Cryogenic Engineering

Cryogenic Engineering by Russell B. Scott [1] was written between 1955 and 1959 as a text book, reference book, and data book. It covered liquefaction and separation of gases; thermometry; instrumentation; thermal insulation; storage, transport, and transfer of liquids; and properties of fluids and solids. It contains the best detailed description of the liquefier project that was conducted in the early 1950s at the NBS Boulder Laboratories. The book has been reprinted several times, most recently in 1995, and more than 6000 copies have been sold.

The NBS cryogenics program started in 1904 when Congress appropriated funds to purchase the two-liter-per-hour hydrogen liquefier exhibited at the St. Louis World's Fair by the British Oxygen Company. It was rarely used until 1925, when F. G. Brickwedde, and later Russell Scott, started producing liquid hydrogen for research and as a coolant to liquefy helium. In the early 1930s, Harold C. Urey of Columbia University set out to prove experimentally the existence of an isotope of hydrogen which we now call deuterium. As described elsewhere in this volume, he asked Brickwedde to liquefy hydrogen and, by distillation, to concentrate isotopes for spectroscopic analysis. Urey found deuterium present in the sample [2] and was awarded the Nobel Prize. In 1934, Scott, Brickwedde, Urey, and Wahl [3] published the hydrogen ortho/para uncatalysized conversion rates, and in 1948, Woolly, Scott, and Brickwedde [4] published a compilation and critical evaluation of the thermal properties of the isotopes of hydrogen.

In the 1940s, the emphasis in the field of cryogenics changed dramatically from research to engineering, which stimulated great improvements in system performance. Some of the engineering applications that evolved over the next decades included storage and shipment of gases such as oxygen, nitrogen, hydrogen, helium, and natural gas in liquid form; production of oxygen for making steel; rocket and aircraft fuels; energy transport and storage; electronics; and facilities for high-energy physics. NBS was one of the few U.S. laboratories with equipment, personnel, and experience to meet the national need for information and data.

During World War II, Brickwedde and Scott participated in the Manhattan Project [5], measuring the thermodynamic properties of materials used in the atomic bomb, including uranium. After the war, Brickwedde became a consultant on cryogenics at the Los Alamos Scientific Laboratory (LASL), working with Edward Hammel and members of the LASL cryogenic group. NBS Director Edward U. Condon, who had played a part in the work at Los Alamos during the war, wanted to expand NBS research in atomic and nuclear physics and encouraged Brickwedde to facilitate collaboration with LASL.

When President Truman authorized the design and testing of a hydrogen bomb in 1950 to counter a threat from the Soviet Union, the U.S. Atomic Energy Commission, through LASL Director Norris Bradbury, asked NBS to participate. He requested that NBS build a large hydrogen-liquefaction plant; set up and run a hydrogen/deuterium electrolysis plant; test prototype dewars for Los Alamos; assist MIT and Arthur D. Little Company (ADL) in the design and construction of dewars and refrigerators; test hydrogen transport dewars; and train personnel in large-scale hydrogen production and hydrogen handling.

Russell Scott, assisted by William Gifford, Victor Johnson, and Dudley Chelton, designed and built the critical components (heat exchangers and gas purifiers) for four 320 L/h hydrogen/deuterium liquefiers in the NBS shops in Washington. The NBS staff quickly expanded to include Bascom Birmingham, Richard Kropschot, Douglas Mann, Robert Powell, Robert Jacobs, Leon Wagner, and Peter Vander Arend. In 1950, the City of Boulder gave NBS a 28-acre site for relocation of the Central Radio Propagation Laboratory and, later, other NBS units from Washington. Under NBS direction, Stearns Roger Engineering erected two of the liquefiers in Boulder. The third liquefier was erected by Holmes and Narver on the Eniwetok Atoll, site of an upcoming nuclear test, under the direction of Herrick Johnston of Ohio State University, with assistance from George Freeman and Leon Wagner of NBS. The fourth liquefier was used for spare parts.

In order to obtain deuterium, two water electrolyzers were installed in Boulder, heavy water was imported from Canada, and work was begun to produce deuterium gas needed for the upcoming nuclear test. The deuterium was compressed into high-pressure tanks and shipped to the atomic proving station on Eniwetok in the Marshall Islands where it was condensed using the NBS liquefier.

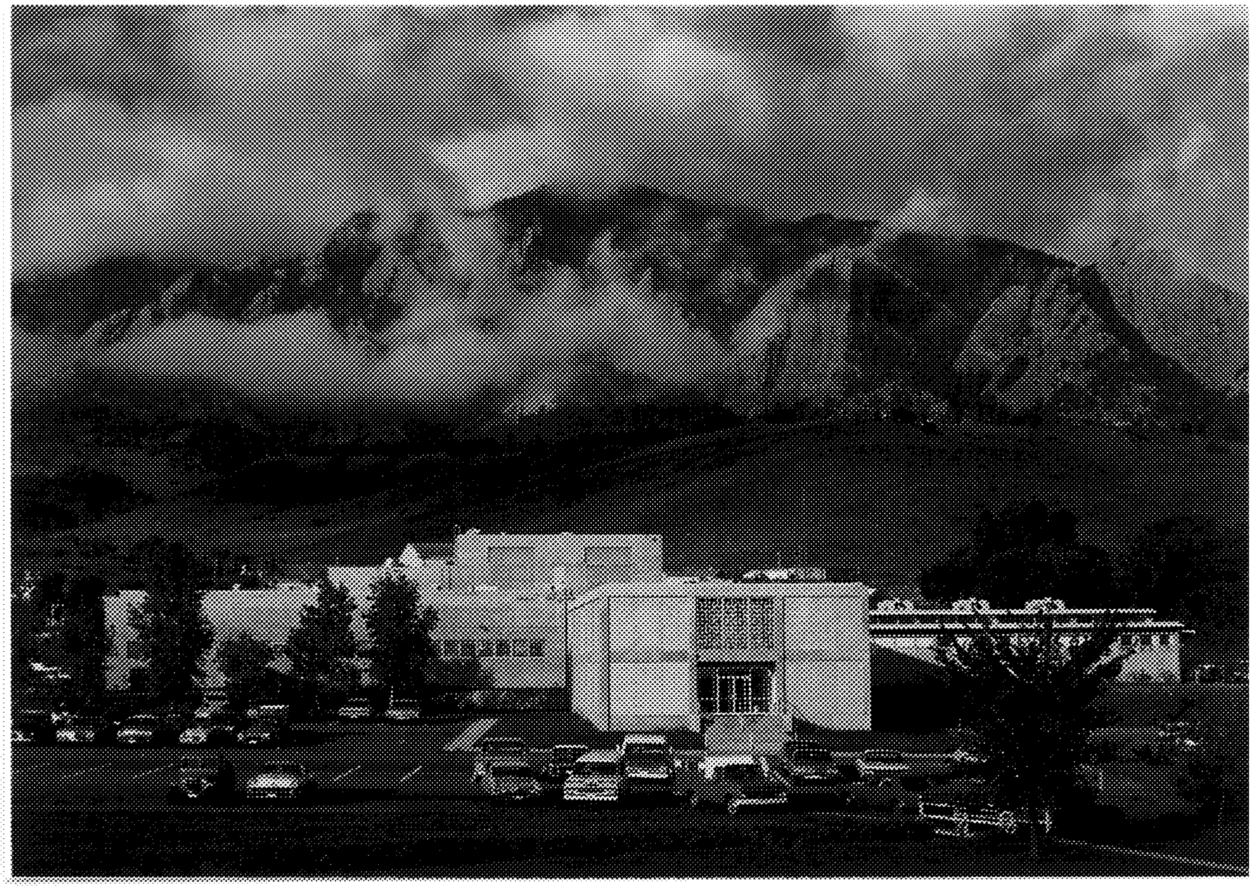

Fig. 1. The Cryogenics Building at the NBS Boulder Laboratories was the first ever designed specifically for cryogenic-engineering research. Photograph from NBS Archives, taken in 1968.

The thermonuclear device was designed at Los Alamos [6]. Liquid hydrogen used to test the components was safely transported from where it was produced in Boulder to Los Alamos in dewars designed and built by the Cambridge Corporation. Because of program priorities, the Cambridge Corporation and LASL took on the primary responsibility for the design and testing of the dewars. In March and April 1952, Herrick Johnston and his staff visited Boulder to participate in liquefier operation as part of the preparation for assembling and operating the liquefier on Eniwetok. On November 1, 1952, the Eniwetok Atoll was evacuated of all personnel, and the "ivy MIKE" shot was detonated. It was the first hydrogen thermonuclear device and was regarded as extremely successful, yielding 10.4 megatons of TNT equivalent and providing scientific data for future tests and development of weapons. The liquefier described in Scott's book played a critical role in the success of this test.

In 1953, the NBS staff (Brickwedde, Scott, Baird, Birmingham, Chelton, Freeman, Gifford, Goddard, Johnson, Kropschot, Powell, and Vander Arend) were awarded the Department of Commerce Gold Medal for "The design, construction and operation of large and unique hydrogen and nitrogen liquefiers."

As the need for cryogenics in nuclear testing diminished, the NBS cryogenics facilities, led by Russell Scott, turned attention to a growing national need for scientists and engineers to be trained in cryogenics, as well as to the measurement and collection of very low temperature data. Scott organized the Boulder staff into discipline-oriented groups to provide the data necessary for cryogenic design. These groups included Thermodynamic Properties of Cryogenic Fluids; Mechanical and Thermal Properties of Solids; Instrumentation (thermometry, liquid level, pressure); Systems (liquefaction and refrigeration, fluid flow, dewar design, distillation); Data Center (compilation, critical evaluation and dissemination of data); and Production of Cryogenic Fluids (hydrogen, helium, nitrogen).

Scott was committed to on-going training, and in 1954 he initiated the first Cryogenic Engineering Conference (CEC) in Boulder, which attracted more than 400 participants. The technical papers were published in the first volume of *Advances in Cryogenic Engineering (ACE)*. Since then there have been a total of 40 CEC conferences with commensurate *ACE* publications involving an estimated 25,000 participants.

An entire generation of engineers and scientists has used Scott's *Cryogenic Engineering,* which not only outlines fundamentals, but also includes detailed design principles and techniques. It was the first of its kind and is still considered an important reference today. The book begins with a description of how fluids are liquefied and gas mixtures are separated. The examples illustrate the basics of design and operation for all types of cryogenic equipment. Thermometry is fundamental to all of cryogenics. The book includes a discussion of temperature scales and temperature measurements, as well as guidance on how to avoid common errors when making these measurements. It continues with a discussion of representative technology including heat exchangers, valves, transfer lines, expansion engines, and insulation technology—since once gases are liquefied, they are ready for transfer, storage, and transport. Both tables and graphs are used to illustrate typical thermal insulations. The small heats of vaporization coupled with relatively large temperature differences warrant sophisticated insulations. These insulations almost always require double-walled high vacuum designs. The vacuum space is often filled with low-density powder or multilayers of radiation-reflecting material. The thermodynamic properties of cryogenic fluids—helium, hydrogen, neon, nitrogen, and oxygen—are presented graphically. The book also includes data on the thermal and mechanical properties of some of the more widely used structural materials. Each chapter cites references to handbooks and review articles that are fundamental to cryogenic research. In the preface, Scott acknowledged the assistance of NBS staff members who contributed to the preparation of the book and who helped establish NBS as a world-class research facility and a national resource.

In 1960, Scott was invited by the director of the UCLA Engineering Extension Division to teach a two-week short course using Cryogenic Engineering as the text. Assisted by R. H. Kropschot, Scott presented his first course in December 1960. The UCLA course was taught annually for more than 35 years by a variety of instructors from the NBS Boulder Laboratories. Other courses followed in Boulder, at various NASA facilities, universities, National Laboratories, and other institutions. Over the years, an estimated 5,000 students have taken these NBS-initiated short courses. In 1967, Scott received the Department of Commerce Gold Medal for Exceptional Service for "Exceptional Leadership and Meritorious Authorship in the Development of Cryogenic Engineering."

Fig. 2. Russell B. Scott (second from right) receives gift at his retirement in 1965. The presentation is being made by (from left to right) F. G. Brickwedde (Pennsylvania State University), former Director Edward U. Condon (NBS), Division Director B. W. Birmingham (NBS), Associate Director Edward Hammel (LASL), and Director Allen Astin (NBS). Photograph from NBS Archives.

Scott's legacy is more than a book and the organization that he helped to build at NBS. Members of his staff participated in all the major U.S. cryogenic engineering programs for more than 25 years. Some examples of his legacy may be mentioned. In his Nobel acceptance speech, Luis Alvarez (University of California, Berkeley) acknowledged the work of Chelton, Mann, and Birmingham for design contributions to the Lawrence Berkeley Laboratory hydrogen bubble chamber. NBS programs funded by NASA supported Centaur, the first hydrogen/oxygen space vehicle; storage of hydrogen and oxygen for fuel cells and breathing oxygen; hydrogen/oxygen safety; fluid and solid properties; instrumentation; and fluid flow. Measurements, compilation, and critical evaluation of the thermodynamic properties of fluids by NBS scientists (Corruccini, Goodwin, McCarty, Strobridge, Roder, Diller, Weber, and Younglove) have fulfilled governmental and industrial requirements for engineering design. They assisted in the design and construction of the NASA hydrogen liquefiers (the Bear Plants—Baby, Mama, and Papa); design of high energy physics accelerators and detectors; and the formulation of LNG safety procedures. A data book describing safety regulations and thermodynamic properties [7] was developed for the liquefied-natural-gas (LNG) industry. And finally, one of Scott's legacies most often cited is that of technology transfer, which has had a wide impact as former NBS employees move into new positions in industry and academia.

Russell B. Scott was born in Ludlow, Kentucky, on April 17, 1902. He received his B.S. (1926) and M.S. (1928) in physics from the University of Kentucky and joined NBS immediately afterward. He was Director of the Boulder Cryogenics Laboratory from 1952 to 1962 and Director of NBS Boulder Laboratories from 1962 to 1965. He died September 24, 1967 in Boulder.

Prepared by Richard H. Kropschot.

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