'dilute' reflected the temperature-dependent choice of a typical interatomic spacing, chosen with a particular calculational method in mind.

During the 10th International Conference on Low Temperature Physics, held in Moscow in 1966, John J. Gniewek, John C. Moulder, and Richard H. Kropschot reported measurements of the electrical conductivity of copper single crystals and polycrystalline wire in the temperature range from 4 K to 77 K.[202] Resistivity ratios (273 K/4 K) exceeded 3×10^4 and 1×10^4, respectively. In a related effort, L. A. Hall reported results of a survey of electrical resistivity measurements on 16 pure metals in the range 0 K to 273 K.[203] Graphs illustrating the differences between samples of varying size and purity were included.

Integrated tables of pressure, volume, and temperature, from the triple point to the critical point of saturated liquid oxygen, nitrogen, argon, and parahydrogen, were presented by Hans M. Roder, Robert D. McCarty, and Victor J. Johnson.[204]

[200] G. E. Childs and H. J. M. Hanley, "The viscosity and thermal conductivity coefficients of dilute nitrogen and oxygen," *NBS Technical Note 350,* October 1966.

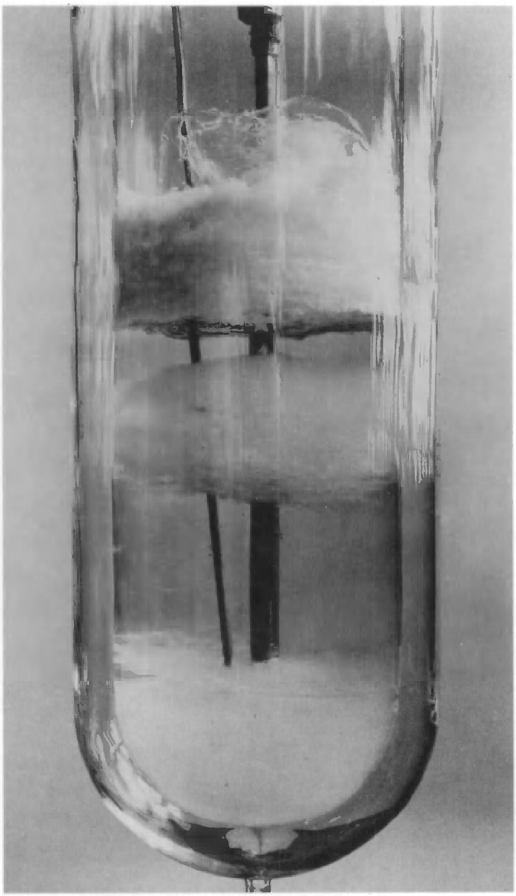
[201] H. J. M. Hanley and G. E. Childs, "The viscosity and thermal conductivity coefficients of dilute neon, krypton, and xenon," *NBS Technical Note 352,* March 1967.

[202] J. J. Gniewek, J. C. Moulder. and R. H. Kropschot, "Electrical conductivity of high purity copper," in *Proc. Tenth Intern. Conf. Low Temperature Physics, Moscow, USSR, Aug. 31-Sept. 9, 1966,* (Moscow, USSR: Viniti, 1967), pp. 366-370.

[203] L. A. Hall, "Survey of electrical resistivity measurements on 16 pure metals in the temperature range 0 to 273 °K," *NBS Technical Note 365,* February 1968.

[204] H. M. Roder, R. D. McCarty, and V. J. Johnson, "Saturated liquid densities of oxygen, nitrogen, argon, and parahydrogen," *NBS Technical Note 361,* January 1968. 70 pp.

In a study related to the needs of the National Aeronautics and Space Administration for data on liquid and solid hydrogen, David E. Daney, Paul R. Ludtke, Dudley B. Chelton, and Charles F. Sindt described certain physical properties of "slush" hydrogen, composed of partially frozen hydrogen of high enthalpy content.[205]



Slush hydrogen was formed at the bottom of this Dewar flask. Solid hydrogen, formed on the surface of liquid hydrogen, sank to the bottom and broke into very fine particles. This combination of liquid and very fine, solid particles of hydrogen—slush hydrogen—provided a desirable rocket fuel.

As a first step in the critical evaluation of the thermophysical properties of methane at low temperatures, L. A. Hall presented a bibliography of these properties selected for the temperature range 0 K to 300 K.[206] The bibliography contained more than 600 references.

[205] D. E. Daney, P. R. Ludtke, D. B. Chelton, and C. F. Sindt, "Slush hydrogen pumping characteristics," *NBS Technical Note 364*, April 1968.

[206] L. A. Hall, "A bibiography of thermophysical properties of methane from 0 to 300 °K," *NBS Technical Note 367*, May 1968.

Cryogenic Thermometry

Lawrence L. Sparks and Robert L. Powell described the results of a study of low-temperature thermocouple thermometers in the range 78 K to the ice point.[207] In this work, they produced tables of emf *vs* temperature, as well as typical levels of reproducibility.

Cryogenic Flow

In a study that also was related to the design of cryogenic fluid-transport equipment, James A. Brennan, D. K. Edmonds, and Raymond V. Smith recorded experimental results of two-phase, mass-limiting flow measurements on hydrogen and nitrogen.[208] The experimental data were compared to the results of simple analytical model calculations.

Design of Cryogenic Apparatus

Ray Radebaugh presented a complete and consistent set of data for the thermodynamic properties of liquid ^{3}He – ^{4}He solutions for the temperature range 0 K to 1.5 K.[209] The information was important for the optimization of the design of a novel, effective type of cryogenic refrigeration based on the injection of liquid ^{3}He into liquid ^{4}He in the region below 1 K. The so-called "^{3}He – ^{4}He dilution refrigerator" had been suggested by Heinz London in 1951, but only in 1966 had a successful model been built by Hall, Ford, and Thompson of the University of Manchester in the United Kingdom.

A detailed analysis of the performance of the type of refrigerator conceived in 1873 for use at much higher temperatures by George Brayton, a Boston engineer, was presented by R. C. Muhlenhaupt and T. Richard Strobridge.[210] The Brayton cycle had seen extensive use in aircraft cooling and was considered a good candidate for use in space-flight power systems. Muhlenhaupt and Strobridge discussed the use of nitrogen, parahydrogen, and helium as potential refrigerants. Some 75 tables of projected performance data were included in the note.

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[207] L. L. Sparks and R. L. Powell, "Cryogenic thermocouple thermometry," *Meas. Data* **1**, No. 2, 82-90 (1967).

[208] J. A. Brennan, D. K. Edmonds, and R. V. Smith, "Two-phase (liquid-vapor), mass-limiting flow with hydrogen and nitrogen," *NBS Technical Note 359,* January 1968.

[209] R. Radebaugh, "Thermodynamic properties of He^3–He^4 solutions with applications to the He^3–He^4 dilution refrigerator," *NBS Technical Note 362,* December 1967.

[210] R. C. Muhlenhaupt and T. R. Strobridge, "An analysis of the Brayton cycle as a cryogenic refrigerator," *NBS Technical Note 366,* August 1968.

Institute for Materials Research (John D. Hoffman, a theoretician in the field of polymer science, was appointed Director of IMR in 1968).

Whereas the mission of the Institute for Basic Standards was focused on the maintenance and creation of standards of physical measurement, that of the IMR was to assist and stimulate industry in the development of new and improved products by increasing the understanding of the relevant properties of useful materials; to develop criteria by which the performance characteristics of basic materials could be evaluated; and to create standard reference materials to facilitate measurement comparisons and tc aid in the control of production processes.

Office of Standard Reference Materials (Wayne W. Meinke, Chief).

The program in standard reference materials was one of the most successful of all Bureau activities. Even as an unofficial service, the program had benefited U.S. scienc and industry from 1905 by furnishing standard samples, standard materials, and reference materials. The activity had begun in response to a request from the Americar Foundrymen's Association for help in producing standard samples of cast iron to promote uniform analytical and manufacturing techniques.[211] In 1950, Congress amended the NBS enabling legislation—in part to create a more direct emphasis on standard reference materials. In 1964, the title Standard Reference Materials was given to a freshly integrated program and the OSRM was formed with Meinke as its head.

The official mission of the OSRM was to evaluate the requirements of science and industry for carefully characterized reference materials and to stimulate NBS efforts to create, produce, and distribute such materials. As a "matrix-management" office, the OSRM was substantially smaller than a technical division. J. Paul Cali served as Deputy Chief, John L. Hague was coordinator for research on inorganic standards, Robert E. Michaelis coordinated work on metallic standards, Thomas W. Mears was the coordinator for organic standards, Hugh F. Beeghly provided technical liaison, and Margaret E. Guggenheimer was the Administrative Officer. There were about a dozen other OSRM employees. Two were machinists, preparing samples; Herbert L. Carter and G. Eugene Deardorff. The others were administrative staff; Margaret E. Graury, Linda L. Grimes, James L. Izlar, Suzanne Chew Love, Ruth H. Meyer, William P. Reed, Mary H. Roth, Patricia E. Schmitz, Connie L. Stanley, Robert J. Stewart, and Leo F. Wright. Their responsibilities included preparing certificates, tracking funding and expenditures, interacting with the public, and preparing program information.

As a consequence of their many contributions to the Nation's technology, standard reference materials were one of the outputs of the Bureau that was easiest for the layman to understand.

[211] See "Measures For Progress," p. 93.

Standard Reference Materials (SRMs) were well-characterized materials that proved extremely useful in calibration programs or as references for the control of commercial or scientific processes. After preparation at the Bureau or elsewhere, SRMs were compared to NBS master standards and certified with respect to a particular characteristic. The NBS certification was provided as a quantity, with a numerical value and uncertainty limits that enabled the users to make comparisons with their own products rather than to perform absolute determinations of the characteristic, a far more challenging task.

In 1968, NBS Miscellaneous Publication 260, *Standard Reference Materials: Catalog and Price List of Standard Materials Issued by the National Bureau of Standards* provided a ready guide to the availability and cost of these materials. Over 650 different types of SRM's in 70 different categories were in production, in compositions as diverse as biological specimens, ceramics, chemicals, gases, metals, minerals, ore samples, polymers, and radioisotopes. These materials were used as references in such enterprises as aerospace, oceanography, pollution control, nuclear energy, medicine, and transportation, as well as in the manufacture of pharmaceuticals, plastics, glass, cement, steel, and non-ferrous metals.

The SRM program at the Bureau circa 1968 was partly self-supporting through sales of the individual units; the sales price of each unit was set so as to recover the cost to produce it. In 1968 some 43,000 units were sold to more than 4500 customers, returning just over $1 million to NBS to continue the program. Often a particular SRM was developed in the course of a project whose objective was essentially unrelated to the eventual use of the unit; demand for the standard from potential customers would then be satisfied by initiating a production project within NBS which would last until the demand was satisfied or until the reference standard might become available from a source outside the Bureau.

During 1968 more than 100 SRMs were introduced or renewed. Thirteen of the Bureau's technical divisions were involved in producing these standards. Among the new materials were the following:

- *SRM 911, Certified Purity Cholesterol.*

This standard, requested by the College of American Pathologists and the American Association of Clinical Chemists, provided a cholesterol reference of high purity, (99.4±0.3) %, for laboratory comparisons. The purity was determined using several methods—gas chromatography; thin-layer chromatography; and mass, infrared, and nuclear magnetic resonance spectroscopy. The analyses were performed by Alex Cohen, David H. Freeman, Robert T. Leslie, Rolf A. Paulson, Charles B. Romain, and Robert Schaffer of the Analytical Chemistry Division and Connie L. Stanley of the Office of Standard Reference Materials.[212]

[212] Copies of the certificates that accompanied each shipment of SRMs were kept on file in the OSRM. The information given in this section came mostly from review of certificates in the files.

- *SRM 680 and 681, High-Purity and Doped Platinum.*

These standards were prepared as reference materials for the analysis of purified platinum, which was used in a variety of technical applications. The high-purity samples contained a total of only about 10 parts per million (ppm) by weight of oxygen or metallic impurities; each lot was certified as to impurity levels. The doped samples typically contained 2 ppm to 10 ppm each of a list of a dozen common impurities, again with the amounts in each lot certified. In this case, the samples were prepared by commercial laboratories, then tested both at NBS and at participating laboratories for impurity levels and homogeneity.

- *SRM 1621 and 1622, Sulfur in Residual Fuel Oil.*

About 16 % of the sulfur dioxide that appeared as an air pollutant in 1968 came from residual fuel oil. SRMs 1621 and 1622 were produced to provide references for the analysis of fuel oil for sulfur. They were prepared from commercial fuel oils with natural sulfur contents. Gravimetric analysis of the sulfur content showed values certified to be (1.05 ± 0.02) % and (2.14 ± 0.01) %. The analytic work was performed by Booker S. Carpenter, Rolf A. Paulson, and William P. Schmidt of the NBS Analytical Chemistry Division.

- *SRM 701b, Standard Light-Sensitive Papers.*

This standard was developed to evaluate the dosage of radiant energy of commercial carbon-arc lamps that were used to test textiles for fading on exposure to light. The papers used in the SRM were prepared at the NBS paper mill under the supervision of Donald G. Fletcher, then calibrated by Paul J. Shouse and Elio Passaglia of the Polymers Division, using a standard carbon arc.

- *SRM 114L, Surface Area of Portland Cement.*

This type of standard had been used for more than a quarter-century as a reference in cement manufacture. The mean particle diameter and the surface area per gram as determined by two commercially available instruments were certified by members of the NBS Building Research Division.

- *SRM 981, 982 & 983, Isotopic Standards for Lead.*

Isotopic abundance ratios of lead samples were used in measuring the age of rocks, meteorites, and mineral deposits—important information for geological work throughout the world. However, great accuracy in measurement of the ratios was required in order to achieve believable results. These three new SRMs allowed laboratory personnel to calibrate with suitable accuracy the instruments used in this type of geologic measurements, as well as satisfying the many other requirements for isotopic standards of lead.

The SRMs provided three different ratios of the lead isotopes of mass 204, 206, 207, and 208, with the atomic fraction of each isotope certified within 0.01 % or better (substantially better, for the geological-age projects mentioned above). Preparation and analysis were performed by Edward J. Catanzaro, Thomas J. Murphy, William R. Shields, and Ernest L. Garner of the Analytical Chemistry Division.

- *SRM 1010, Microscopy Resolution Test Charts.*

American industrial and governmental organizations spent nearly $300 million annually to preserve records on microfilm. To ensure that the records were of adequate quality, it was necessary to evaluate the resolving power of the filming system in several positions of the focusing field. This SRM, periodically renewed, provided test patterns for that purpose. The latest charts provided 26 patterns ranging from 1 to 18 cycles per mm. The samples were prepared in the Institute for Basic Standards.

Responsibilities of Other IMR Divisions

Apart from the Office of Standard Reference Materials, the divisions of the IMR shared several responsibilities, including the following:

- Conduct research on constants of chemistry and physics, on properties and structure of matter.
- Develop methods for the preparation, purification, and analysis of materials.
- Investigate fundamental phenomena of importance to science and industry, including the effects of extremes of temperature and pressure and of radiation.
- Assist in the development of standard testing methods for materials.
- Develop and produce standard reference materials.
- Provide advice to government, science, and industry on basic materials problems.

Analytical Chemistry Division (Wayne W. Meinke, Chief).

The Analytic Chemistry Division housed a wide range of research and service work in nine sections—radiochemistry, James R. DeVoe, chief; spectrochemistry, Bourdon F. Scribner, chief; electrochemistry, Roger G. Bates, chief; analytical coordination chemistry, Oscar Menis, chief; microanalysis, John K. Taylor, chief; mass spectrometry, William R. Shields, chief; organic chemistry, Robert Schaffer, chief; activation analysis, Philip D. La Fleur, chief; and separation and purification, David H. Freeman, chief.

Section Summaries

An excellent summary of the activities of the Analytical Chemistry Division in the area of spectrochemical analysis was prepared as an *NBS Technical Note.*[213] Technical

[213] "Spectrochemical Analysis Section: Summary of Activities, July 1967 to June 1968," Bourdon F. Scribner, editor, *NBS Technical Note 452*, January 1968.

areas covered in the summary included optical spectrometry, electron probe microanalysis, x-ray fluorescence spectrometry, spark-source mass spectrometry, and analysis of high-purity materials.

A similar synopsis, this time in the areas of gravimetry, titrimetry, spectrophotometry, spectrofluorometry, and the analysis of gases in metals, was published in *Technical Note 424.*[214]

Technical Note 429, edited by David H. Freeman, Chief of the Separation and Purification Section of the Analytical Chemistry Division, contained a discussion of the activities in that section in ion exchange, ultrapure reagents, purification techniques, and crystallization.[215]

Roger G. Bates, Chief of the Electrochemical Analysis Section, prepared a summary of work done in that area.[216] Types of projects covered included acidity measurements, solvent effects on electrolyte processes, standardization of ion-selective electrodes, equilibrium ionic systems, conductance and transport by electrolytes, and preparation and properties of solvents.

The activities of the Microchemical Analysis Section, headed by John K. Taylor, the "grand old man" of NBS who, on his retirement in 1986, had accumulated 57 years of continuous service with the Bureau, were summarized in NBS Technical Note 455.[217] Topics covered included gas analysis, polarographic analysis, coulometric analysis, electroanalytical measurements, and microscopic and classical microchemical analysis.

Progress in mass spectrometry and testing of a new mass spectrometer, the formation of a new chemistry group to perform precise analytical work, and results in that area were summarized by William R. Shields, Chief of the Analytical Mass Spectrometry Section.[218]

Section chief Robert Schaffer reviewed progress in the Organic Chemistry Section in carbohydrate synthesis, structure, and characterization; clinical chemistry; polycyclic air-pollutant properties; and standard reference materials.[219]

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[214] "Analytical Coordination Chemistry: Titrimetry, Gravimetry, Flame Photometry, Spectrophotometry, and Gas Evolution," Oscar Menis, editor, *NBS Technical Note 424,* January 1968.

[215] "Separation and Purification Section: Summary of Initial Activities, February 1966 through June 1967," David H. Freeman, editor, *NBS Technical Note 429,* February 1968. The summary is continued in Technical Note 459, December 1968.

[216] "Electrochemical Analysis Section: Summary of Activities, July 1967 to June 1968, Roger G. Bates, editor," *NBS Technical Note 453,* July 1968.

[217] "Microchemical Analysis Section: Summary of Activities, July 1967 to June 1968," John K. Taylor, editor, *NBS Technical Note 455,* October 1968.

[218] "Analytical Mass Spectrometry Section: Summary of Activities, July 1967 to June 1968," William R. Shields, editor, *NBS Technical Note 456,* November 1968.

[219] "Organic Chemistry Section: Summary of Activities, July 1967 to June 1968," Robert Schaffer, editor, *NBS Technical Note 457,* September 1968.

Isotopic Characterization

In a series of investigations of absolute isotopic abundance ratios of high-purity elements important to science and industry, Edward J. Catanzaro, Thomas J. Murphy, William R. Shields, and Ernest L. Garner reported mass-spectrometric evaluations of the isotopic abundance ratios for several types of carefully prepared elemental samples. One of these was magnesium; the natural abundance ratios $^{25}Mg/^{24}Mg$ and $^{26}Mg/^{24}Mg$ were found to be 0.12663 ± 0.00013 and 0.13932 ± 0.00026, respectively, at the level of 95 % confidence, yielding a new value of the atomic weight for Mg (based on $^{12}C = 12$) of 24.30497 ± 0.00044.[220] Another study focused on common lead, "equal-atom" lead, and "radiogenic" lead, important for geological dating.[221] Yet a third investigation, of terrestrial rubidium, established the abundance ratio $^{85}Rb/^{87}Rb = 2.59265 \pm 0.00170$, indicating an atomic weight of 85.46776 ± 0.00026, again at 95 % confidence.[222] The authors made particular efforts to calibrate the two mass spectrometers used in the study in order to provide absolute values. The isotopic lead mixtures were offered for sale through the Standard Reference Materials Program.

Chemical Synthesis

Alexander J. Fatiadi was clearly one of the more prolific writers among the chemists at the Bureau during this period. He published 10 papers by himself between 1966 and 1968, and several others in collaboration with colleagues. His forte was the synthesis and analysis of polycyclic, aromatic hydrocarbons of importance to air-pollution studies.[223, 224, 225]

Microanalysis

Kurt F. J. Heinrich completed development of a new technique for microanalysis that utilized scans with an electron microprobe x-ray emission spectrometer.[226] The new method was expected to be particularly useful where spatial relationships were important. Heinrich also wrote a description of the principles and techniques of

[220] E. J. Catanzaro, T. J. Murphy, E. L. Garner, and W. R. Shields, "Absolute isotopic abundance ratios and atomic weight of magnesium," *J. Res. NBS* **70A**, No. 6, 453-458 (1966).

[221] E. J. Catanzaro, T. J. Murphy, W. R. Shields, and E. L. Garner, "Absolute isotopic abundance ratios of common, equal-atom and radiogenic lead isotopic standards," *J. Res. NBS* **72A**, No. 3, 261-267 (1968).

[222] E. J. Catanzaro, T. J. Murphy, E. L. Garner, and W. R. Shields, "Absolute isotopic abundance ratio and atomic weight of terrestrial rubidium," *J. Res. NBS* **73A**, No. 5, 511-516 (1969).

[223] A. J. Fatiadi, "Preparation and purification of some oxidation products of perylene," *J. Res. NBS* **72A**, No. 1, 39-47 (1968).

[224] A. J. Fatiadi, "Periodic acid, a novel oxidant of polycyclic, aromatic hydrocarbons," *J. Res. NBS* **72A**, No. 4, 341-350 (1968).

[225] A. J. Fatiadi, "Effects of temperature and of ultraviolet radiation on pyrene adsorbed on garden soil," *Envir. Sci. Tech.* **1**, No. 7, 570-572 (1967).

[226] K. F. J. Heinrich, "Scanning electron probe microanalysis," *NBS Technical Note 278*, February 1967.

electron-microprobe analysis for the book *Advances in Materials Research.* [227] The subject "Quantitative Electron Probe Microanalysis" was the topic of a two-day seminar featuring a baker's dozen of speakers. The papers given during the seminar were preserved in NBS Special Publication 298, edited by Heinrich and issued during October 1968.

Automatic Data Acquisition

To assist scientists interested in the use of computers in the acquisition of laboratory data, Stanley D. Rasberry, Marvin Margoshes, and Bourdon F. Scribner described the use of a time-sharing computer in optical emission and x-ray fluorescence measurements.[228] Their installation involved the use of a teletype terminal that could utilize the Dartmouth College time-sharing computer system.

Chemical Constants

Robert A. Robinson and Roger G. Bates, in collaboration with A. K. Covington, a colleague on leave from the University of Newcastle-upon-Tyne in England, determined the ionization constant of deuterium oxide (heavy water) near room temperature.[229] The measurements were accomplished in an electromotive cell without a liquid junction; in presenting their results, the authors illustrated the differences among values of pK—the negative of the logarithm to the base 10 of the ionization constant—as expressed on the scales of molality (14.955), molarity (14.869) and mole fraction (16.653).

In August 1968 Marion Maclean Davis published Monograph 105, *Acid-Base Behavior in Aprotic Organic Solvents.* This 150-page work contained a unified picture of acid-base behavior in organic solvents of comparatively inert character. In such solvents as benzene, toluene, motor oils, and transformer oils, acids and bases behaved quite differently than they did in water; thus the solvents were often called "inert" or "aprotic." The study was based partly upon research done by the author and his colleagues, partly upon information obtained from literature in the field. Various erroneous ideas were corrected in the discussion, which contained a unifying explanation of acid-base concepts, hydrogen bonding, and types of acids, bases, and solvents.

Activation Analysis

Gilbert W. Smith, Donald A. Becker, George J. Lutz, Lloyd A. Currie, and James R. DeVoe illustrated the use of neutron activation analysis for the determination of the concentration of trace elements in high-purity substances such as Standard Reference

[227] K. F. J. Heinrich, "Electron probe microanalysis," in *Experimental Methods of Materials Research: Advances in Materials Research* (New York: John Wiley and Sons, Inc., 1967), pp. 145-162.

[228] S. D. Rasberry, M. Margoshes, and B. F. Scribner, "Applications of a time-sharing computer in a spectrochemistry laboratory: optical emission and x-ray fluorescence," *NBS Technical Note 407,* February 1968.

[229] A. K. Covington, R. A. Robinson, and R. G. Bates, "The ionization constant of deuterium oxide from 5 to 50 °," *J. Phys. Chem.* **70**, 3820-3824 (1966).

Materials.[230] The authors discussed the care necessary to obtain accurate results when using neutron activation analysis of trace impurities in complex materials; they found bias due to radiation unintentionally induced in the matrix, geometric placement errors, nonconstant shielding effects, and gamma-ray attenuation corrections.

In a related project, a four-person group from the division prepared a major compendium of references on activation analysis.[231] Dating the beginning of the activation analysis technique from work by Hevesy, Levi, Seaborg, and Livingood during the late 1930s, the Analytical Chemistry Division group noted that the rate of literature entries had grown exponentially over a 20-year period, exceeding 500 papers per year during 1968. George J. Lutz, Robert J. Boreni, Rosemary S. Maddock, and W. Wayne Meinke made up the group. They provided references to more than 8000 papers written throughout the world on activation analysis.

Crystal Studies

In a collaborative effort with Harvey Yakowitz of the Metallurgy Division, Donald L. Vieth developed a Kossel pattern generator to provide the means for obtaining crystal-lattice spacing with a precision of 1 ppm to 2 ppm and crystal orientation within an angle of 0.1°.[232] The instrument consisted of an electron beam column, a vacuum system, a light microscope, a film cassette, and a Kossel camera.

Polymers Division (Robert R. Stromberg, Acting Chief).

Work in the Polymers Division spanned the areas of dielectrics, under the leadership of Martin G. Broadhurst; the chemistry and physics of polymers, headed by Leo A. Wall and Ronald K. Eby, respectively; characterization, molecular and thermophysical properties, the first two areas in the charge of Cornelius A. J. Hoeve and the last under Alden B. Bestul; interfaces, led by Stromberg; and dental research, under George R. Dickson.

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[230] G. W. Smith, D. A. Becker, G. J. Lutz, L. A. Currie, and J. R. DeVoe, "Determination of trace elements in standard reference materials by neutron activation analysis," *Anal. Chim. Acta* **38**, 333-340 (1967).

[231] G. J. Lutz, R. J. Boreni, R. S. Maddock, and W. W. Meinke, editors, "Activation analysis: a bibliography, Part 1," *NBS Technical Note 467*, Part 1, September 1968;

G. J. Lutz, R. J. Boreni, R. S. Maddock, and W. W. Meinke, editors, "Activation analysis: a bibliography, Part 2—Appendices," *NBS Technical Note 467*, Part 2, September 1968;

G. J. Lutz, R. J. Boreni, R. S. Maddock, and W. W. Meinke, editors, "Activation analysis: a bibliography, Part 1, Addendum 1," *NBS Technical Note 467*, Part 1, Addendum 1, December 1969;

G. J. Lutz, R. J. Boreni, R. S. Maddock, and W. W. Meinke, editors, "Activation analysis: a bibliography, Part 2—Appendices, Revision 1," *NBS Technical Note 467*, Part 2, Revision 1, December 1969.

[232] D. L. Vieth and H. Yakowitz, "Design of a new Kossel pattern generator," *J. Res. NBS* **70C**, No. 4, 313-318 (1967).

Martin G. Broadhurst cut leaf wafers for a 1968 study of the dielectric properties of foliage. The data were employed in the design of radio antennas for use in heavily wooded areas.

Polymer Crystallization

John Lauritzen, Jr., an Institute Scientist, Elio Passaglia, newly appointed Chief of the Metallurgy Division, and Edmund A. DiMarzio discussed the kinetics of crystallization of binary mixtures of n-paraffins.[233] No data existed for this type of system, so the authors were constrained to a theoretical treatment of the topic. They employed a theory for the rate of growth of chains, assuming them to be strips of crystalline material composed of both components growing on a uniform substrate. They proposed a number of conclusions that would be subject to experimental verification.

Polymer Properties

With the collaboration of Jeffrey T. Fong, an NRC-NBS Postdoctoral Resident Research Associate, Jack C. Smith studied the mathematical theory of the coupling of longitudinal and transverse waves in a linear, three-element viscoelastic string that was subjected to transverse impact.[234]

[233] J. I. Lauritzen, Jr. , E. Passaglia, and E. A. DiMarzio, "Kinetics of crystallization in multicomponent systems: I. Binary mixtures of *n*-paraffins," *J. Res. NBS* **71A**, No. 4, 245-259 (1967).

[234] J. C. Smith and J. T. Fong, "On the coupling of longitudinal and transverse waves in a linear three-element viscoelastic string subjected to transverse impact," *J. Res. NBS* **72B**, No. 3, 201-214 (1968).

Theoretical models were developed for the dielectric and mechanical relaxation effects found in the polymers polyethylene and polychlorotrifluoroethylene. The new work, reported by John D. Hoffman, G. Williams, and Elio Passaglia, shed light on the processes of chain-folding in these polymers.[235]

Frederick I. Mopsik reported on the temperature, pressure and density variations of the dielectric constant of n-hexane.[236] He also described the apparatus used in the measurements, a cell that was both a bellows dilatometer and a three-terminal electrode set that could be used to measure the density and the dielectric properties of liquid samples *vs* temperature and pressure, from 120 K to over 300 K and from 100 kPa to 2×10^8 Pa, with an overall uncertainty of 0.03 %.

Shu-Sing Chang, J. A. Horman, and Alden B. Bestul studied the interesting thermal properties of diethyl phthalate both below and above its crystalline-glass transition.[237] The temperature range covered was 10 K to 360 K; the data appeared to be precise within about 0.1 %.

Gerhard M. Brauer, George Durany, and Harold Argentar measured the ionization constants of substituted benzoic acids in an ethanol-water solution, part of a study of the reactivity of substituted phenols.[238] They found that the pK values increased with ethanol content, but that the relative acid strength did not depend on solvent concentration.

Robert E. Lowry, Daniel W. Brown, and Leo A. Wall discussed the radiation-induced polymerization of hexafluoropropylene at high temperature and pressure.[239] The experimental temperature range was 100 °C to 230 °C and the pressure range was 4.5×10^8 Pa to 15×10^8 Pa. At the top of both ranges and under a radiation flux of 1.5 kilorad/h, the polymerization rate was 15 %/h.

Measurement Techniques

A new low-frequency bridge for the measurement of dielectric constants was described by W.P. Harris.[240]

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[235] J. D. Hoffman, G. Williams, and E. Passaglia, "Analysis of the α, β, and γ relaxations in polychlorotrifluoroethylene and polyethylene: dielectric and mechanical properties," *J. Polymer Sci. Pt. C,* No. 14, 173-235 (1966). This paper was listed by the Science Citation Index as a "Citation Classic" with more than 200 citations even during the period 1974-89, some 8-23 years after its publication.

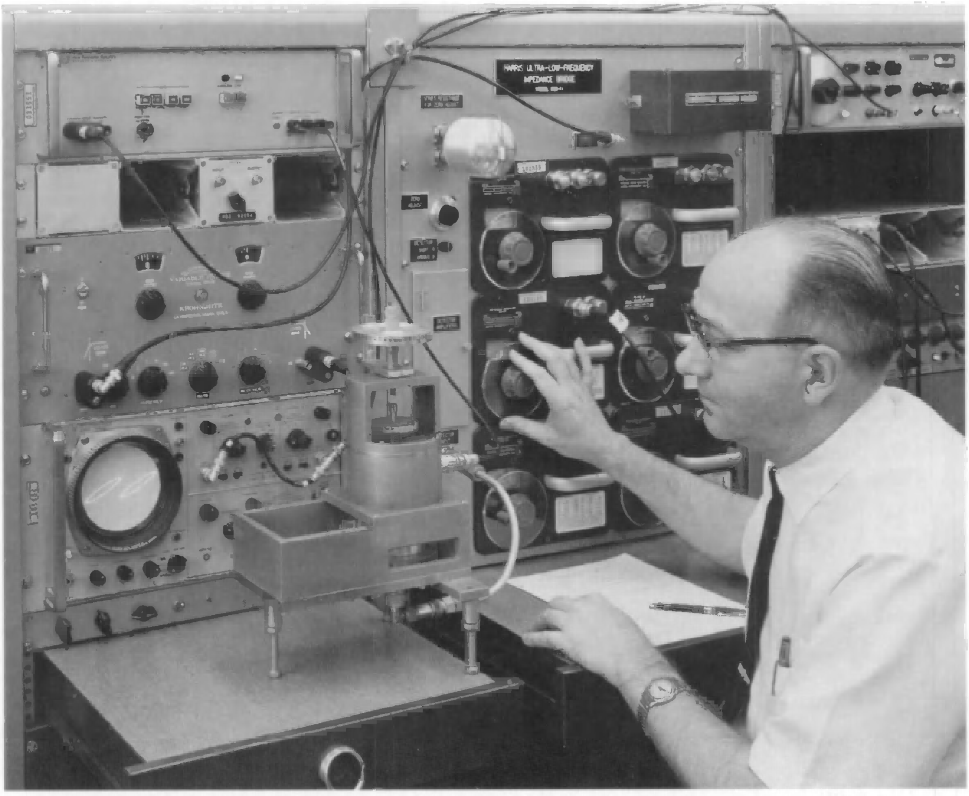
[236] F. I. Mopsik, "Dielectric constant of n-hexane as a function of temperature. pressure, and density," *J. Res. NBS* **71A**, No. 4, 287-292 (1967).

[237] S. S. Chang, J. A. Horman, and A. B. Bestul, "Heat capacities and related thermal data for diethyl phthalate crystal, glass, and liquid to 360 °K," *J. Res. NBS* **71A**, No. 4, 293-305 (1967).

[238] G. M. Brauer, G. Durany, and H. Argentar, "Ionization constants of substituted benzoic acids in ethanol-water," *J. Res. NBS* **71A**, No. 5, 379-384 (1967).

[239] R. E. Lowry, D. W. Brown, and L. A. Wall, "The radiation induced polymerization of hexafluoropropylene at high temperature and pressure," *J. Polymer Sci.* **4**, Part A-1, No. 9, 2229-2240 (1966).

[240] W. P. Harris, "A new ultra-low-frequency bridge for dielectric measurements," *1966 Annual Report Conf. Electrical Insulation and Dielectric Phenomena,* National Academy of Sciences-National Research Council, Mt. Pocono, PA, 1966, pp. 72-74.



William P. Harris of the National Bureau of Standards made dielectric measurements on a specimen with an NBS-constructed ultralow-frequency bridge. Such measurements were important for determining the suitability of materials for electrical insulation and for molecular behavior studies.

James P. Colson and Edward S. Clark, a colleague from duPont, produced tables of solutions to Bragg's equation for the Kα radiation from copper, cobalt, iron, and chromium.[241]

Dental Materials

A group of scientists working in the area of dental research, Philip L. Oglesby, George R. Dickson, M. L. Rodriguez, Ruth M. Davenport, and W. T. Sweeney, treated dental amalgams as viscoelastic materials.[242] They subjected the amalgams to tensile

[241] James P. Colson and Edward S. Clark, "Tables of solutions to Bragg's equation for copper, cobalt, iron, and chromium Kα radiation and small diffraction angles," *NBS Technical Note 461*, August 1968.

[242] 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).

stress and successfully analyzed the results in terms of the theory of viscoelasticity. Dickson, Oglesby, and Davenport further analyzed dental amalgam in terms of its steady-state creep behavior.[243]

Metallurgy Division (Elio Passaglia, Chief).

Research in the Metallurgy Division covered many areas. A section on engineering metallurgy was in the charge of Melvin R. Meyerson. Lawrence H. Bennett headed the alloy physics section. Work on lattice defects and microstructure was led by Arthur W. Ruff. Metallic corrosion was studied in a section headed by Jerome Kruger. John R. Manning headed the metal physics section. Abner Brenner was chief of the electrolysis and metal deposition section, and Robert L. Parker headed the metal crystallization section.

Corrosion

Fielding Ogburn and M. Schlissel completed a corrosion study of galvanic pitting in metallic coatings.[244] In this project, they made use of an electrolytic cell which simulated a corrosion pit that extended through the metal coating. By the use of this technique they were able to measure the cell currents. Combinations studied included chromium, copper, and nickel on substrates of zinc, iron, nickel, and copper.

In a related study, Jerome Kruger and Joan P. Calvert, using a fast-recording ellipsometer, observed the kinetics of film growth on samples of iron that had been passivated in various ways.[245] Three stages of growth were differentiated: diffusion-limited, limitation by other processes, and logarithmic or inverse-logarithmic rates.

Crystal Growth

Sam R. Coriell, formerly a Postdoctoral Research Associate in the Heat Division, and Robert L. Parker reported a theoretical investigation of the interface kinetics and the stability of the shape of a solid sphere growing from the melt.[246]

With the assistance of Hans Oser of the Applied Mathematics Division, John A. Simmons and Sam Coriell developed an integral equation describing the rate of growth of "whiskers." [247]

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[243] G. Dickson, P. Oglesby, and R. Davenport, "The steady-state creep behavior of dental amalgam," *J. Res. NBS* **72C**, No. 3, 215-218 (1968).

[244] F. Ogburn and M. Schlissel, "Galvanic pitting in metal coatings," *Plating* **54**, No. 1, 54-62 (1967).

[245] J. Kruger and J. P. Calvert, "Ellipsometric-potentiostatic studies of iron passivity. I. Anodic film growth in slightly basic solutions," *J. Electrochem. Soc.* **114**, No. 1, 43-49 (1967).

[246] S. R. Coriell and R. L. Parker, "Interface kinetics and the stability of the shape of a solid sphere growing from the melt," *Crystal Growth,* a Supplement to *J. Phys. Chem. Solids* **J3**, 703-708 (1967).

[247] J. A. Simmons, H. Oser, and S. R. Coriell, "On the solution of the Stefan problem for whisker growth," *Crystal Growth,* a Supplement to *J. Phys. Chem. Solids* **C8**, 255-264 (1967).

Field-Emission Microscopy

Allan J. Melmed was very productive during this period, even without considering work published jointly with other scientists. In 1967 he published a review of field-emission miscroscopy, treating the field-electron-emission microscope and the field-ion microscope separately. Elements covered included the imaging process and the capabilities, limitations and applications of each type of instrument.[248]

In the same year Melmed wrote a paper about diffusion on the surfaces of nickel and platinum leading to rearrangement which appeared to be due to a combination of electric fields and surface tension.[249] This process was studied by field-electron-emission spectroscopy. He also described the epitaxial growth of iron crystals by vapor deposition on tungsten field-emission point probes.[250] The crystals tended to nucleate in one particular crystallographic orientation.

In another study, Melmed observed differences between hexagonal-close-packed (hcp) and body-centered-cubic (bcc) metals in field-ion microscopy.[251] This work had been motivated in part by observations on field-ion micrographs of field-evaporated ruthenium compared with those of rhenium, both hcp.[252]

Melmed constructed a microscope that produced an electron shadow "image" of small electrically conducting objects in ultra-high vacuum. The instrument used an electron field emitter as a pseudo point source of electrons that shadowed the object on a phosphor screen.[253] In 1968 he wrote a chapter for a field-ion-microscopy text covering the topics of field-ion microscopy of whiskers, field-ion microscopy of thin films, field-ionization mass spectrometry, and biological-molecule imaging.[254]

Working with Howard P. Layer and Jerome Kruger, Melmed developed an experimental approach that permitted the simultaneous application of three techniques—ellipsometry, low-energy electron diffraction, and field-electron-emission microscopy—to the study of surface phenomena.[255] They demonstrated the technique by studying the adsorption of oxygen on the (001) plane of tungsten.

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[248] A. J. Melmed, "Field emission spectroscopy," chapter in *Advances in Materials Research*. Vol. **1**, Experimental Methods. H. Herman, editor, (New York: Interscience Publ. Inc., 1968), pp. 103-143.

[249] A. J. Melmed, "Surface self-diffusion of nickel and platinum," *J. Appl. Phys.* **38**, No. 4, 1885-1892 (1967).

[250] A. J. Melmed, "Epitaxial growth of iron on tungsten field emission points," *Surface Sci.* 7, No. 3, 478-81 (1967).

[251] A. J. Melmed, "Helium field-ion microscopy of hexagonal close-packed metals," *Surface Sci.* **8**, No. 12, 191-205 (1967).

[252] A. J. Melmed, "The structure of field-evaporated hexagonal close-packed metal surfaces: rhenium and ruthenium," *Surface Sci.* **5**, No. 3, 359-379 (1966).

[253] A. J. Melmed, "Field emission shadow spectroscopy," *Appl. Phys. Lett.* **12**, No. 3, 100-102 (1968).

[254] A. J. Melmed, "Whiskers, thin films, and applications (real and imagined) to mass spectrometry and biological molecule imaging," Chapter in *Field-Ion Microscopy*, J. J. Hren and S. Ranganathan, editors, (New York: Plenum Press Inc. , 1968), pp. 183-212.

[255] A. J. Melmed, H. P. Layer, and J. Kruger, "Ellipsometry, low energy electron diffraction and field emission microscopy combined," *Surface Sci.* **9**, 476-483 (1968).

Mechanical Properties

As part of a comprehensive program on the mechanical behavior of metals at elevated temperatures, William D. Jenkins and William A. Willard described creep tests on titanium-aluminum-molybdenum-vanadium alloys at temperatures as high as 650 °C.[256] Relation of the results to creep theory and to previous thermo-mechanical treatment of the materials yielded guidance for the engineering use of this type of material.

Mössbauer Effect

Lydon J. Swartzendruber reported the results of graduate research performed at the Bureau on the use of the Fe^{57} Mössbauer effect to study magnetic ordering in copper-rich copper-nickel-iron alloys.[257] Swartzendruber discussed the possible origin of a doublet structure observed in certain high-temperature spectra.

Properties of Nickel

A 150-page *NBS Monograph,* No. 106 issued in May 1968, illustrates one of the roles played by research associates at NBS. Samuel J. Rosenberg, a Research Associate from the International Nickel Company, prepared an extensive review of the available information on the production, properties, and uses of both high-purity and commercial forms of nickel and its alloys. Superseding a 10-year-old NBS Circular on the same topic, the document offered guidance on chemical and physical properties and methods of analysis.

Project Summaries

A summary of eight high-temperature, materials-research projects at NBS that were supported by the Advanced Research Projects Agency was edited by Elio Passaglia, the Metallurgy Division chief. [258] The projects were performed in several different divisions of NBS. Each project was briefly described by the scientist involved: diffusion in refractory metals, by John B. Wachtman, Jr. , and Alan L. Dragoo; deformation and fracture of ionic crystals, by Sheldon M. Wiederhorn and Leonard H. Bolz; optical constants of titanium, by Allan J. Melmed and James J. Carroll; high-temperature creep in metals, by Armin A. O. Rukwied, William A. Willard, and D. E. Darne; electronic structure of hard, refractory metals, by John R. Cuthill and

[256] W. D. Jenkins and W. A. Willard, "Creep rupture properties of Ti-8Al-1Mo-1V alloy," *J. Res. NBS* **72C**, No. 2, 167-174 (1968).

[257] L. J. Swartzendruber, "Mössbauer effect study of magnetic ordering in copper-rich Cu-Ni-Fe alloys," NBS *Technical Note 463,* August 1968.

[258] "Research on high temperature materials at the National Bureau of Standards," Elio Passaglia, Editor, *NBS Technical Note 447,* July 1968.

Archie J. McAlister; crystal growth from vapor, by Harry S. Parker and Chester A. Harding; high-temperature crystal growth from solvents, by Jun Ito and Harold Johnson; high-temperature thermodynamics, by E. Dale West and Shigeru Ishihara; and the volatilization and decomposition of materials, by Joseph H. Flynn, Sidney Strauss, Lee A. Dunlap, and Leo A. Wall.

Inorganic Materials Division (John B. Wachtman, Jr.).

The Inorganic Materials Division consisted of six sections: inorganic chemistry, with Thomas D. Coyle at the helm; inorganic glass, under Wolfgang K. Haller; high-temperature chemistry, William S. Horton, chief; inorganic physical properties, under Sheldon M. Wiederhorn; crystallography, led by Stanley Block; and solid-state physics, Hans P.R. Frederikse, chief.

Calibrations

The Inorganic Materials Division provided calibration service for several magnetic materials used as standards. NBS Special Publication 250 listed tests for normal induction and hysteresis, and ac permeability and core loss. The Division's Solid State Physics Section, which performed these calibrations, also calibrated magnetic testing apparatus, including mutual inductors, search coils, fluxmeters, solenoids, Helmholtz coils, and standard magnets.

Crystal Studies

As part of a continuing study of the motion of point defects in crystals, H. Steffen Peiser and John B. Wachtman, Jr., reported further conclusions regarding symmetry conditions that influence such motion.[259] The authors concluded that the symmetry groups describing the trap and the defect strongly influence or completely determine the rate of migration, or "jump."

The subject of mass transport in oxides was the topic of a symposium held at NBS late in 1967. The proceedings of the symposium, edited by John B. Wachtman, Jr., and Alan D. Franklin, were published in *NBS Special Publication 296,* issued in August 1968. About 100 scientists and engineers from the United States, Great Britain, the Netherlands, Canada, Australia, and France attended the four-day meeting. Specialized topics addressed by the speakers included the motion of point defects and impurity ions, lattice dynamics, diffusion coefficients, and ionic conductivity.

Melting Phenomena

Samuel J. Schneider, Jr. and Clyde L. McDaniel studied the effects of various atmospheres on the melting temperature of Al_2O_3.[260] The authors noted the effects of

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[259] H. S. Peiser and J. B. Wachtman, Jr., "Jump rates for point defects in special positions held by a trapping center of noncubic symmetry," *J. Res. NBS* **72A**, No. 3, 231-237 (1968).

[260] S. J. Schneider and C. L. McDaniel, "Effect of environment upon the melting point of Al_2O_3," *J. Res. NBS* **71A**, No. 4, 317-333 (1967).

vacuum, air, argon, and helium, with the samples contained in iridium or tungsten holders. The samples appeared to be least disturbed when contained in a vacuum environment. Induction heating was used to melt the specimens. The melting temperature of Al_2O_3 *in vacuo* was determined as (2051 ± 6) °C on the *International Temperature Scale.* The experimental imprecision level was ± 1.5 °C.

Surface Effects

Alan D. Franklin, Samuel Marzullo, and John B. Wachtman, Jr., studying the dielectric spectrum of CaF_2, observed the effects of surface-layer relaxation.[261] The surface-layer conductivity of samples doped with 0.1 % GdF_3 appeared much higher than the bulk values; the authors attributed this effect to large numbers of anion vacancies produced by dissolved oxygen.

Spin-Lattice Relaxation

The process of energy exchange between the paramagnetic spin system of neodymium ethylsulfate and its matrix was studied by use of electron spin resonance (ESR) techniques by George A. Candela and Robert E. Mundy.[262] This salt was particularly interesting because it was used in low-temperature paramagnetism studies following an early demonstration of its utility by Horst Meyer.[263] The dominant lattice-bath relaxation time was found to be inversely proportional to the square of the bath temperature, but independent of the crystal size or orientation.

Optical Properties of $SrTiO_3$

Robert F. Blunt and Martin I. Cohen reported on the creation of color centers in MgF_2 by the use of 50 kV x rays.[264] They tentatively identified F centers as the source of an absorption band near 260 nm. Blunt and Cohen also determined the absorption coefficient, the reflectivity and the electroreflectance near the fundamental absorption edge in $SrTiO_3$, a material which was interesting both as a semiconductor and as a superconductor.[265]

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[261] A. D. Franklin, S. Marzullo, and J. B. Wachtman, Jr., "Surface-layer relaxation in the dielectric spectrum of CaF_2 doped with GdF_3," *J. Res. NBS* **71A**, No. 5, 355-362 (1967).

[262] G. A. Candela and R. E. Mundy, "Influence of paramagnetic resonance on the static susceptibility. The lattice-bath relaxation time of neodymium ethylsulfate," *J. Chem. Phys.* **46**, No. 1, 47-54 (1967).

[263] H. Meyer, *Phil. Mag. 2*, 521 (1957).

[264] R. F. Blunt and M. I. Cohen, "Irradiation-induced color centers in magnesium fluoride," *Phys. Rev.* **153**, 1031-1038 (1968).

[265] M. I. Cohen and R. F. Blunt, "Optical properties of $SrTiO_3$ in the region of the absorption edge," *Phys. Rev.* **168**, No. 3, 929-933 (1968).

A theoretical study of the optical properties of $SrTiO_3$ under mechanical stress and electric fields was reported by Russell C. Casella.[266] $SrTiO_3$, the only known oxide superconductor, had been the subject of experiments on the relation between superconducting transition temperature and uniaxial stress. Casella's calculations indicated that the position of the Fermi surface was very susceptible to uniaxial stress; experimental observation of the large influence of uniaxial stress on the superconducting transition temperature corroborated his ideas. Ludwig H. Grabner described experiments on photoconductivity and luminescence in the same material during a conference on the physics of the solid state.[267]

X-Ray Powder Patterns

Standard x-ray diffraction powder patterns for some 140 substances were presented by Howard E. Swanson, Howard F. McMurdie, Marlene C. Morris, and Eloise H. Evans. Miller indices for d-values, densities, and refractive indices were included wherever possible. Publication of the patterns took place as Sections 6 and 7 of NBS Monograph 25, a comprehensive document that, beginning in 1962, superseded NBS Circular 539 as a source of up-to-date information useful in identifying many materials.

Ceramics

Wachtman also served as editor for the 250-page proceedings of a symposium on Mechanical and Thermal Properties of Ceramics, sponsored by the American Ceramic Society, the American Society for Testing and Materials, and NBS.[268] The symposium was held at the Gaithersburg site on April 1-2, 1968. Fourteen papers, half of them by Bureau scientists, were presented before some 210 participants of the symposium.

Physical Chemistry Division (James R. McNesby).

The activities of the Physical Chemistry Division took place in six sections. The leaders of these sections were George T. Armstrong, thermochemistry; Ralph Klein, surface chemistry; David Garvin, elementary processes; Henry M. Rosenstock, mass spectrometry; McNesby, photochemistry; and Pierre J. Ausloos, radiation chemistry.

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[266] R. C. Casella, "Optical properties of $SrTiO_3$ under applied stress and electric field," *Phys. Rev.* **154**, No. 3, 743-749 (1967).

[267] L. H. Grabner, "Oscillatory photoconductivity and luminescence in $SrTiO_3$," *Proc. Cairo Solid State Conf. American University, Cairo, Egypt, Sept. 3-8, 1966,* (Book, Interaction of Radiation With Solids, A. Bishay, editor, (New York: Plenum Press Inc. , 1967), pp. 155-160.

[268] J. B. Wachtman, Jr., editor, "Mechanical and thermal properties of ceramics," *Proceedings of a Symposium Held at Gaithersburg, MD, April 1-2, 1968, NBS Special Publication 303,* May 1969, 275 pages.

Thermodynamic Data

A 260-page revision of Tables 23, 33, and 34 of Series I of NBS Circular 500, *Selected Values of Chemical Thermodynamic Properties,* was published in 1968 by Donald D. Wagman, William H. Evans, Vivian B. Parker, Iva Halow, Sylvia M. Bailey, and Richard H. Schumm.[269] In the course of revising the massive circular, eight NBS Technical Notes (270-1 through 270-8) were published over a period of time. In 1982 these were compiled into a single document by the scientists named above with the collaboration of Kenneth L. Churney and Ralph L. Nuttall.[270]

Calorimetry

Eugene S. Domalski and George T. Armstrong completed several calorimetric projects during the period 1967-68. Much of this work was accomplished while they participated in a Heat Division program—a U.S. Air Force project on the use of refractory materials for rocket propellants. Using a bomb calorimeter, the authors determined the heat of formation of crystalline boron in gaseous fluorine.[271] They also provided measurements of the heats of formation of two aluminum borides, AlB_2 and AlB_{12}.[272] And they were able to deduce the heat of formation of a boron carbide of composition $B_{4.222}C$ by measuring the heats of combustion of polytetrafluoroethylene and of boron carbide-polytetrafluoroethylene mixtures.[273]

Photolysis and Radiolysis

An interesting series of papers on the topics of photolysis and radiolysis was written during this period by Pierre J. Ausloos in collaboration with several colleagues. With Sharon G. Lias, he investigated isobutane in the gas phase, obtaining information on the possible modes of decomposition;[274] with Lias and Richard E. Rebbert, he discussed the structure of propyl ions formed in the radiolysis of alkanes;[275] the same

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[269] D. D. Wagman, W. H. Evans, V. B Parker, I. Halow, S. M. Bailey, and R. H. Schumm, "Selected values of chemical thermodynamic properties. Tables for the first thirty-four elements in the standard order of arrangement," *NBS Technical Note 270-3,* January 1968, 267 pages.

[270] D. D. Wagman, W. H. Evans, V. B. Parker, R. H. Schumm, I. Halow, S. M. Bailey, K. L. Churney, and R. L. Nuttall, "The NBS tables of chemical thermodynamic properties. Selected values of inorganic and C_1 and C_2 organic substances in SI units," *J. Phys. Chem. Ref. Data* **11**, Supplement No. 2, 392 pp. (1982).

[271] E. S. Domalski and G. T. Armstrong, "The heat of formation of boron trifluoride by direct combination of the elements," *J. Res. NBS* **71A**, No. 3, 195-202 (1967).

[272] E. S. Domalski and G. T. Armstrong, "Heats of formation of aluminum diboride and α-aluminum dodecaboride," *J. Res. NBS* **71A**, No. 4, 307-315 (1967).

[273] E. S. Domalski and G. T. Armstrong, "The heat of formation of boron carbide," *J. Res. NBS* **72A**, No. 2, 133-139 (1968).

[274] S. G. Lias and P. Ausloos, "Gas-phase photolysis and radiolysis of isobutane," *J. Chem. Phys.* **48**, No. 1, 392-400 (1968).

[275] P. Ausloos, R. E. Rebbert, and S. G. Lias, "Structure and reactivity of propyl ions in gas-phase radiolysis," *J. Am. Chem. Soc.* **90**, No. 18, 5031-5033 (1968).

authors reported results of the photolysis of cyclohexane, observing the production of ions and superexcited molecules.[276] Rebbert and Ausloos also performed photolysis at low temperatures, observing the production of free radicals from methyl iodide in various organic matrices.[277]

Vernon H. Dibeler, James A. Walker, and Susan K. Liston completed the latest work in a comprehensive mass spectrometric study of photoionization, obtaining photoionization efficiency curves for molecular NO_2, NO, and for fragments of these molecules.[278]

Walter Braun, Karl H. Welge, and James R. McNesby reported flash photolysis results on methane, performed in the vacuum ultraviolet range.[279] This was to be the first of a series of articles on this topic.

Using photolysis to produce atomic fluorine at 14 K, Marilyn E. Jacox and Dolphus E. Milligan detected the presence of the free radicals $H(^{14}N)F$, $H(^{15}N)F$, and $D(^{14}N)F$ resulting from the reaction of the fluorine with NH in an argon matrix.[280] This was the first observation of the species HNF. Using infrared and visible-ultraviolet spectroscopy, Jacox and Milligan were able to identify vibrational fundamental lines and electronic transitions involving molecular bending modes.

Theory of Chemical Reactions

A calculation of the energy surfaces for interaction of two atomic states of the element lithium with hydrogen molecules was reported by Morris Krauss.[281] Krauss also prepared a 139-page compendium illustrating the successes and failures of variational ab initio calculations of molecular properties, especially electronic energies, as found in the scientific literature.[282]

Frederick H. Mies and Morris Krauss reported the development of a quantum-mechanical theory describing the behavior of reacting molecular species and the effect on the reaction rate constant.[283]

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[276] P. Ausloos, R. E. Rebbert, and S. G. Lias, "Gas-phase photolysis of cyclohexane in the photoionization region," *J. Phys. Chem.* **72**, No. 11, 3904-3914 (1968).

[277] R. E. Rebbert and P. Ausloos, "Photolysis of methyl iodide in matrices of organic compounds at 20 ° and 77 °K. Reactions of hot methyl radicals," *J. Chem. Phys.* **48**, No. 1, 306-311 (1968).

[278] V. H. Dibeler, J. A. Walker, and S. K. Liston, "Mass spectrometric study of photoionization. VII. Nitrogen dioxide and nitrous oxide," *J. Res. NBS* **71A**, No. 5, 371-378 (1967).

[279] W. Braun, K. H. Welge, and J. R. McNesby, "Flash photolysis of methane in the vacuum ultraviolet. I. End-product analysis," *J. Chem. Phys.* **45**, No. 7, 2650-2656 (1967).

[280] M. E. Jacox and D. E. Milligan, "Production and reaction of atomic fluorine in solids. Vibrational and electronic spectra of the free radical HNF," *J. Chem. Phys.* **46**, No. 1, 184-191 (1967).

[281] M. Krauss, "Interaction energy surfaces for $Li(2^2S)$ and $Li(2^{2P})$ with H_2," *J. Res. NBS* **72A**, No. 6, 553-557 (1968).

[282] Morris Krauss, "Compendium of ab initio calculations of molecular energies and properties," *NBS Technical Note 438*, December 1967.

[283] F. H. Mies and M. Krauss, "Time-dependent behavior of activated molecules. High-pressure unimolecular rate constant and mass spectra," *J. Chem. Phys.* **45**, No. 12, 4455-4468 (1966).

Surface Studies

Adsorption of nitrogen on rhenium metal was studied with the use of the field-ion microscope, which permits atom-by-atom examination of samples, by Ralph Klein and James W. Little.[284] Klein and Little undertook the study in order to extend the field-ion adsorption method from body-centered and face-centered cubic metals to the hexagonal-close-packed structure.

The two scientists were successful in obtaining clear field-ion patterns from the nitrogen-covered rhenium surface, which closely mimicked those of a clean rheniun surface. Their results allowed them to discuss the modes and locations of the adsorption process, as well as some of the energetics involved.

Institute for Applied Technology (Lawrence M. Kushner, an expert in metal physics, was newly appointed as director of IAT in 1968).

The IAT provided a wide range of technical services to promote the use of available technology and to facilitate innovation in technology in industry and government.

Manager, Engineering Standards (Malcolm W. Jensen, Manager).

Jensen's duty was to plan and administer the programs of the Office of Weights and Measures and the Office of Engineering Standards Services and to help formulate policy with respect to engineering standards. Rudolph A. Vignone, an attorney, helped to avoid legal problems in this area.

Office of Engineering Standards Services (Donald R. Mackay, Chief).

The OESS assisted government at all levels, as well as industry, in developing product and safety standards. Sampling, testing, and dissemination of information on standards were part of the workload of this office. Herbert A. Philo directed the work in product standards. William J. Slattery was acting chief of the standards information section. Mackay filled the role of chief of mandatory standards.

In collaboration with Malcolm Jensen and a committee of the U.S. National Conference on Weights and Measures, Mackay prepared in 1965 the third edition of NBS Handbook 44 *Specifications, tolerances, and other technical requirements for commercial weighing and measuring devices.* This handbook, first issued in 1949, provided assistance to individual states in their efforts to achieve uniformity of weights and measures laws and methods of inspection. It incorporated sections on scales, weights, liquid measure, linear measure, fabrics, cordage, taximeters, odometers, dry measures, and tables of equivalents.

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[284] Ralph Klein and James W. Little, "Nitrogen on rhenium observed with the field emission microscope," *Surface Sci.* **6**, No. 2, 193-207 (1967).

Office of Weights and Measures (Malcolm W. Jensen, Chief).

The OWM provided assistance to the states and to industry in the area of model laws and regulations and all the many features of maintaining the usefulness of standards of weights and measures. This assistance included training of weights and measures officials as well as consultation on legal requirements.

In June 1968 the 53rd National Conference on Weights and Measures was held at a large Washington, DC, hotel. The week-long conference was an important tool in the effort of NBS and weights and measures officials from all levels of government, industry, and consumer organizations for coordinating their activities. Daily sessions permitted the airing of many issues relating to weights and measures. Allen Astin, Director of NBS, served as the Conference President, and Malcolm Jensen, OWM chief, was the Conference Secretary. Standing committees existed on liaison with the Federal government, on education, on specifications and tolerances, and on laws and regulations.

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

This office had the responsibility for analyzing the effect of Federal laws on invention and innovation throughout the United States. In addition, the office encouraged invention through specific programs and by collaboration with state governments. These activities were carried out in three program areas: the innovation studies program, Joseph D. Crumlish, chief; the invention programs, Leonard S. Hardland, chief; and the engineering education program, John M. Tascher, chief.

De Simone described some of the principles of educating students in the concepts of innovation in an article published by the journal *IEEE Spectrum*.[285] The discussion advocated an engineering curriculum, with emphasis on fostering creativity.

Office of Vehicle Systems Research (Paul J. Brown, Chief).

This office was the focus of a collaborative effort between NBS and the National Highway Safety Bureau to provide the technical basis for Federal safety standards for motor vehicles and other motorized equipment. Its staff also had responsibility for developing methods to determine the levels of compliance with these standards.

Most of the work of the office was accomplished in three sections: tire systems under F. Cecil Brenner, occupant-restraint systems led by Richard W. Armstrong, and braking systems with Robert J. Forthofer as chief.

Clearinghouse for Federal Scientific and Technical Information (Hubert E. Sauter, Director).

The Clearinghouse provided a single point of contact within the Federal government through which the general public could obtain the results of government-sponsored research. Translation service also was available through this office.

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[285] D. V. De Simone, "Education for Innovation," *IEEE Spectrum* 5, No. 1, 83-90 (1968).

As part of a 1968 research project, Glenn Ludwig of the NBS Office of Vehicle Systems Research (OVSR) adjusted an antenna for picking up a telemetry signal indicating tire temperature. The instrumentation was used to study tire performance under an automobile safety program conducted by OVSR for the Department of Transportation's National Highway Safety Bureau.

Enormous numbers of publications were involved in the work of the Clearinghouse; a substantial organization was required to fulfill its work. The organization consisted of four branches in addition to a joint publications research service headed by Gustav Blackett. The branches were:

- Document distribution and reproduction, Alvin W. Alexander, chief.
- Automated systems and services, M. A. Krazny, chief.
- Administrative operations, Joseph G. Coyne, chief.
- Document processing, George K. Kudravetz, acting chief.

Product Evaluation Division (Sanford B. Newman, Chief).

This division developed measurement techniques and test methods for technical materials; maintained standard reference materials for rubber and paper; advised other government agencies on product standards; and performed developmental work on materials of interest to Federal agencies.

Five sections existed in the division: plastics and textiles, Karl F. Plitt, chief; fibrous systems, Donald G. Fletcher, chief; viscoelastic materials, George E. Decker, acting chief; paper evaluation, William K. Wilson, chief; and fabric flammability, James V. Ryan, chief.

Among other responsibilities, this division was home to the work mandated by the *Flammable Fabrics Act.*

NBS/GSA Test and Development Division (Phillip J. Franklin, Chief).

To assist the General Services Administration in evaluating the myriad products purchased each year for the Federal government, the Bureau maintained a small division with the responsibility for testing certain of these products. Among the items routinely tested by the NBS/GSA Test and Development Division were batteries, lamps, security cabinets, chemicals, and concrete. The division also had the capability to perform mechanical testing and soil testing.

The activities of this division were considered more relevant to GSA than to the Bureau. Just before his retirement, Allen Astin arranged the transfer of the division to GSA.

Building Research Division (James R. Wright, Chief).

Under the leadership of John P. Eberhard—trained as an architect and Director of the Institute for Applied Technology in 1966-67—and BRD chief James R. Wright, the Bureau's building research program underwent a complete reorientation with the move to the Gaithersburg site. The more spacious facilities permitted the group to study the behavior of entire buildings rather than to limit its research efforts to building components and materials. In addition, emphasis was placed on assisting governmental analysis of building problems and on participating in the new National Conference of States on Building Codes.

As a result of the broadened scope, the Bureau's building research program was given a new focus: fleshing out the concept of performance standards. In an article for *Scientific American,* Wright explained the idea:

> The performance approach demands a statement of performance in terms of function. Since buildings serve people, function is defined by the attributes necessary to serve human requirements. The means of delivering an attribute is open. It is in this way that the builder or supplier of a building component is invited to innovate. Indeed, the encouragement of innovation is sometimes cited as the reason for the performance approach. In any event, the philosophy of performance begins and ends with—and puts its principal emphasis on—the satisfaction of human needs.[286]

[286] James R. Wright, "Performance criteria in building," *Scientific American,* March 1971, pp. 16-25.

As part of its responsibility for developing criteria for performance standards for building products, structures, and systems, the BRD collaborated with the building industry, with other government agencies, and with professional associations. A major project, *Operation Breakthrough,* was shared with the Department of Housing and Urban Development (see Sect. 2.8.15).

Besides its other responsibilities, this division responded to the demands of the *Fire Research and Safety Act.*

The sections of the division and their chiefs were the following:

- Structures, Edward O. Pfrang.
- Fire research, Irwin A. Benjamin.
- Environmental engineering, Henry E. Robinson.
- Materials durability and analysis, William C. Cullen.
- Codes and standards, Gene A. Rowland.
- Building systems, R. W. Blake.
- Scientific and professional liaison, W. W. Walton.

Thermal Measurements

Paul R. Achenbach, Clinton W. Phillips, and Ronald W. Penney offered a testing and rating method for the cooling loads of refrigerated trucks.[287] This work was sponsored by the U.S. Department of Agriculture to assist the haulers of frozen foods or fresh produce. Achenbach also described new NBS test procedures for evaluating the performance criteria for building components and systems, including heating, air conditioning, and sanitary plumbing.[288]

Materials Properties

Charles M. Hunt reported to the *Highway Research Board Symposium* the results of nitrogen sorption measurements and surface areas of hardened cement pastes.[289]

In an effort to create a basis for the use of commercial platinum as a thermal conductivity reference material, Daniel R. Flynn and M. E. O'Hagan, a doctoral candidate at the George Washington University, studied both its thermal conductivity and electrical resistivity in the range 100 °C to 900 °C.[290]

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[287] P. R. Achenbach, C. W. Phillips, and R. W. Penney, "A testing and rating method for refrigerated trucks with respect to cooling load," *Annex to Proc. Intern. Inst. Refrigeration, Comm. VII,* (London, England, Sept. 1966), pp. 29-35.

[288] P. R. Achenbach, "Performance criteria for building components and systems," *Proc. Porcelain Enamel Institute Forum, University of Illinois, Urbana, Ill., Sept. 28-30, 1966,* **28**, 176-195 (1966).

[289] C. M. Hunt, "Nitrogen sorption measurements and surface areas of hardened cement pastes," (Highway Research Board Symp. Structure of Portland Cement Paste, Washington, DC, January 1965). *Highway Research Board Special Report* **90**, 112-122 (1966).

[290] D. R. Flynn and M. E. O'Hagan, "Measurements of the thermal conductivity and electrical resistivity of platinum from 100 to 900 °C," *J. Res. NBS* **71C**, No. 4, 255-284 (1967).

Along with his colleague Bradley A. Peavy, Jr., Flynn served as co-editor of the 800-page proceedings of the Seventh Conference on Thermal Conductivity, held November 13-16, 1967 at the Gaithersburg site.[291] This conference series was initiated in 1961 by participants in the *Symposium on Temperature, Its Measurement and Control in Science and Industry,* who wished to provide an extended forum for the discussion of high-temperature thermal conductivity measurements in solids. The eighth *Thermal Conductivity Conference* included more than 180 participants from 11 countries. The 90 papers presented by these scientists appeared in sessions on theory, methods, metals at low and high temperatures, non-metallics, nuclear materials, construction materials, gases, liquids, two-phase systems, and conductivity across interfaces. The proceedings of previous thermal conductivity conferences had not been published, thus preventing much of the material from reaching the open literature. A ninth conference was held at Iowa State University during October 1969.

Sub-freezing measurements of important properties—breaking load, elongation and thermal expansion—for nine types of built-up roofs were outlined by Thomas H. Boone, Leopold F. Skoda, and William C. Cullen.[292] One purpose of the study was to elucidate the differences between roofing membranes prepared in the field by roofing contractors and those prepared in the laboratory by NBS laboratory technicians. The performance of the field-prepared roofing was found to be substantially the same as the laboratory samples, justifying the retention of existing standards of construction.

Fire Studies

A study of the effectiveness of dwelling-unit entrance doors as barriers to fire and smoke was described in the Building Science Series by Harry Shoub and Daniel Gross.[293] Without raising their fire resistance or their smoke resistance to the level of commercial doors, an impractical goal, various suggestions were offered to improve the performance of the doors. For example, they found that smoke penetration into apartments from a smoke-filled corridor could be minimized by providing suitable openings in an exterior wall of the corridor; if the openings were above the top of the door, air would tend to flow from the room to the corridor and thence out of the openings.

Instrumentation

E. Carroll Creitz refined the ideas underlying the use of the Nerheim version of the Martin gas-density balance as a detector in gas chromotography.[294] Creitz showed how to better define the significant balance variables for column effluents of differing densities.

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[291] Daniel R. Flynn and Bradley A. Peavy, Jr. , Editors, "Thermal Conductivity; Proceedings of the Seventh Conference," *NBS Special Publication 302,* September 1968.

[292] T. H. Boone, L. F. Skoda, and W. C. Cullen, "Laboratory-field comparisons of built-up roofing membranes," *NBS Technical Note 473,* December 1968.

[293] H. Shoub and D. Gross, "Doors as Barriers to Fire and Smoke," *Building Science Series* 3, March 1966, 10 pp.

[294] E. C. Creitz, "Gas density balance design considerations," *J. Res. NBS* **72C**, No. 3, 187-195 (1968).

Electronic Technology Division (Myron G. Domsitz, Chief).

The ETD had responsibility for developing criteria for the evaluation of electronic instrumentation—including standards and codes—and for identifying needs for new technological instrumentation. Four sections accomplished these tasks: semiconductor characterization, under W. Murray Bullis; electron devices, Judson C. French, chief; instrumentation application, led by Joshua Stern; and semiconductor processing, under Joseph A. Coleman.

Data Compilations

A compilation of data on Soviet electronic devices was prepared by Charles P. Marsden.[295] The compilation was prepared as part of the Bureau *Electron Devices Data Service,* established in 1948 for NBS staff guidance on nearly two dozen types of vacuum tubes, transistors, and other devices.

Semiconductor Measurements

A progress report on methods of measurement used in the areas of semiconductor materials, process control, and electronic devices, assembled by W. Murray Bullis, provided the reader with a wealth of information on this Bureau activity.[296] The project was sponsored jointly by NBS, the Defense Atomic Support Agency, the U.S. Naval Ammunition Depot, and the National Aeronautics and Space Administration. Some 40 NBS staff members involved in the project were identified, related activities were briefly noted, and some 15 types of semiconductor measurements were outlined.

Harry A. Schafft and a colleague, Susan Gayle Needham, prepared a bibliography on the methods for measuring inhomogeneities in semiconductors. [297] The types of inhomogeneities discussed related to resistivity, impurity concentration, diffusion length, lifetime, surface conditions, mobility, and p-n junctions.

A more specialized survey—on minority carrier lifetimes—was prepared by W. Murray Bullis.[298] Containing references to about 300 papers, the survey covered measurement methods, typical results, and theoretical models.

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[295] C. P. Marsden, "Tabluation of published data on Soviet electron devices through October 1967," *NBS Technical Note 441,* July 1968.

[296] "Methods of measurement for semiconductor materials, process control, and devices. Quarterly report July 1 to September 30, 1968," W. Murray Bullis, Editor, *NBS Technical Note 472,* December 1968.

[297] H. A. Schafft and S. G. Needham, "A bibliography on methods for the measurement of inhomogeneities in semiconductors (1953-1967)," *NBS Technical Note 445,* May 1968.

[298] W. M. Bullis, "Measurement of carrier lifetime in semiconductors—an annotated bibliography covering the period 1949-1967," *NBS Technical Note 465,* November 1968.

The phenomenon of high-current transistor operation known as "second breakdown," an increasingly prevalent problem, was discussed in detail by Harry A. Schafft and Judson C. French in order to document the status of public understanding of the phenomenon.[299]

Another contribution to the understanding of transistor electronics came from Joseph A. Coleman and Lydon J. Swartzendruber, who provided an analysis of the effective charge-carrier lifetime in positive-intrinsic-negative (p-i-n) junctions in silicon.[300]

Measurement Methods

Paul S. Lederer discussed the *Interagency Transducer Project,* work done at the Bureau since 1951 and supported in 1968 by the National Aeronautics and Space Administration and by the U.S. Department of Defense.[301] The project was important to the supporting agencies because of the critical dependence of many telemetry techniques on the quality and performance of the transducer involved. The NBS participants provided performance data and developed standardized test procedures for a variety of sensors, including accelerometers, shock tubes, vibration sensors, and pressure sensors. Lederer also provided details of the performance testing of electromechanical pressure transducers, used in aerospace testing and a variety of other applications.

Technical Analysis Division (Walter E. Cushen, Chief).

In this division, cost-benefit analyses on other Institute programs were conducted. It was hoped that this approach to management systems would be useful throughout the government. Managers of the different program areas were: socio-economic studies, George Suzuki, acting chief; simulation and transportation studies, Louis C. Santone; operations research in behavioral sciences, June Cornog; Post Office studies, William F. Druckenbrod; and corridor model systems, Ralph E. Schofer.

Center for Computer Sciences and Technology (Herbert R.J. Grosch, Director).

This center had responsibility for research and technical support for the General Services Administration under provisions of *Public Law 89-306,* the "Brooks Act" which required NBS to provide guidance to the U.S. government on automatic data processing (ADP).

[299] H. A. Schafft and J. C. French, "A survey of second breakdown," *IEEE Trans. Electron. Devices* **ED-13**, No. 8-9, 613-618 (1966). More information on this topic appears in Ch. 6.

[300] J. A. Coleman and L. J. Swartzendruber, "Effective charge carrier lifetime in silicon p-i-n junction detectors," (Proc. 10th Scintillation and Semiconductor Counter Symp., Washington, DC, March 23-24, 1966), *IEEE Trans. Nucl. Sci.* **NS-13**, No. 3, 240-244 (1966).

[301] P. S. Lederer, "Performance testing, pressure transducers," *Instr. Control System* **40**, No. 9, pp 93-99, Sept. 1967. See also P. S. Lederer, "Life Cycling' test on several strain gage pressure transducers," *NBS Technical Note 434,* October 1967 and P. S. Lederer, "NBS interagency transducer project," *NBS Technical Note 469,* October 1968.

The Bureau developed a number of techniques and devices for calibrating and evaluating transducers within the Interagency Transducer Project. In this photograph, NBS engineer Paul Lederer prepared to trigger a pneumatic step-function calibrator.

As Director, Grosch established policy on ADP and directed the work of two offices and three divisions:

Office for Information Processing Standards (Joseph O. Harrison, Jr., Chief)

This office coordinated programs and standards on computer-generated information processing throughout the government.

Office for Technical Information Exchange (Margaret R. Fox, Chief)

The Technical Information Exchange office provided a referral service for programs on automatic data processing.

Computer Services Division (W.B. Ramsay, Acting Chief)

The CSD staff provided computing and data-conversion services to NBS and other agencies.

Systems Research and Development Division (Charles T. Meadow, Chief)

The SRDD evaluated existing computer systems.

Chemical Structures on Computers

A useful project undertaken in this division provided guidance in the transposition of chemical structures for use with computers. George F. Fraction, Justin C. Walker, and Stephen J. Tauber wrote a brief account of this type of work in an NBS Technical Note.[302]

Assembly Language

Input-output software for use with the Assembly Language Processor of the Systems 360 computer was described by Paul A. D. deMaine.[303]

Character Recognition

Mary Elizabeth Stevens reported on European progress in the recognition by computer of optical characters and other patterns, library automation, and linguistic data processing.[304]

Computer Graphing

A study of the theory of specialized graphs was completed by Arthur M. Hobbs and Jerrold W. Grossman.[305]

Electronic Printing

In February 1968, NBS issued *Special Publication 295,* edited by Richard W. Lee and Roy W. Worral. It contained the proceedings of a symposium on electronic composition in printing that had been held at the Bureau the previous summer. The four sessions of the symposium covered the following topics: State of the Art, Government

[302] G. F. Fraction, J. C. Walker, and S. J. Tauber, "Connection tables from Wiswesser chemical structure notations—a partial algorithm," *NBS Technical Note 432,* September 1968.

[303] P. A. D. deMaine, "Input/output packages for the Systems 360 assembly language processor," *NBS Technical Note 433,* September 1968.

[304] M. E. Stevens, "Nonnumeric data processing in Europe: a field trip report," *NBS Technical Note 462,* November 1968.

[305] A. M. Hobbs and J. W. Grossman, "A class of thickness-minimal graphs," *J. Res, NBS* **72B**, No. 2, 145-153 (1968).

Policy, Non-Government Applications and Research, and Government Applications. The Government Printing Office and the congressional Joint Committee on Printing figured strongly in the setting of policy on electronic composition.[306]

Information Processing Technology Division (James P. Nigro, Chief)

This division utilized computer methods for information processing.

Fingerprint Identification

In a particularly interesting project, Joseph H. Wegstein, his Bureau colleague John F. Rafferty, and Walter J. Pencak from the Federal Bureau of Investigation described a procedure for computing a set of numerical descriptors that identify a single fingerprint.[307]

The work of Wegstein, Rafferty, and Pencak was continued nearly a decade later with even more powerful tools. Raymond T. Moore and James R. Park developed an economical, semiautomatic device that could record information from low-quality fingerprints such as those often found at the scene of a crime. They called the device a 'Graphic Pen'. In the hands of a trained operator, the computerized sensor provided digital information on the "minutiae" of the print—ridge endings and ridge bifurcations—for later comparison with FBI files.[308]

Center for Radiation Research (Carl O. Muehlhause, Acting Director).

The Center for Radiation Research was newly created in 1968. It was formed by combining the Radiation Physics Division, formerly led by H. William Koch—who had recently departed to the American Institute of Physics—and the Reactor Radiation Division, headed by Muehlhause. The principal driving force in its formation was the desire to centralize the management of all the Bureau's major radiation-producing facilities—a newly commissioned 10 megawatt nuclear research reactor, a 100 MeV linear accelerator, various radioactive sources, a 4 MeV Van de Graaff accelerator and a synchrotron. This array of equipment could hardly have been assembled without the spacious environment provided by the new Gaithersburg site.

Because of the relative expense and scarcity of the center's machines, most were regarded as national facilities, to be used as much by scientists outside NBS as by the Bureau staff itself. The synchrotron, a modification of a small betatron-type electron

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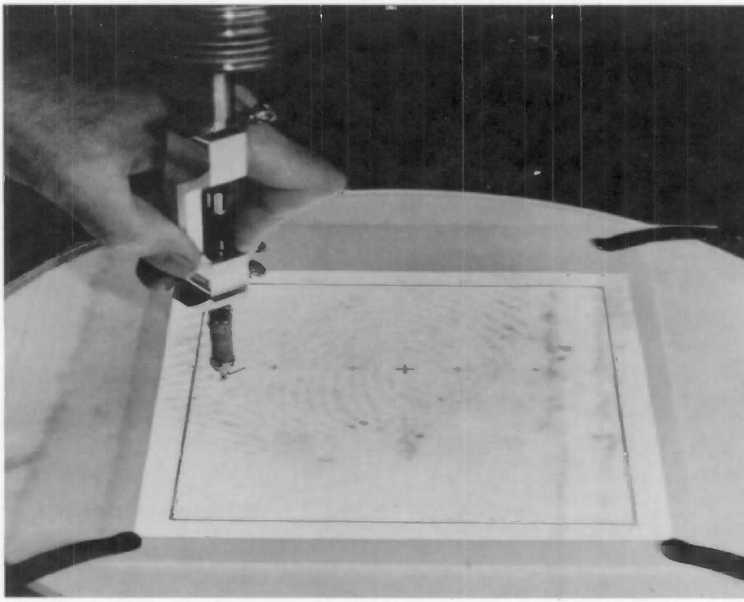
[306] R. W. Lee and R. W. Worral, "Electronic composition in printing," *(Proceedings of a symposium held at NBS,* Gaithersburg, MD. June 15-16, 1967), *NBS Special Publication 295,* February 1968, 133 pp.

[307] J. H. Wegstein, "A computer oriented single-fingerprint identification system," *NBS Technical Note 443,* March 1968. See also J. H. Wegstein, J. F. Rafferty, and Walter J. Pencak, "Matching fingerprints by computer," *NBS Technical Note 466,* July 1968.

[308] R. T. Moore and J. R. Park, "The Graphic Pen, an economical semiautomatic fingerprint reader," *Proc. 1977 Carnahan Conf. on Crime Countermeasures, Carnahan House, Lexington, Kentucky, April 6-8, 1977,* pp. 59-62.

In research sponsored by the Federal Bureau of Investigation, NBS Information Processing Technology Division scientists prepared a fingerprint (upper portion of photo) for classification and identification by marking its ridge endings and bifurcations on an overlay (lower portion of photo). The system provided descriptors for fingerprint details based on direction and location. The descriptors could be obtained, sorted, and matched with others by computer.



In a refinement of the work shown in the previous illustration, the Graphic Pen, a semiautomated device for marking the fine details of a fingerprint on an overlay, was developed to record fingerprint details.

accelerator, was moved from the Connecticut Avenue site.[309] Its primary use was as a source of far-ultraviolet radiation; although operated by the Center for Radiation Research, its main user group was the Far Ultraviolet Physics Section of the Atomic Physics Division.

Calibration Services

The need for standards in the areas of neutron physics, radioactive samples, and beams of x rays, gamma rays and electrons was large and growing in 1968. Consequently, the Center offered calibration services in all these fields. NBS Special Publication 250, *Calibration and Test Services of NBS,* listed services in neutron physics (neutron-source emission rate, neutron dosimeters, and neutron irradiation of test foils), radioactivity (both liquid and solid sources of alpha, beta, and gamma emitters), and x rays and gamma rays (measuring instruments, sources, and dosimeters).

Attached to the Center Office were a radiation theory group, whose research benefited the whole Center, and a health physics group, which had responsibility for

[309] "NBS Installs Synchrotron at Gaithersburg Laboratories," *NBS Technical News Bulletin*, Vol. 53, January 1969, pp. 4-5.

the safe utilization of sources of ionizing radiation. Typical radiation-theory research projects included the following:

Radiation Theory

As part of the Center service to users of radiation sources, Charles M. Eisenhauer utilized scattering theory to derive expressions for the radiation flux of gamma rays originating from a point source and singly scattered in air.[310]

Leonard C. Maximon developed analytic expressions for the production of an electron-positron pair in a Coulomb field, using the Born approximation to derive the cross section.[311]

Michael Danos and his colleagues Walter Greiner, of the Institut für Physik at the University of Frankfurt in Germany, and C. Byron Kohr, of the University of Maryland, described a static theory of the giant quadrupole resonance in deformed nuclei.[312] The authors stated that, in view of the great success of the hydrodynamic model of the giant dipole resonance in predicting its details, it appeared useful to press the model even further.

Irradiation of Foods

The radiation processing of foods, a technique important for the purification and durability of comestibles, required careful regulation of sources and dosages. H. William Koch and Elmer H. Eisenhower discussed the various criteria used for this type of irradiation.[313] Of special importance in their discussion was limiting any radioactivity induced in the target foods to negligible levels. The safety and efficacy of the radiation-processing technique was still debated publicly as this history was written.

Reactor Radiation Division (Robert S. Carter, Acting Chief).

The NBS nuclear reactor achieved criticality on December 7, 1967, following 9 years of planning and 4 years of construction.[314] It took another year for the reactor to achieve its full capabilities—a power level of 10 MW, a flux of 10^{14} neutrons/(cm^2 s), filtered neutron beams, intermediate-energy standard neutron field, neutron diffractometers, neutron radiography, time-of-flight neutron spectrometer, and neutron

[310] C. Eisenhauer, "Gamma radiation fluxes near a ground-air interface using an image source technique," *Nucl. Sci. Engr.* **32**, 166-177 (1968).

[311] L. C. Maximon, "Simple analytic expressions for the total Born approximation cross section for pair production in a coulomb field," *J. Res. NBS* **72B**, No. 1, 79-88 (1968).

[312] M. Danos, W. Greiner, and B. C. Kohr, "Static theory of the giant quadrupole resonance in deformed nuclei," *Phys. Rev.* **151**, No. 3, 761-772 (1966).

[313] H. W. Koch and E. H. Eisenhower, "Radioactivity criteria for radiation processing of food," Chapter 7 in *Radiation Preservation of Foods*, pp. 87-108 (Advances in Chemistry Series **65**, Am. Chem. Soc., Washington, DC, 1967.)

[314] "NBS Reactor Achieves Criticality," *NBS Technical News Bulletin*, Vol. 53, March 1968, p. 50.

In 1963 heavy machinery moved great quantities of earth to make way for construction of the NBS research reactor. The nearby farm buildings emphasize the change in character brought by NBS to Gaithersburg, Maryland.

irradiation and separation facilities.[315] Tawfik M. Raby was Acting Chief of Reactor Operations.

The division offered calibration services for neutron sources and instrumentation, as well as neutron irradiation of foils.

An Ethic of Collaboration

An explicit aim of the division was to encourage collaborative reactor projects with users from outside NBS. To prepare for the time when the NBS reactor would become available, the division staff had collaborated with outside groups for some time. In one of these collaborative efforts, John J. Rush performed an experiment with H. E. Flotow, D. W. Connor, and D. L. Thaper, colleagues from Argonne National Laboratory in Illinois. The group used cold neutrons from the CP-5 research reactor at Argonne to study the vibrational spectra of yttrium and uranium hydrides.[316] They observed inelastic (energy-gain) scattering of the neutrons, obtaining spectra that were split into two bands—a higher-energy optical band presumably arising from optical hydrogen vibrations, and a lower-energy band which they ascribed to metal-atom vibrations.

[315] H. L Mason and Iris M. Lloyd, editors, "Special Technical Facilities at the National Bureau of Standards," *NBS Special Publication 413*, March 1976, pp. 30-34.

[316] J. J. Rush, H. E. Flotow, D. W. Connor, and D. L. Thaper, "Vibration spectra of yttrium and uranium hydrides by the inelastic scattering of cold neutrons," *J. Chem. Phys.* **45**, No. 10, 3817-3825 (1966).

Vernon W. Myers had utilized the Brookhaven National Laboratory cold-neutron source in late 1966 to obtain information on inelastic scattering in gray tin.[317] Later, he provided solutions of the time-dependent Klein-Gordon and Dirac equations for the motion of a charged particle in a classical, uniform electrostatic field.[318]

Neutron Cross Sections

The *Second Conference on Neutron Cross Sections and Technology* was held at a Washington, DC, hotel in March 1968. The 123 papers given at the meeting filled the two-volume *NBS Special Publication 299,* edited by David T. Goldman.[319] The conference was useful in promoting dialog between basic researchers and those performing applied radiation tasks. The eight sessions were intended to address the need for accurate measurements, theoretical and experimental methods, and applications.

Linac Radiation Division (James E. Leiss, Acting Chief).

The Linac Division operated a linear-accelerator facility which provided high-intensity beams of electrons, photons, and neutrons. The beam energy was continuously variable over the range 10 MeV to 150 MeV, with a spread of 2 %. The pulse length could be varied from 1 ns to 5 μs, with a repetition rate as high as 720 pulses/s. Four experimental rooms were available; users could occupy any room not under irradiation.[320]

The division also offered programs on instrumentation, headed by Louis Costrell; photonuclear physics, under Everett G. Fuller; and electronuclear physics, under the leadership of Samuel Penner.

Many applications were possible using the Linac—from neutron cross section studies to electron and photon dosimetry, biochemical radiolysis, and photonuclear physics experiments. In the following, we note some of these applications.

Detector Development

John W. Lightbody, Jr. and Samuel Penner described a 12-channel array of lithium-drifted silicon detectors to be used for detecting high-energy electrons in the focal plane of a magnetic spectrometer.[321] The system exhibited good momentum resolution and stable efficiency.

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[317] V. W. Myers, "Inelastic scattering of cold neutrons in polycrystalline gray tin," *J. Chem. Phys. Solids* **28**, 2207-2210 (1967).

[318] V. W. Myers, "Solutions of the time-dependent Klein-Gordon and Dirac equations for a uniform electric field," *J. Res. NBS* **72B**, No. 1, 37-42 (1968).

[319] D. T. Goldman, editor, *Neutron cross sections and technology,* Proceedings of a conference held in Washington, DC, March 4-7, 1968, NBS Special Publication 299, September, 1968, Vol. 1, 660 pp., Vol. 2, 2718 pp.

[320] H. L Mason and Iris M. Lloyd, editors, "Special Technical Facilities at the National Bureau of Standards," *NBS Special Publication 413,* March 1976, pp. 2-3.

[321] J. W. Lightbody, Jr. and S. Penner, "A 12-channel semiconductor counter system for the NBS electron scattering spectrometer," *IEEE Trans. Nucl. Sci.* **NS-15**, 419-425 (1968).

Photodisintegration

Calculations of two- and three-body photodisintegration cross sections for ^3H and ^3He were performed by James S. O'Connell and Francisco Prats.[322] As the ground-state wave function, they used an exact solution of the three-body Schrödinger equation.

Photonuclear Data Center

Members of the staff of the Photonuclear Physics Section of the division had established a photonuclear data center, in which data on photonuclear reactions were collected. An index to more than 600 publications, organized by element and isotope, was published in 1966.[323]

Nuclear Radiation Division (Harry H. Landon, Acting Chief).

Neutron physics, headed by Landon; radioactivity, under Wilfred B. Mann; and nuclear spectroscopy, led by Raymond W. Hayward, were active areas of research within the Nuclear Radiation Division during 1968.

Scattering

The backscattering of alpha particles from metallic surfaces was the focus of a project by J.M. Robin Hutchinson, Carol R. Naas, Delores H. Walker, and Wilfred B. Mann.[324]

Nucleon-Field Interactions

Raymond W. Hayward prepared a discussion of the interactions of nuclei with electromagnetic fields for the Condon-Odishaw *Handbook of Physics*.[325]

Applied Radiation Division (Joseph W. Motz, Acting Chief).

The Applied Radiation Division calibrated equipment for the detection of alpha, beta, gamma and x-ray radiation. In addition, the staff worked in the area of dosimetry under the leadership of Robert Loevinger.

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[322] J. S. O'Connell and F. Prats, "Photodisintegration of the trinucleon system in a separable potential model," *Phys. Lett.* **26B**, No. 4, 197-200 (1968).

[323] *"Photonuclear Data Index,"* prepared by the NBS Photonuclear Data Group (N. V. Baggett, Theresa M. Collins, Everett G. Fuller, Julia C. Holland, John H. Hubbell, and James S. O'Connell), *NBS Miscellaneous Publication 277*, April 1966.

[324] J. M. Robin Hutchinson, Carol R. Naas, Delores H. Walker, and Wilfred B. Mann, "Backscattering of alpha particles from thick metal backings as a function of atomic weight," *Intern. J. Appl. Radiation Isotopes* **19**, No. 6, 517-522 (1968).

[325] R. W. Hayward, "Nuclear electromagnetic radiation," Chapter 6 in *Handbook of Physics, Second Edition, Part 9*, Nuclear Physics, E. U. Condon and H. Odishaw, eds. pp. 9-172 to 9-194 (1968).

Electron Interactions and Detection

Samuel E. Chappell, Jimmy C. Humphreys, Joseph C. Motz, Martin J. Berger, and Stephen M. Seltzer evaluated the response of silicon detectors to monoenergetic electrons.[326]

Measurement of the energy and the current of accelerated electron beams was simplified by a device that incorporated a thin aluminum foil placed in the beam. Developed by Motz and Julian H. Sparrow, the device was found to yield accurate energy measurements over the range 50 keV to 500 keV.[327]

Stopping Power

Additions to existing tabular data on stopping power relative to protons, mesons, and electrons were provided by Martin Berger and Stephen Seltzer. They also corrected earlier data on electrons in muscle and bone.[328]

Summary

This chapter has provided a glance at only a tiny fraction of the numerous projects taking place in the technical divisions of NBS during the last years of Allen Astin's service as Director. Nevertheless the list illustrates the intense scientific nature of the Bureau at that time. It also provides a measure of the strength of the Bureau's technical staff, many of whom were world leaders in their specialties.

As a look at Appendix K shows, changes in the formal structure of NBS occurred frequently. The main lines of research, however, changed less frequently and usually in an evolutionary way. Particular lines of study opened and matured over periods of time that were as likely to be measured in decades as in years. New programs or lines of inquiry were often undertaken through the hiring of new staff members rather than through shifts of interest on the part of long-time employees.

In the following chapters, we trace the progress of some of the projects described in this section, although more frequently we introduce work that has not previously been discussed.

[326] S. E. Chappell, J. C. Humphreys, J. C. Motz, M. J. Berger, and S. M. Seltzer, "Response of silicon transmission detectors to monoenergetic electrons," *IEEE Trans. Nuclear Sci.* **NS-15**, No. 3, 359-362 (1968).

[327] J. W. Motz and J. H. Sparrow, "A simple device for the energy and current measurement of an accelerator electron beam," *Record of the IEEE 9th Annual Symposium on Electron, Ion, and Laser Beam Technology, May 9-11, 1967,* Berkeley, *California* (San Francisco: San Francisco Press, 1967) pp. 34-41.

[328] M. J. Berger and S. M. Seltzer, "Aditional stopping power and range tables for protons, mesons, and electrons," *NASA-SP,* 3036 (1966).

The End of an Era

While the Bureau staff busied itself with its manifold duties during 1968, it awaited the coming change in its leadership. When Astin, with typical concern for order and planning, had made known his intention to resign after the coming presidential election, there was a strong sense among NBS employees that the agency was witnessing the end of an era.

Allen Astin had been appointed Director by President Harry Truman; he had served with distinction under Presidents Eisenhower, Kennedy, and Johnson as well. Under Astin, the Bureau had seen the passing of the remnants of the World War II projects from its organization, had heard the accusations of villainy in the AD-X2 affair and the vindication of its integrity that followed, and had enjoyed the flowering of a re-invigorated staff utilizing the "new science and the new scientists" sought by Condon but brought to NBS mostly by Astin.

Astin earned many laurels during his long career. His numerous awards for scientific and administrative service to the U.S. government included *His Majesty's Medal for Service in the Cause of Freedom* (1947), the *Presidential Certificate of Merit* (1948), the *Department of Commerce Gold Medal* (1952), the *Eli Whitney Memorial Award* of the *American Society of Tool Engineers* (1960), the *Scott Gold Medal* of the *American Ordnance Association* (1962), the *Rockefeller Public Service Award* (1963), the *ASTM Award to Executives* (1965), the *Standards Medal* of the *American National Standards Institute* (1969), and a *Certificate of Commendation* presented jointly by the Nation's 50 Governors.

Astin decided to remain as Director through the 1968 elections despite the possibility of the loss of his choice as successor—Lewis Branscomb—should the Republicans take over the Executive Branch of the government. There would be no "emeritus advisor" role for Astin to circumvent the legitimate process of succession.

And there would be no machinations to pre-empt the normal course of events by Branscomb, either. He would take what came. Never mind that—married to an active worker for the Democratic Party—Branscomb might be passed over, should the White House be captured by a Republican. In any case, his creation, the Joint Institute for Laboratory Astrophysics, still attracted his restless interest. JILA, only four years old, was quickly maturing as a scientific organization. It was becoming a more potent force in its field with each passing year. There was plenty to do in Boulder.

Director Astin gave no indication, during his last months in office in 1968 and 1969, that he was a man fatigued by a full career of service. He continued his long-term efforts to fine-tune NBS for smooth operation:

- In February of 1968, he directed the Cryogenics Division to report to the Director of the Institute for Basic Standards.[329] In June, he established the position of Deputy Director, IBS/Boulder, with Bascom W. Birmingham as the incumbent.[330] He also named Ernest Ambler to the post of Director, IBS.

[329] NBS Admin. Bull. 68-22, 21 Feb 68.

[330] NBS Admin. Bull. 68-118, 24 June 68.

- Also in February 1968, he directed the Physical Chemistry Division to report to the Director of the Institute for Materials Research.[331] He named John D. Hoffman as Director, IMR.
- In June of 1968, Astin appointed Lawrence M. Kushner to the post of Director of the Institute for Applied Technology.[332] By the following January, Astin had named Kushner to the position of Acting Deputy Director of NBS to replace Irl C. Schoonover, who retired after 41 years of service to the Bureau (1928-1969).[333] To take Kushner's place, Astin appointed Howard E. Sorrows, previously Deputy Director of the Institute for Materials Research, to the position of Acting Director of the Institute for Applied Technology.
- The NBS/General Services Administration Test and Evaluation Division, formed in 1966 to test items purchased by the GSA and other government agencies, was transferred bodily by Astin to the GSA. This action brought to a close a million-dollar-a-year activity that the Bureau regarded as barely relevant to its mission.
- In July 1968 Astin acted to create an Equal Employment Opportunity office for NBS. Donald G. Fletcher, Robert F. Bain, and Karl E. Bell were appointed to a committee to receive any staff complaints of discrimination on the basis of race, sex, creed, or national origin.[334]
- The Center for Radiation Research was created by Astin during 1968 as well, with Carl O. Muehlhause appointed as its first Director.
- The Center for Computer Sciences and Technology, established in 1966 in response to the "Brooks Act" (PL 89-306, 1965), was made a separate organizational entity late in 1968. Astin asked Herbert R.J. Grosch to continue as its Director.
- One of Astin's last major organizational moves occurred late in 1968 when he created the office of Associate Director for Information Programs. Edward L. Brady, former Chief of the Office of Standard Reference Data, was named Associate Director. Brady's responsibilities included the following:
  - Supervision of the OSRD—then headed on an Acting basis by David Lide, Jr.
  - The Clearinghouse for Federal Scientific and Technical Information, located in Springfield, Virginia and headed by Hubert E. Sauter.
  - The Office of Technical Information and Publications, under W. Reeves Tilley.
  - The Library Division headed by Elizabeth L. Tate.
  - The Office of Public Information, with A. Victor Gentilini as Chief.
  - The Office of International Relations under Ladislaus L. Marton.

[331] NBS Admin. Bull. 68-22, 21 Feb 68.

[332] NBS Admin. Bull. 68-113, 17 June 68.

[333] Kushner's initial responsibilities as Deputy Director included management of the Instrument Shops Division, the Measurement Engineering Division, and the Offices of Industrial Services and Engineering Standards Liaison. By mid-1969, Astin had transferred the Instrument Shops Division to the Institute for Applied Technology.

[334] Memo to all employees, 12 July 68.

Preparing to retire as Director on August 31, 1969, Allen Astin was still responsible for presenting the NBS budget before Congress one last time. This last appearance—May 13, 1969—might have become the occasion for a brief reference to Astin's long and faithful service.[335] But as had been the case since 1963, the budget hearing was chaired by Congressman John Rooney. In contrast to the civil—even friendly—manner of predecessors such as Prince Preston of Georgia or George Andrews of Alabama, Mr. Rooney consistently presented a less conciliatory demeanor to all public servants who appeared before him.

Allen Astin had suffered at Congressman Rooney's seances as much as any agency head but, characteristically, he suffered in silence. Even during his last appearance before the subcommittee Astin was calm, turning the other cheek when his tormentor attacked. He presented an austere budget of some $38.7 million, cut by the Department of Commerce and by the Bureau of the Budget from an initial request of $48.1 million. Over and over again, Congressman Rooney asked Astin to repeat the two numbers, as if to stress the enormity of Astin's sin in requesting more money than even the spendthrift Executive Branch could countenance.

In connection with a proposed high-purity materials preparation facility, Astin mentioned that day the need for "clean rooms" where super-pure materials could be processed; Mr. Rooney saw this request as "... incongruous that you should be talking about cleanliness. I can remember when nobody washed the windows out there at Connecticut Avenue. Do you remember that, Doctor?"

Perhaps as something of a farewell to Astin—certainly not because the topic was relevant to the day's discussion—Rooney called to mind that day another incident from the past. A year or two previously, a specialized painting job on one of the Bureau buildings had been performed inadequately and—at no cost to the government—had been repaired by the contractor when the fault had been discovered. "Can you approximate the amount of cost to the taxpayer as a result of this fiasco, regardless of who was to blame for it?," demanded the Congressman. Astin patiently provided the subcomittee with NBS records that showed no cost to the taxpayer. However, if the citizens of Brooklyn needed further proof of the concern felt by their elected representative for their pocketbooks and for their government's integrity, Mr. Rooney provided it one more time.

Astin had begun his day's testimony by saying:

> This is probably the last time I shall have the privilege of appearing before this committee since I have announced plans to retire at the end of August. I would, therefore, like to express my thanks and appreciation for your thoughtful consideration of my budget requests over the past 17 years.

If Congressman Rooney—or any of the other subcommittee members, for that matter—felt that Astin's nearly 40 years of public service merited thanks that day, the record fails to show it. Nor does the historical record anywhere indicate whether Allen Astin indulged himself with a small celebration late in the day on May 13, 1969.

[335] 1970 House Subcommittee Hearings, May 13, 1969, p. 895.

Lewis Branscomb, the heir-apparent to the directorship of NBS, was busy during 1968 and 1969, too. In addition to his duties as chairman of JILA and Chief of the Laboratory Astrophysics Division, he served as adjunct professor to the University of Colorado. He also made several contributions to the scientific literature: he edited a conference proceedings that included his own paper, a summary of atomic collision processes of importance to astronomy;[336] he produced a historical review of the field of electron, atomic, and molecular physics;[337] he wrote a critique of quality control in the publication of the results of scientific measurements;[338] with Robert E. LeLevier, a colleague from Rand Corporation in Santa Monica, CA, he published a theoretical discussion of the ion chemistry involved in the concentration of mesospheric electrons;[339] and with Gary C. Tisone, a Research Associate in the Joint Institute for Laboratory Astrophysics, he described the results of electron detachment experiments on H^- and O^-.[340]

Branscomb's interests clearly reached beyond the laboratory to national topics, too, as evidenced by an article in Physics Today that asks the reader, "Please imagine that it is January 1980 and this talk is entitled 'Retrospective Look at How Physics has Changed in Relation to Society in the Past Twelve years.'"[341] He also continued his service as a member of President Johnson's Science Advisory Committee.

Outside NBS, the situation in national affairs was dismal. Many events conspired to touch the Nation with a sense of impending trouble—President Johnson's March 1968 announcement that he would not be a candidate for the office of President, the political rise and untimely snuffing out of the life of Robert Kennedy, the nomination of Hubert Humphrey for President in a violent Democratic convention, the accession of Richard Milhous Nixon and Spiro Theodore Agnew as the Republican Party's presidential team, the public distress arising from the war in Vietnam, and the loss by assassination of Martin Luther King, Jr.

But the national unease contrasted in a curious way with the eager anticipation at NBS for a leader who was worthy to don the mantle being shed by Allen Astin.

How strange the path ahead was to become, for the Nation and the Bureau, no one could possibly know in 1968.

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[336] L. M. Branscomb, "The role of atomic collision processes in astrophysics," Chapter in *The Physics of Electronic and Atomic Collisions: Invited papers from the Fifth International Conference, Leningrad, U.S.S.R., July 17-23, 1967,* L. M. Branscomb, ed., (Boulder, CO: Joint Institute for Laboratory Astrophysics, University of Colorado, 1968), pp. 12-31.

[337] L. M. Branscomb, "Twenty years of physics: atoms, molecules and electrons," *Physics Today* **21**, No. 5, 36-39 (1968).

[338] L. M. Branscomb, "The misinformation explosion: Is the literature worth reviewing?" *Sci. Res.* **3**, No. 11, 49-52 (1968).

[339] R. E. LeLevier and L. M. Branscomb, "Ion chemistry governing mesospheric electron concentrations," *J. Geophys. Res.* **73**, No. 1, 27-41 (1968).

[340] G. C. Tisone and L. M. Branscomb, "Detachment of electrons from H^- and O^- negative ions by electron impact," *Phys. Rev.* **170** No. 1, 169-183 (1968).

[341] L. M. Branscomb, "Physics and the nation in a crystal ball," *Physics Today* **21**, No. 8, 23-28 (1968).