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HISTORIC ASSESSMENT NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY RADIO TRANSMITTER FACILITIES FORT COLLINS, COLORADO AND KEKAHA, HAWAII

TASK ORDER: 9102-RCG-01

PREPARED FOR:

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

ON BEHALF OF:

METROPOLITAN ARCHITECTS & PLANNERS

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Historic Assessment
National Institute of Standards and Technology
Radio Transmitter Facilities
Fort Collins, Colorado
and
Kekaha, Hawaii

Task Order: 9102-RCG-01

Final Report

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Executive Summary

This report presents the results of the intensive architectural survey and evaluation of the National Institute of Standards and Technology (NIST) radio transmitter facilities at Fort Collins, Colorado, and Kekaha, Hawaii. NIST is a non-regulatory Federal agency within the U.S. Department of Commerce (National Institute of Standards and Technology [NIST] 2014).

This study presents a comprehensive study of the history, development, and relationship of the radio transmitter facilities with the atomic clock located in Building 1 of NIST Boulder Colorado campus. This report presents the results of the individual and collective evaluation of the radio transmitter facilities within the historic context of NIST applying the National Register Criteria for Evaluation (36 CFR 60.4 [a-d]) to all buildings, structures, objects, and landscapes within the satellite facilities.

R. Christopher Goodwin & Associates, Inc. (RCG&A) undertook this project for Metropolitan Architects and Planners, Inc. (MAP) on behalf of NIST to support the agency in its program to identify, evaluate, and manage historic properties in accordance with the National Historic Preservation Act of 1966, as amended (NHPA). This investigation was completed through a progressive program of archival research, field investigation, and data analysis. The current work incorporated previously compiled data contained in *Historic Assessment Department of Commerce Boulder Laboratories, Boulder, Colorado* and *Historic Assessment National Institute of Standards and Technology, Gaithersburg, Maryland (*RCG&A 2016; RCG&A 2015).

Architectural investigations were completed by a team of architectural historians whose professional qualifications exceed those established by the Secretary of the Interior in the field (36 CFR Part 61). The facilities were described in full and assessed for those aspects of historical significance and integrity.

Evaluation of the two satellite facilities in accordance with National Register standards and guidelines found that the facilities possess the qualities of significance and integrity necessary for listing on the National Register of Historic Places for their national level of importance under Criterion A in the area of science (National Park Service [NPS] 1983). The radio transmitter facilities in Fort Collins, Colorado, and Kekaha, Hawaii, are integral to receiving and transmitting the national standard for time calibrated through the atomic clock located at Building 1 at the NIST Boulder, CO campus. The transmitter stations also are historically responsible for the transmitting frequencies that maintain the integrity of the nation's radio airwaves.

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Chapter 1

Introduction

1.1 Project Description

This report presents the results of the intensive-level architectural survey and evaluation of the National Institute of Standards and Technology (NIST) satellite facilities at Fort Collins, Colorado, and Kekaha, Hawaii, applying the Criteria for Evaluation (36 CFR 60.4 [a-d]) of the National Register of Historic Places (NRHP). NIST is a non-regulatory Federal agency within the U.S. Department of Commerce (National Institute of Standards [NIST] 2014a). The agency historically was known as the National Bureau of Standards (NBS) from 1901 to 1988.

NIST maintains two primary campuses and two satellite facilities in the United States. The campuses located in Gaithersburg, Maryland, and Boulder, Colorado, are major scientific research, testing, and administrative facilities. The satellite facilities at Fort Collins, Colorado, and Kekaha, Hawaii, are radio transmitting and receiving stations, which support the cesium atomic clock located in Building 1 of the Boulder, Colorado campus. For the purpose of this report, these stations will be referred to as radio transmission stations. Building 1 previously was determined individually eligible for listing on the National Register of Historic Places (NRHP) (see *Section 1.4. Previous Investigations*). The satellite facilities also transmit frequencies important to the orderly operations of the nation's radio airwaves.

The Fort Collins facility is located in Larimer County approximately 46 miles north of Boulder, Colorado (Figure 1.1). The facility encompasses approximately 300 acres (Lombardi 2002:1). The facility is accessed from East County Road 58. North Poudre Reservoir Number 6 forms the eastern and northern boundaries, and East County Road 58 forms the southern boundary. An unnamed manmade lake and a series of private, residential developments form the facility's western boundary. The NIST facility at Fort Collins is over 50 years of age, the suggested age generally established for the consideration of resources for inclusion in the NRHP.

The Kekaha facility is located in Kauai County on the Department of the Navy's Barking Sands Missile Range Facility, approximately 35 miles from Lihue. The facility encompasses approximately 30 acres and is surrounded by the Barking Sands Missile Range Facility (Figure 1.2). The NIST campus at Kekaha will reach 50 years of age in 2021.

The current investigation documented and assessed the significance and integrity of the radio transmission stations within the NIST historic context. The study included comprehensive architectural survey and evaluation applying the NRHP Criteria for Evaluation (36 CFR 60.4 [a-d]) for all buildings, structures, objects, and landscapes included at the NIST satellite facilities.

Master Planning has recently been completed for the two primary NIST campuses in Gaithersburg and Boulder. This project is related to those efforts through the advance planning, identification and evaluation historic properties at the NIST facilities in Fort Collins and Kekaha. R. Christopher Goodwin & Associates, Inc. (RCG&A) undertook this project for Metropolitan Architects and Planners, Inc. (MAP) on behalf of NIST to support the agency in its program to identify, evaluate, and manage historic properties in accordance with the National Historic Preservation Act of 1966, as amended (NHPA).

1.2 Objective

The objective of the current investigation was to support NIST through the systematic identification of historic properties pursuant to NHPA. RCG&A accomplished this objective through an integrated and progressive program of archival

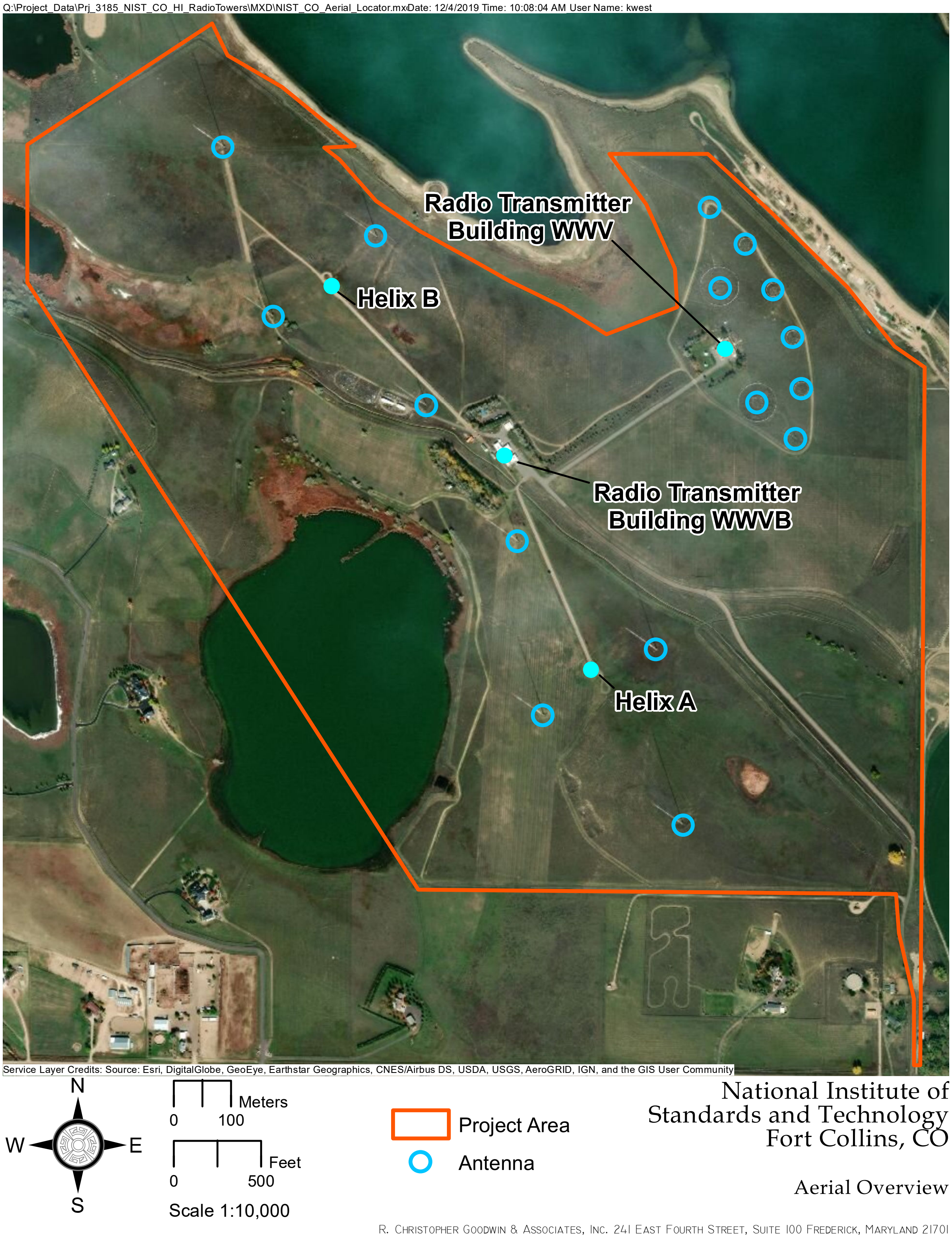

Figure 1.1: Site Map of the Kekaha Facility.

Figure 1.2: Site Map of the Fort Collins Facility.

research, site investigation, and data analysis. Archival research was undertaken to develop the historic context appropriate for the assessment of NIST built resources. An historic context defines the events, trends, and patterns of history through which a property is understood and makes possible the evaluation of its local, state, or national significance.

Comprehensive architectural survey of built resources within the satellite facilities was completed to systematically document all buildings, structures, objects, and landscapes. Archival and field data then were analyzed applying the NRHP Criteria for Evaluation (36 CFR 60.4 [a-d]) to identify properties that possess the significance and integrity necessary for listing in the NRHP.

All work was completed in accordance with the guidelines set forth in the Secretary of the Interior's Standards and Guidelines for Historic Preservation (NPS 1983), the Colorado State Historic Preservation Office (COSHPO)'s *Guidelines for Identification: History and Archaeology* (History Colorado 2007), and the Hawaii State Historic Preservation Office (HISHPO)'s *Guidelines: Architectural Historic Resource Surveys and Documentation* (Hawaii State Historic Preservation Division 2018). All work was undertaken by project staff who exceed the Secretary of the Interior's Professional Qualifications Standards (36 CFR Part 61) in the fields of history and architectural history.

1.3 Regulatory Overview

The NHPA is a Federal law that established planning and stewardship responsibilities for historic properties controlled by Federal agencies. The NRHP was established by NHPA and defines the criteria for significance and integrity used in the identification of historic properties. The NRHP is the official list of properties significant in American history, architecture, archeology, engineering, and culture. NHPA eligibility and/or listing recognizes properties worthy of preservation; the NRHP continuously is expanded to represent the multiple facets and growing understanding of American history. The Secretary of the Interior maintains the NRHP and has developed regulations defining the procedures for listing properties in the NRHP (36 CFR 60.4). The NRHP program is administered by the National Park Service (NPS).

Section 106 of NHPA requires Federal agencies to take into consideration the effects their undertakings upon historic properties and to afford the Advisory Council on Historic Preservation the opportunity to comment on the action. An historic property is any resource, i.e., building, structure, object, site, or district, that is eligible for inclusion or listed in the NRHP. NHPA emphasizes Federal stewardship of historic resources through agency practice and policy. It encourages Federal agencies to identify, evaluate, and nominate resources to the NRHP.

NIST's compliance with Federal cultural resources laws and regulations is directed through the Department of Commerce's broader environmental compliance program. Specific regulations and policies governing the treatment of historic properties are presented in two documents. The Department of Commerce Administrative Order 216-16, issued on 5 April, 2012, directs the implementation of NHPA and further directs all departmental offices and operating units to comply with all Federal, state, and local environmental and cultural and historic resources laws and regulations in addition to complying with Executive Orders and other Department of Commerce regulations, policies, and requirements (U.S. Department of Commerce 2012a:2). The Administrative Order further mandates compliance with the *Department of Energy and Environmental Management Manual*. The Energy and Environmental Management Manual is an extension of the Administrative Order and outlines the department's cultural resources management program and department responsibilities. As an agency within the Department of Commerce, NIST is responsible for implementing all cultural resources management regulations, policies, and directives (U.S. Department of Commerce 2012b:24-5).

NIST manages historic properties in accordance with Federal laws, including the NHPA, and Department of Commerce regulations. The primary steps undertaken in cultural resources management include:

Resource identification;
Resource evaluation;

Planning; and
Treatment of historic properties.

1.4 Previous Investigations

In 2015, comprehensive architectural surveys and evaluations were completed for the NIST Gaithersburg and NIST Boulder campuses (RCGA 2015; RCGA 2016). The NIST Boulder and Gaithersburg properties are large, multi-acre, urban research campuses. Both campuses include mid-century built resources and are representative of research campus design in the 1950 and 1960s. The NIST Gaithersburg campus as a whole was found to possess National Register significance and integrity. Consultation with Colorado SHPO determined that Building 1 at the Boulder campus individually was "eligible for listing on the National Register of Historic Places under Criterion A (History) and Criterion C (Architecture and Engineering)" (RCG&A 2015:235).

1.5 Archival Research

Archival research into primary and secondary sources was completed to develop a site-specific historic context for NIST for the radio satellite facilities. The following areas of investigation were pursued to develop:

- General historic overview for the NIST Fort Collins and NIST Kekaha facilities to understand the role that each facility plays within the larger NIST mission and history;
- Important historical themes and time periods associated with the development of the facilities in Fort Collins and Kekaha;
- Important events and individuals associated with the satellite facilities; and,
- Site Selection, Construction history and property types associated with the physical development of the satellite facilities.

Research was undertaken at the following repositories: the National Archives and Records Administration, Denver; the Colorado State Library; the NIST Boulder Library; the Hamilton Library at the University of Hawaii, the NIST Kekaha Campus; and the NIST Gaithersburg Library. Oral histories and interviews were undertaken with NIST physicists and engineers at Boulder, Fort Collins, and Kekaha; including Dr. Judah Levine, Matthew J. Deutch, and Dean Okayama.

1.6 Comprehensive Architectural Survey

The purpose of the architectural field investigations was to collect data sufficient to document the current appearance of permanent built resources at the satellite facilities to enable their individual and collective assessment of significance and integrity. The current investigation comprised survey of buildings, structures, sites, objects, and landscapes located at the Fort Collins and Kekaha facilities; no archeological investigations were undertaken as part of the current investigation.

Comprehensive survey data were compiled for the subject real property. In addition, architectural historians identified and documented landscape features; building interiors also were surveyed. Temporary buildings, such as trailers and prefabricated storage buildings not integral to NIST's core missions, were excluded from the architectural survey.

The following information was collected for each property:

- Date constructed;
- Type of construction;
- Overall descriptive data including building type, style, location, number of stories, plan shape and type, exterior wall materials, roof shape and materials, placement of building openings, and modifications over time;
- Function; and,
- Association with NIST and Fort Collins and Kekaha missions.

Using electronic data collection tools, RCG&A personnel collected written, graphic, and digital photographic data for each resource.

This provided the ability to process data to support data analysis, including resource mapping.

1.7 Data Analysis Guidelines

The National Register Program establishes guidance for the evaluation of historic properties. In order for a property to merit consideration for inclusion in the NRHP, a property must have significance and retain integrity. The NRHP Criteria for Evaluation (36 CFR 60.4 [a-d]) were applied to the NIST resources to determine whether the resources are significant. Criteria Consideration G was applied to the NIST resources determined not to have met the recommended 50-year threshold for eligibility. Resources also were analyzed for historical integrity. Integrity is a property's ability to convey its significance, a concept discussed in greater detail later in this chapter.

In addition to that issued by the NPS, RCG&A staff consulted guidance prepared by the ACHP. *Balancing Historic Preservation Needs with the Operation of Highly Technical or Scientific Facilities* provides direction on the evaluation of resources associated with highly technical or scientific facilities. As the report notes, "Many of the facilities and much of the equipment associated with scientific engineering advancements remain in active use today, but need to be continuously upgraded and modified to stay at the cutting edge of technology" (Advisory Council on Historic Preservation [ACHP] 2002). The report acknowledges that a balance between cultural resources management needs and the needs of active research institutions is necessary. Further, the report makes a distinction between the quantity and changes in use or character as opposed to "natural, ongoing change and improvement to and in structures or equipment as they are continually subjected to minor change while they continue to function for their original purpose" (ACHP 2002). The ACHP guidance acknowledges that resources used for scientific purposes can be altered and modified to enable the resources to continue to be used for their scientific purposes. Consequently, these changes may not necessarily affect resource integrity.

NIST actively has been responsible for its real property since the agency was established. NIST maintained real property oversight after the creation of the General Services Administration (GSA) in 1949, which established a division within the Federal government to design, construct, and manage buildings in the Federal inventory (General Services Administration [GSA] 2005:10). Internal real property oversight by NIST was reinforced through continuous modification to the agency's Organic Act, which was last revised in 2010. Under the 2010 revisions regarding the administration and functions of NIST, the Secretary of Commerce was authorized to use NIST-appropriated funds to "undertake such construction of buildings and other facilities and to make such improvements to existing buildings, grounds, and other facilities occupied or used by the institute" (RCG&A 2015:8).

Guidance developed by other Federal agencies for the identification and evaluation of properties comparable to the NIST resources were reviewed. This review included technical guidance developed by GSA, which was consulted during previous investigations at the Boulder and Gaithersburg campuses. GSA developed an historic context for Federal buildings in the GSA real property inventory designed during the Modern period. *Growth, Efficiency, and Modernism. GSA Buildings of the 1950s, 60s, and 70s* identifies key design philosophies of Modern architecture, provides a summary history of the GSA, and presents policies and guidelines that governed Federal construction during the 1950s through the 1970s (GSA 2005). The report provides a framework for the management of buildings constructed between 1950 and 1970 that are in the GSA real property inventory. This guidance was reviewed for applicability to the NIST radio transmitter facilities owing to these similar period of construction.

A review of guidelines issued by other Federal agencies with science and technology missions also was undertaken. In particular, the policies developed by the National Aeronautics and Space Administration (NASA) were reviewed for application to NIST.

1.8 Evaluation of Built Resources

Archival and architectural field data were analyzed within the appropriate historic context applying the NRHP Criteria for Evaluation (36

CFR 60.4 [a-d]). The historic context prepared as part of this investigation provided the basis for assessing resources located at the NIST Fort Collins and Kekaha facilities for the qualities of significance in American history, architecture, engineering, and culture; and for aspect of integrity in location, design, setting, materials, workmanship, feeling, and association. Individual and collective (as a potential multiple property nomination) assessments were made for associations with events that have made a significant contribution to the broad patterns of our history (Criterion A); for associations with the lives of persons significant in our past (Criterion B); and for the ability to embody the distinctive characteristics of a type, period, or method of construction, to represent the work of a master or possess high artistic values, or to represent a significant and distinguishable entity whose components may lack individual distinction (Criterion C). Criteria Considerations are applicable to properties under the general age threshold for National Register listing.

1.9. The Evaluation of Properties Using the NIST Historic Context

1.9.1 NRHP Categories

The NRHP recognizes five resource categories. These include buildings, structures, objects, sites, and districts. Buildings are those resources constructed as human shelter whereas structures are those built for purposes other than human shelter. Sites, which may include archeological resources, may also include resources associated with the environment including landscape design and site plan. Landscape design and site plan can incorporate elements such as circulation networks, building setbacks, and vegetation (NPS 1993).

The primary significance of the NIST main campuses was established in the areas of science and architecture. The facilities subject to this investigation are radio transmitter stations with antenna systems that work together to transmit official U.S. time standards and other scientific data. Therefore, the Fort Collins and Kekaha facilities are best classified as districts, which include component buildings, structures, and landscapes. These facilities are integral to, and best understood, within the context of the NIST history and mission.

The framework established by the historic context presented in this report allows for the assessment of resources located at Fort Collins and Kekaha within the history of the specialized aspects of science applied by NIST in support of national commerce. NIST's primary mission is to support innovation and industrial competitiveness through the advancement and development of measurement science, standards, and technology. The operations carried out at the Fort Collins and Kekaha districts are associated with this larger scientific and technological effort.

1.9.2. Integrity

In addition to possessing significance within an historic context, NRHP eligibility requires that a property must possess integrity or the ability to convey its significance through the retention of essential physical characteristics from its period of significance. The seven aspects of integrity include location, design, setting, materials, workmanship, feeling, and association. Architectural historians from RCG&A evaluated the extent to which the Fort Collins and Kekaha facilities retain the seven aspects of integrity in order to further determine their assessment.

Located at Boulder laboratories, the cesium atomic clock is an object with several mechanical and electrical components working in conjunction to keep the most accurate record of time (Figure 1.3). The atomic clock occupies dedicated laboratories within Building 1 of the campus, a building that has been determined eligible for NRHP listing, in part, for its association with science and the NIST mission. The facilities at Fort Collins and Kekaha are, in part, best understood for their relationship to Building 1 at Boulder.

1.10 Organization of the Report

This report is organized into five chapters with two appendices. Chapter 1 summarizes the purpose of the investigations and presents the project research design and methodology. Chapter 2 provides an overview history of NIST from its founding to World War II, and a summary history of the cesium atomic clock. Chapter 3 provides a summary history Fort Collins and Kekaha

Figure 1.3: Mechanical Room Equipment for the Cesium Atomic Clock at Building 1 of Boulder Laboratories in Colorado.

facilities. Chapter 4 presents the architectural survey data and evaluation results.

Copies of the Colorado History Survey Form for the Fort Collins facility and the Hawaii State Historic Preservation Excel Form for the Kekaha facility are included as Appendix A. Correspondence from the CO SHPO concurring with the NRHP eligibility for Building 1 at the NIST Boulder campus and the associated CO SHPO Survey Form are included in Appendix B.

Chapter 2

History of NIST and the Atomic Clock

2.1 Introduction

The Fort Collins and Kekaha radio transmitter facilities are scientifically sophisticated, specialized complexes that were constructed by the National Institute of Standards and Technology (NIST) to support aspects of their core mission. NIST is charged with establishing national measurement standards and keeping those standards uniform, compatible, and reliable. Basic measurements include mass, length, *time*, temperature, electric current, resistance, and chemical composition.

This chapter presents an overview of NIST, the Boulder Laboratories, and the cesium atomic clock. The narrative provides a framework for understanding the role of the radio transmitter facilities within the agency mission. NIST undertakes highly technical work at the forefront of the scientific disciplines. The following discussion emphasizes the history of that work.

2.2 NIST Mission

NIST disseminates data regarding national measures to government, industry, and the public. This task has expanded exponentially over the agency's history. From its founding as the National Bureau of Standards (NBS), data from the experiments conducted at NIST have been published as research bulletins, disseminated as scientific and technical studies, articles in professional journals, circulars, data reference materials, standard reference materials, and conference materials. In 1988, Congress changed the agency's name to the National Institute of Standards and Technology and refocused the agency's mission through a major role in revitalizing U.S. trade. The current NIST mission statement reflects that change "To promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life" (NIST 2012a).

2.3 Overview History of NIST

Founded in 1901, NIST initially occupied a campus located at the intersection of Connecticut Avenue and Van Ness Street in Washington, D.C. NIST was created to establish national measurement standards and to keep those standards uniform, compatible, and reliable; a mission that the agency continues to fulfill. Basic measurements include mass, length, time, temperature, electric current, resistance, and chemical composition.

Established as an agency under the Department of the Treasury, NIST addressed the need for legislated standards for weights and measurements among Federal agencies and state governments, as well as the need for new standards in electrical measurements. In 1903, NIST was assigned to the Department of Commerce and Labor and, ten years later, when the department was divided, assigned to the Department of Commerce. NIST originally was organized into divisions according to research area. Division I included weights and measures, heat and thermometry, light and optical instruments, engineering instruments, instrument shop, and administration. Division II was devoted to electricity, including resistance and electromotive force, magnetism and absolute measurement of current induction and capacity, electrical measuring instruments, photometry, and the engineering plant. Division III later was added and focused on chemistry (Cochrane 1966:74-75).

NIST quickly expanded into new areas of research. In 1904, NIST scientists purchased the liquid hydrogen production equipment exhibited by the British Oxygen Company at the 1904 St.

Louis World Fair. The purchase of the equipment initiated research into cryogenics, the study of low temperatures (Cochrane 1966:83).

Between 1909 and 1911, NIST staff investigated how states were applying their standards. NIST staff visited each state and tested 30,000 scales, weights, and dry and liquid measures. The results of the tests indicated that a large proportion of the weights and measures used in the marketplace were fraudulent. These results eventually led to states adopting a model law of standards for weights and measure proposed by NIST.

NIST explored numerous new areas of research during World War I. These areas included research into aircraft materials; airplane frames, wing fabrics, engines, and concrete for cargo ships. Following World War I, NIST continued to expand as an agency. Projects undertaken during this time reflected political priorities and the agency's basic scientific programs were highlighted.

NIST undertook studies into all aspects of radio transmission and receiving and established the WWV radio station at Beltsville, Maryland, in 1923 to transmit standard radio frequencies and time (NIST 2014a). Radio research also included the investigation of the layers in the upper atmosphere that interfered with radio waves. Telecommunication engineer and radio expert, John Howard Dellinger, Ph.D., who was the chief of the Central Radio Propagation Laboratory, conducted research that linked interruptions in long-distance radio transmissions to solar eruptions. As a result of Dellinger's work, NIST initiated monthly forecasts of ionospheric and radio conditions in 1937 (Cochrane 1966:350-353). Immediately before, during, and after World War II, NIST also was engaged in the successful construction of an atomic clock that supported the National Primary Frequency Standard (NPFS).

2.4 Time Measurement and The Atomic Clock

The scientific interest in time and frequency standards have a long history. Time measurement generally is divided into two categories: time interval measurement and time synchronization measurement. The former measures the duration between two events, while the latter makes possible event scheduling by aligning time tags (year, month, day, hour, minute, and second). Both types of time measurement are referenced to the frequency of a periodic event that repeats at a constant rate. Periodic events include the swing of a clock pendulum or the resonant transitions in atoms (Lombardi 2014: 41-1).

Lord Kelvin, recognizing that atoms, unlike mechanical resonators, do not wear out or change properties over time, proposed using transitions in sodium and hydrogen atoms as timekeeping oscillators in 1879 (Lombardi et. al. 2007:76). The first atomic oscillator experiments were initiated in the late 1930s after significant advancements in quantum mechanics and microwave electronics. Many of these experiments were led by NIST scientists and were based on the principle that atoms of the same element are identical and produce identical frequencies when they absorb or release energy (Lombardi 2000).

Currently, atomic oscillators based on rubidium, cesium, and hydrogen atoms are employed commercially for time measurement. Cesium oscillators are employed in many laboratories and are internationally recognized as a time interval standard. Cesium must be synchronized with another source for use as a synchronization reference (Lombardi 2000).

At its core, the cesium atomic clock is the mean (average) of several cesium devices, scientifically known as oscillators. Oscillation is the repetitive variation, typically in time, of some measure around a central value (often a point in an equilibrium) or between two or more different states. An oscillator is a device used to generate oscillatory electric currents or voltages through non-mechanical means. These oscillators funnel cesium atoms down a tube where they pass through radio waves. If the frequency is just right, the cesium atoms will resonate and change their energy state. A detector at the end of the tube keeps track of the number of cesium atoms that have changed their energy state and feeds that information back to the radio wave generator. This generator synchronizes the frequency of the radio waves with the peak number of cesium atoms striking it. Numerous cesium devices undergo this process each second and the generator, known as the cesium atomic clock, averages the data into the national performance frequency standard (NPFS). Satellite radio transmitter facilities at Fort Collins, Colorado, and Kekaha, Hawaii, receive and relay time produced by the NPFS.

Early, rudimentary concepts of atomic oscillators were developed by Isidor Rabi and his colleagues at Columbia University during the 1930s and 1940s. Rabi informally discussed using molecular beam magnetic resonance as a time and frequency standard with NIST scientists in 1939. The first experiments to measure the frequency of cesium resonance were performed in 1940 by Rabi's colleagues at Columbia University. Further exploration was halted by World War II.

The world's first working atomic oscillator was not based on cesium atoms. Instead, it was based on a 23.8 GHz inversion transition in the ammonia molecule (Lombardi et. al., 2007:78). Harold Lyons and his associates developed an ammonia device at NIST. It consisted of a quartz crystal oscillator, electronically stabilized by the ammonia absorption line, and frequency dividers that produced a 50 Hz signal from the stabilized quartz oscillator. Developed for use as a frequency standard, the device was first operated on August 12, 1948, though it was not publicly demonstrated until January 1949.

During the same year in which Lyons introduced the ammonia frequency standard, work by Norman Ramsey of Harvard University provided a critical improvement, the separated oscillatory field method. This method is utilized by all primary frequency standards. In the early work of Rabi, the atomic resonance was investigated as one long microwave pulse. This approach provided the required long interaction time between the atom and microwave field, but subjected the output frequency of the standard to Doppler shifts[1] and other uncertainties. The separated oscillatory field method limited these uncertainties by exciting the atoms with two short microwave pulses that were separated by some distance along the beam path. Applying the oscillating field in two steps had many benefits, and made possible more stable and accurate standards. By the early 1950s, work had begun in several international laboratories to build atomic frequency standards based on cesium, most notably the National Physical Laboratory (NPL) in England and at NIST in the United States.

NIST scientists utilized seven different cesium beam devices for the U.S. NPFS over an approximate 39-year period (1959-1998). The time standards were generated by thermal cesium beam devices that operated by directing a beam of cesium atoms through a microwave cavity. These devices were known as NBS-1 through NBS-6, and NIST-7.[2]

NBS-1 generated the original cesium beam primary frequency standard at NIST. Derived from a principle developed by Dr. Harold Lyons of the Institute's microwave research laboratory, NBS-1 was the first NIST cesium beam used to develop a primary frequency standard and was controlled by a constant frequency derived from a microwave absorption line of ammonia gas, providing a time constancy of 1 part in 10 million (National Bureau of Standards [NBS] 1949:17). NBS-1 was the only cesium beam that was not constructed at the Boulder campus. Rather, it was relocated to Building 1 at Boulder Laboratories in 1954. NBS-1 was redesigned before its designation as the national standard for frequency in spring 1959 (Lombardi et. al., 2007:82).

On January 1, 1960, NBS-1 was replaced by NBS-2 as the NPFS. NBS-1 continued to operate and was compared to the new NBS-2 to gauge accuracy until 1962. Later that year, NBS-2 was converted to an experimental thallium beam and was soon replaced by the NBS-3 in September 1965 (Figure 2.1). NBS-3 generated the NPFS standard until 1970, when it was completely dismantled. Parts of its vacuum system were later used in NBS-5 (Barnes 1982:9; Lombardi et. al., 2007:83).

The primary time standard was not generated by NIIST during the period from 1970 to 1972. Cesium based standards for the NPFS were generated in commercial laboratories while work on physical development of NBS-4 and NBS-5 were underway at NIST. NBS-4 was physically

1 The Doppler shift is the change in frequency or wavelength of a wave in relation to an observer who is moving relative to the wave source.

2 The agency's name was changed from NBS to NIST in 1988 between employment of NBS-6 and its successor, NIST-7.

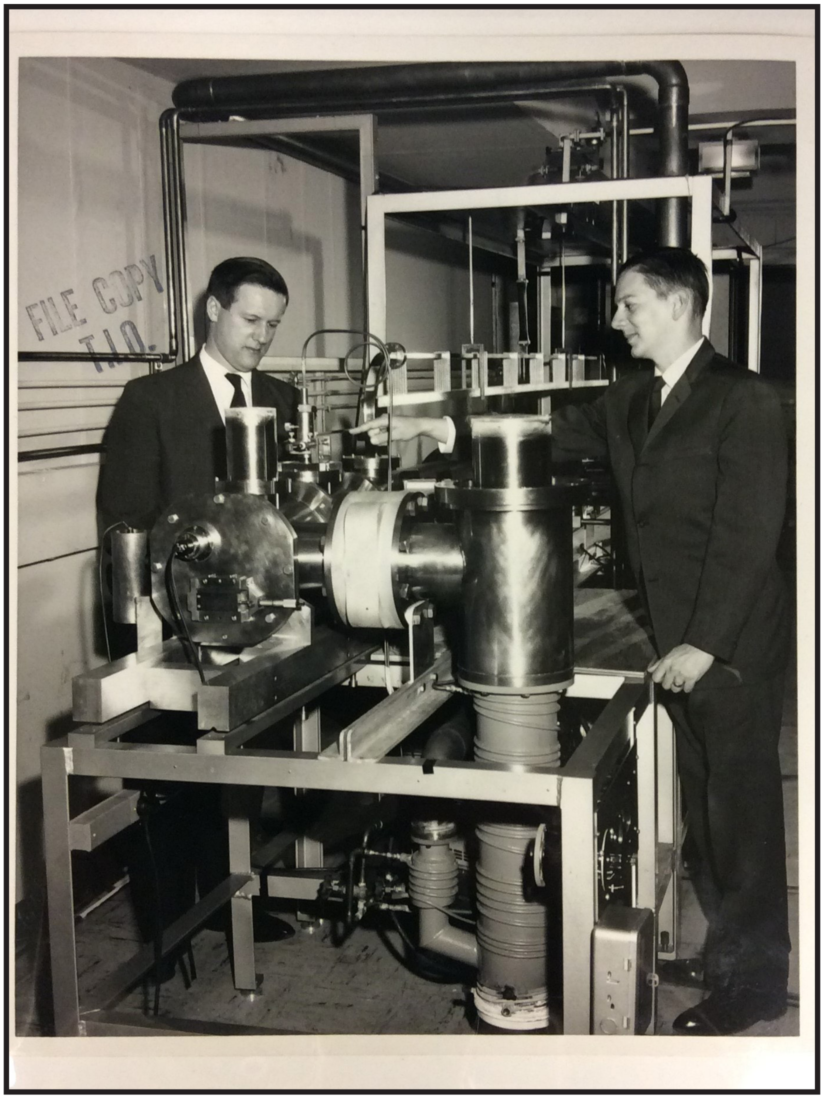

Figure 2.1: Roger E. Bechler (right), physicist and project leader in the Atomic Frequency and Time Interval Standards of the Radio Standards Laboratory at Bolder, points out a detail in the construction of NBS 3 in 1964 (courtesy of the National Archives at Denver).

the smallest of the primary frequency standards, yet had the longest operating life. NBS-4 was a joint experimental venture between NIST and the Hewlett-Packard Company and not intended to generate a primary frequency standard. While work on NBS-4 actually began in late 1965, the physical standard was not operational until early 1973. NBS-4 was never designated officially as the NPFS. Instead, its official role was to provide, in conjunction with the NBS-5 and later NBS-6, comparative data and to serve as the primary standard when main devices were not operational (Lombardi et. al., 2007:83-84).

The next two standards, NBS-5 and NBS-6, served at the NPFS for more than 20 years. Work on NBS-5 began in 1966 and it served as the NPFS from January 1973. Substantial modifications to NBS-5 lead to its designation as NBS-6. These improvements were a direct result of more effective filtering of high velocity atoms, reduced scattering of low velocity atoms, and reduced velocity of the atomic beam. The redesigned standard NBS-6 became fully operation by 1975 and eventually served as the NPFS until 1993 (Lombardi et. al., 2007:84).

NIST-7 was the last thermal beam frequency standard developed at NIST and differed significantly from its predecessors. It used the newly developed narrow linewidth lasers for state selection and detection, replacing the magnets and detectors used by its predecessors. Using light instead of magnets conferred advantages Unlike magnetic selection, which merely filtered out atoms in the wrong energy state, the lasers optically pumped as many atoms as possible into the desired energy state. This produced more atoms and generated a much stronger signal. Work on NIST-7 began in 1988. The initial goal was to build a standard with timekeeping accuracy of 1 nanosecond per day. This goal was exceeded by a factor of two. NIST-7 was replaced in 1998 by NIST-F1, but the former remained operational for a few years afterwards. It now resides in the NIST museum in Boulder (Lombardi et. al., 2007:85).

The most recent atomic clock at NIST is known as the NIST-F1 and went into operation in 1999 (Figure 2.2). The NIST-F1 sometimes is referred to as a fountain clock because it creates a fountain-like movement of atoms to measure frequency and time interval. It operates when a gas of cesium atoms is introduced into the clock's vacuum chamber. Six infrared laser beams then direct their light at right angles to each other and toward the chamber center. The lasers gently push the cesium atoms together into a ball. In the process of creating this ball, the lasers slow down the movement of the atoms and cool them to temperatures near absolute zero (Lombardi et. al., 2007:85-86).[3]

Two vertical lasers are used to gently toss the ball a meter upward through a microwave-filled cavity, in so doing switching off the fountain movement and then all the lasers. Under the influence of gravity, the ball then falls back down through the microwave cavity. The trip from the ball's peak through the microwave cavity lasts approximately one second. During the trip, the atomic states of the atoms may or may not be altered as they interact with the microwave signal. When their trip is finished, another laser is pointed at the atoms. Those atoms whose atomic state was already altered by the microwave signal emit light. This state is known as fluorescence. The photons (or the tiny packets of light they emit), are measured by a detector (Lombardi et. al., 2007:85-86).

This process is repeated several times while the microwave signal in the cavity is tuned to different frequencies. Eventually, a microwave frequency is found that alters the state of most of the cesium atoms and maximizes their fluorescence. This frequency is the natural resonance frequency of the cesium atom, also known as the frequency used to define a single second.

The combination of the laser cooling and the fountain design allows NIST-F1 to observe cesium atoms for longer periods, thus achieve its unprecedented accuracy. Traditional cesium clocks and those that preceded NIST-F1 measured room-temperature atoms moving at several hundred meters per second. Since the atoms move so fast, the observation time was limited to a few milliseconds. NIST-F1, however, uses a different approach. Laser cooling drops the temperature of the atoms to a few millionths of a degree above absolute zero and reduces the thermal velocity to a few centimeters per second. The laser-cooled atoms are launched vertically and pass twice through a microwave cavity, once going up and once going down. The result is an observation time of roughly one second, limited only by the force of gravity pulling atoms to the ground. The longer observation times make it easier to tune the microwave frequency. Therefore, the improved tuning leads to a better realization and control of cesium resonance frequency. In turn, the improved frequency control leads to what is now one of the world's most accurate clocks (Lombardi et. al. 2007:86).

Signals from the cesium atomic clock have been broadcast through continuous signals for over 60 years. NIST broadcasts these continuous signals from its high-frequency (HF) and low-frequency (LF) stations (Figure 2.3). Radio stations WWV and WWVH operate in the HF portion of the radio spectrum, both radiating 10,000 W on 5MHz, 10MHz, and 15MHz, while WWVB operates on the LF portion of the radio spectrum on

3 Absolute zero is the lowest temperature that is theoretically possible, at which the motion of particles that constitutes heat would be minimal. It is zero on the Kelvin scale, equivalent to -273.15 degrees on the Celsius scale and -469.67 degrees on the Fahrenheit scale.

Figure 2.2: NIST-F1, the current National Performance Frequency Standard (NPFS) in the United States, at Building 1 of Boulder laboratories in Colorado (courtesy of NIST Boulder).

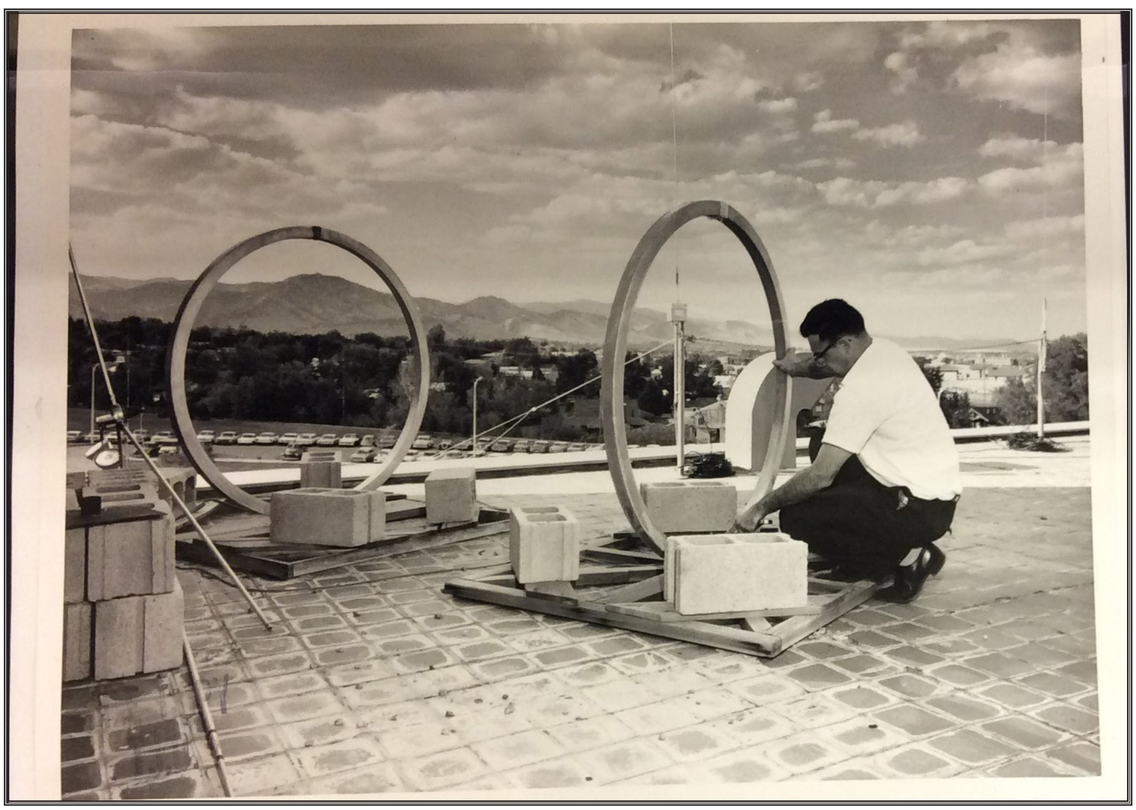

Figure 2.3: NIST physicist Lowell Fey makes an adjustment on the receiving antenna for phase lock control of WWV and WWVL, located at Fort Collins, of the Radio Building of the Boulder Laboratories, 1964. (courtesy of the National Archives at Denver).

a 60kHz signal. All frequencies carry the same announcement program, but because of changes in ionospheric conditions, which sometimes adversely affect the signal transmissions, most receivers are not able to pick up the signal on all frequencies at all times in all locations (Howe 1976:1). Except during times of severe magnetic disturbances, listeners should be able to receive the signal on at least one of the broadcast frequencies. In general, frequencies above 10 MHz provide the best daytime reception while the lower frequencies are better for nighttime reception. The time and frequency broadcasts are controlled by the NPFS at the NIST Boulder laboratories.[4] The frequencies as transmitted are accurate to within one part in 100 billion at all times (Howe 1976:1).

2.4.1 Traceable Time and the Atomic Clock

A key component of the cesium atomic clock, and time in general, is the concept of measurement traceability. Each of the NIST time and frequency services provides a way to establish traceability to NIST and to international standards (Lombardi 2002:7). International time standards are known as coordinated universal time (UTC). Traceability can be visualized as a chain that extends all the way from the definition of the International System of Units (SI)-defined unit[5] to the measurement or application. To keep the chain intact, a series of comparisons are needed. Each link in the chain is continually compared to the previous link. The traceability chain starts with a time and frequency source that is close to perfect.

To understand the importance of traceable time and the history of the NIST cesium atomic clock, an understanding of the standard units and devices of time is important. The standard unit of time interval is the second, which is defined according to a property of the cesium atom (Lombardi 2002:2). Since 1967, the second has been defined as the duration 9,192,631,770 cycles of the radiation associated with a specified transition of the cesium atom. Frequency is expressed in hertz and is obtained by counting events over one second intervals.

The second is one of the seven base units of measurement in the SI. The International Bureau of Weights and Measures (BIPM) located near Paris, France, is responsible for ensuring that the major countries of the world use the SI units. This means that the second and the other base units are defined the same way across the globe (Lombardi 2002:4). To measure one step further, frequency is the rate at which something happens. The unit used to measure frequency is hertz (Hz), or the number of events per second.

Time traceability is intertwined with time accuracy. NIST is comparing its time scale to other standards of the world daily. The process of comparing the NIST time scale to the other standards of the world completes the first link of the traceability chain. The second link is used to control the broadcast services. These services are continuously compared to the NIST time scale, and much care is taken to keep the measurement uncertainty as limited as possible. Most services used to synchronize computer equipment are referenced to atomic standards located outside of NIST's Boulder laboratory. The NIST radio station satellite facilities at Fort Collins, Colorado, and Kekaha, Hawaii, are used for these services. Three cesium standards are kept at Fort Collins and Kekaha to provide the reference for each station's time code generators and transmitters (Lombardi 2002:10). These standards are continuously compared and adjusted to agree with the Boulder time scale. The final link in the traceability chain occurs when someone actually uses the signal. Table 2.1 outlines all time and frequency services offered by NIST.

Time and frequency are closely related. The world heavily depends on time and frequency information relying on millions of clocks and, therefore, oscillators to keep that time and produce frequency. To keep a unified standard, these devices need to be periodically compared to an internationally recognized standard. The time and

4 As of 2019, the NPFS is NIST-7.

5 The SI base units are seven units of measure defined by the International System of Units as the basic set from which all other SI units can be derived. The units and their physical quantities are the second for time, the meter for measurement of length, the kilogram for mass, the ampere for electric current, the Kelvin for temperature, the mole for amount of substance, and the candela for luminous intensity.

Table 2.1: Time and Frequency Services Offered by NIST

Name of Service	Requirements	Time Uncertainty	Frequency Uncertainty
nist.time.gov web site	Computer, internet connection, web browser	< 2 s	Not applicable
Telephone time-of-day service	Telephone	< 30 ms	Not applicable
Autmated Computer Time Service (ACTS)	Computer, analog modem, telephone line, client software	< 15 ms	Not applicable
Internet Time Service (ITS)	Computer, Internet connection, client software	< 100 ms	Not applicable
Radio Stations WWV and WWVH	HF receiver	1 to 20 ms	10-6 to 10-9
Radio Station WWVB	LF receiver	0.1 to 15 ms	10-10 to 10-12
Frequency Measurement Service	Paid subscription, NIST provides equipment	< 20 ns	2 X 10-13

frequency standards maintained by NIST provide the reference for these comparisons. International Atomic Time (TAI) is an atomic time scale maintained by the International Time Bureau (BIH) in Paris, France (Barnes 1982:7). The ultimate accuracy of an atomic clock is dependent on several factors, the most important of which are those governing the width of the spectrum line. Spectrum lines are not infinitely narrow but instead have a finite width covering a considerable frequency range, since atoms or molecules do not emit or absorb radiation at only one frequency but rather over a narrow band of frequencies.

Traceable time standards and frequencies are useful among several fields of pure and applied science. The length of the mean solar day, used in astronomical measurements, fluctuate as much as 1 part in 20 to 30 million, as a result of variations in the rate of rotation of the earth on its axis. Broadcasts of standard frequency are important in keeping all kinds of radio, radar, and electronic equipment properly tuned throughout the world. For example, this equipment is required in international transportation and communications so that an airplane with radio-navigational equipment uses the right frequency wherever it is in the world and whatever airport it may be flying to or from.

The time transmitted to our phones and computers generally is through a Global Positioning System (GPS). GPS is a constellation of satellites, each carrying multiple atomic clocks. The time on each satellite is derived by steering the on-board atomic clocks to the time scale at the GPS Master Control Station, which is monitored and compared to UTC. Since GPS does not adjust for leap seconds, it is ahead of UTC by the integer number of leap seconds that have occurred since January 6, 1980, plus or a minus a small number of nanoseconds. As of November 2019, GPS is ahead of UTC by 18 seconds. As GPS is transmitted through satellites, a variable of uncertainty is present that does not exist through TAI (Levine personal communications 2019). Therefore, the NPFS located at Building 1 of Boulder Laboratories remains the most accurate time standard.

Transmitting time is an operation heavily reliant on several moving parts. LF and VLF broadcasts have long been used to distribute time and frequency standards. These broadcast frequencies are used because their signals have the ability to cover large areas using relatively small amounts of power. NIST radio station WWV began broadcasting standard carrier signals to public frequencies in 1923 for the calibration of radio equipment.

WWVB is part of the LF spectrum, while WWV and WWVH are part of the HF spectrum. As part of the LF spectrum, WWVB continuously broadcasts time and frequency signals at 60 kHz. The WWVB signal includes a time code containing all of the information needed to synchronize radio-controlled clocks in the United States and surrounding areas (Lombardi 2002:13). The WWV and WWVH signals operate in the HF spectrum, commonly known as shortwave. Both stations broadcast continuous time and frequency signals on 2.5, 5, 10, and 15 MHz, and WWV also broadcasts on 20 MHz. Both stations can be heard by telephone and provide announcements other than time, such as marine storm warnings and geoalerts (Lombardi 2002:37).

The original WWVH station site on Maui (Figure 2.4) constantly was threatened by coastal

Figure 2.4: The original WWVH station site at Kihei, Maui, ca. 1950 (courtesy of the National Institute of Standards and Technology [NIST] Library at Gaithersburg, Maryland).

erosion and other environmental issues. Much of the station's equipment and property suffered damages, and it was estimated that 75 feet of shoreline had been lost between 1949 and 1967. As a result, WWVH station moved to its current location, a 30-acre site near Kekaha on the Island of Kauai, Hawaii, in July 1971 (Lombardi 2002:33). This facility is discussed in-depth in Chapter 3.

2.5 Property Types

Archival research undertaken during the investigation into the cesium atomic clock and transmission suggests three property types to generally be found on radio transmitter facilities:

Radio Transmitter Buildings,
Helix Houses, and
Antenna Structures.

These property types operate in unison to receive and relay broadcasts and briefly are overviewed below.

2.5.1. Radio Transmitter Buildings

Radio transmitter buildings typically are one story and occupy square, rectangular, or irregular footprints. Openings include single-leaf doors and single-pane windows. Radio transmitter buildings generally are equipped with a mixture of office space and mechanical rooms for transmission operations. Transmitter buildings include office spaces, restrooms, and galley kitchens. All office spaces and laboratories are accessed through hallways. Transmitters are housed in laboratories, which typically are large, open rooms that often include high ceilings. While most interior walls are permanent fixtures of transmitter buildings, small rooms with equipment used to monitor and transmit time are encapsulated in temporary, fire-resistant walls.

2.5.2 Helix Houses

Helix houses are named for the large helical coil that directly support operations at radio transmitter stations. Variometer and other coupling components that are capable of handling the higher power output radio transmitters are located within helix houses. These variometers, also known as variable inductors, maintain the optimal independence match between antennas and transmitters (Lombardi et. al. 2005:64). Helix houses are modest, square buildings with metal door openings. Window openings are not found on helix buildings as natural light and glass-paned openings can adversely affect the building functions. These buildings typically are clad in corrugated metal and are two stories in height, terminating in a flat roof (Figure 2.5). Despite the fact that the buildings mainly are more than one story, their interiors remain open from floor to ceiling for proper air circulation and to moderate heat.

2.5.3 Antenna Structures

Antennas are structures used to relay signals from transmitters. These structures vary in size and material. The most commonly found antennas are single towers that have static operating characteristics. In other words, these antennas do not move; while there also are similar antennas are designed to move somewhat with wind and ice loads (Lombardi et. al. 2005:65). Antennas generally are constructed using steel materials, though some are encased in fiberglass for added flexibility and easier maintenance.

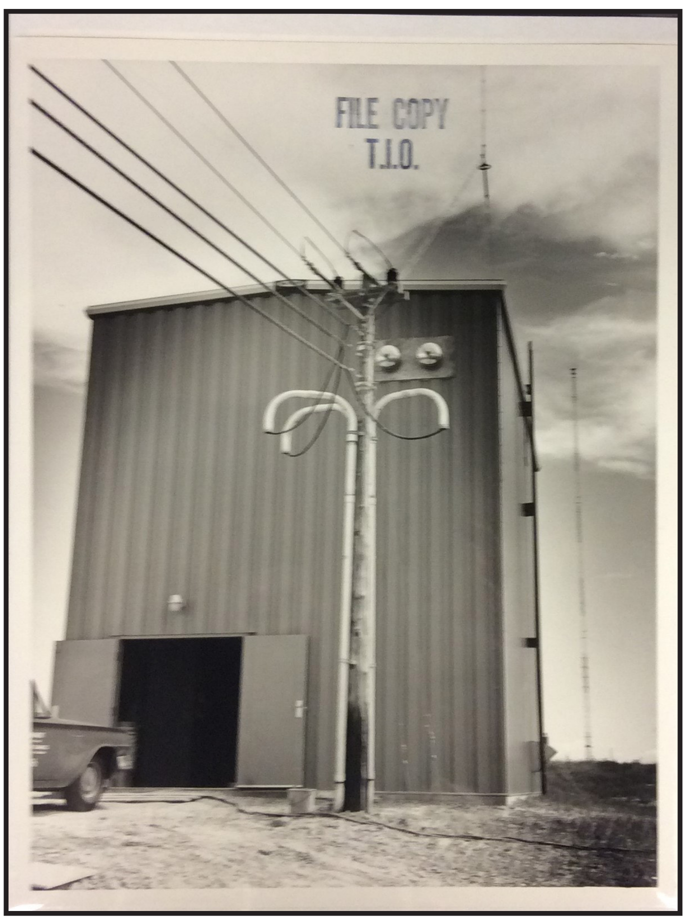

Figure 2.5: Helix House at Fort Collins, Colorado, 1963 (courtesy of the National Archives at Denver).

Chapter 3

Site-Specific History: Fort Collins and Kekaha Facilities

3.1. Introduction

The history of radio stations operated by NIST is complex and is associated closely with national economic expansion and scientific advancement. This chapter summarizes the history of the NIST radio transmitter facilities at Fort Collins and Kekaha. The two facilities are tasked with broadcasting the NPFS. The following narrative was developed from archival data collected from the NIST Library at Gaithersburg, the National Archives and Record Administration, and from interviews with NIST staff at the Fort Collins and Kekaha radio transmitter facilities.

3.2. The Fort Collins Radio Transmitter Facility

On December 1, 1966, the NIST standard time and frequency station WWV located in Greenbelt, Maryland, was deactivated at the same moment that a new station with the same call letters was activated in Fort Collins, Colorado. NIST sited the radio transmitter facilities seven miles north of the City of Fort Collins along E. County Road 58 on a roughly 390-acre parcel bound between two reservoirs that is located east of the foothills of the Rocky Mountains. The site was strategically selected for use: in radio station transmissions. The site is nearly level and the high alkali soil possesses high electrical conductivity. The location also was, in part, chosen for its close proximity to the Boulder campus, which facilitated staffing and management. Fort Collins afforded an important advantage for transmission over the Boulder campus since the distance from the mountains made possible uninterrupted broadcasting and omni-directional signal generation (U.S. Department of Commerce [USDOC] 1965:12; Lombardi 2002:14).

A radio station with the call letter WWV first was established in 1920 in Washington, D.C. Early broadcasts from WWV were generated by the Department of Agriculture. These broadcasts included 500-word reports known as the Daily Market Marketgram, which continued through 1921 (Lombardi et. al., 2005:2). By December 1922, the station's mission changed to the transmission of standard frequency signals, which were used as a reference standard for other radio broadcasters including commercial ventures (Lombardi et. al., 2005:12). In its early days under NIST control, the transmitter was adjusted to the correct frequency using a wavemeter. The first quartz oscillators were developed shortly before WWV went on the air, and soon replaced the wavemeter as a national standard frequency. Quartz oscillators made it possible for WWV to meet the needs of the radio industry for a reliable reference standard for transmission frequencies.

Following World War I, the number of commercial radio stations increased nationwide. The U.S. government had banned private citizens from owning radio equipment and transmitting radio stations during the war, fearing enemy infiltration. The government oversight of radio transitions during the war years resulted in further funding for research. One result was the expansion of commercial radio stations following the conclusion of the war (Myre 2017). This expansion created the need to develop a method for radio stations to maintain their transmissions within their assigned frequencies to avoid interference with another broadcast signals. WWV addressed this need through accurate transmissions that made synchronization possible. Quartz oscillator technology and improved measurement techniques increased the accuracy of frequency transmission for station WWW from parts per thousand to parts per million by 1931 (Lombardi et. al., 2005:6). Signals from WWV; however, did not reach west of the Mississippi River. NIST maintained a list of commercial broadcast stations in the western states that served as frequency references. The frequencies of these stations were measured by NIST and published monthly in their Radio Service Bulletin.

By 1932, WWW was part of the national infrastructure and work began to make the standard frequency signals accessible to more Americans by relocating the station, adding new transmitters, and erecting new antennas to increase the coverage area. The station was moved in December 1932 to a Department of Agriculture site near Beltsville, Maryland to achieve these objectives. By April 1933, the station was broadcasting 30 Kw at 5 MHz; 10 and 15 MHz broadcasts were added in 1935 (Lombardi et. al. 2005:13). By that year, the station was a well-established reference source for frequency and time interval. WWV became the official source for time synchronization in October 1945, when standard time announcements first were broadcast. Time transmission are among WWV's most well-known services. Standard time announcements first were relayed in code; voice announcements were added on January 1, 1950 (Lombardi 2002:31).

The post-war era in the United States was one of increased public funding of science (Kammer 2001:17). The ensuing Cold War sustained this funding, which allowed NIST to emerge as a natural leader in instrumentation and measurement sciences. Between 1955 to 1958, WWV in Beltsville played an important role in the definition of the atomic second. During this period, simultaneous common-view measurements of the signals broadcast from WWV were made from the United States Naval Observatory (USNO) in Washington, D.C. and the National Physical Laboratory (NPL) in Teddington, United Kingdom. The USNO compared the signal to the astronomical time scale (UT2) and NPL compared the signal to the new, recently developed, cesium standard. The collected data helped the USNO and NPL equate the length of the astronomical and atomic second (Lombardi et. al., 2005:15).

When WWV began broadcasting at Fort Collins, Colorado, it joined a LF and a Very Low Frequency (VFL) station already in operation with the call signals WWVB and WWVL, respectively. WWVB began operation as radio station KK2XEI in July 1956 and broadcasted from Boulder, Colorado. The experimental station was operated for four-and-a-half hours each working day. The continuous wave 60 kHz signal was unmodulated, except for a call sign ID that was sent every 20 minutes. The success of the 60kHz broadcast led to the construction of a VFL radio station with the call letters WWVL, which began operation from Sunset, Colorado, in April 1960.

In 1962, NIST began construction of a new facility north of Fort Collins, Colorado, to house radio stations WWVB, WWVL, and WWV (Figures 3.1 and 3.2). By July 1963, WWVB and WWVL went on the air from the 390-acre Fort Collins site located approximately 50 miles from the Boulder laboratories where the national standards of time and frequency currently are maintained. The proximity to Boulder and the use of atomic oscillators at the transmitter site made it possible to control the transmitted frequency to within 2 parts in 1011, an improvement factor of 10 (Lombardi 2002:32). By April 1967, the WWVB station began broadcasting Greenwich Mean Time (GMT) rather than local time; the station transitioned to the current Coordinated Universal Time (UTC) in December 1968. GMT was the universal standard prior to the adoption of UTC in 1968.

Roughly 15 years before WWVB went on the air at Fort Collins, another LF station with the call signals WWVH began operation in November 1948 from Kihei on the island of Maui, in the then Territory of Hawaii. As it does today, the program schedule of WWVH closely follows the format of WWV. NIST constructed WWVH as the second standard frequency station to be operated simultaneously with WWV. Adding WWVH increased the service coverage area, allowed NIST to determine the accuracy possible in synchronizing two or more standard frequency stations, and further allowed NIST to develop methods for operating separate stations on the same frequency. While similarly formatted

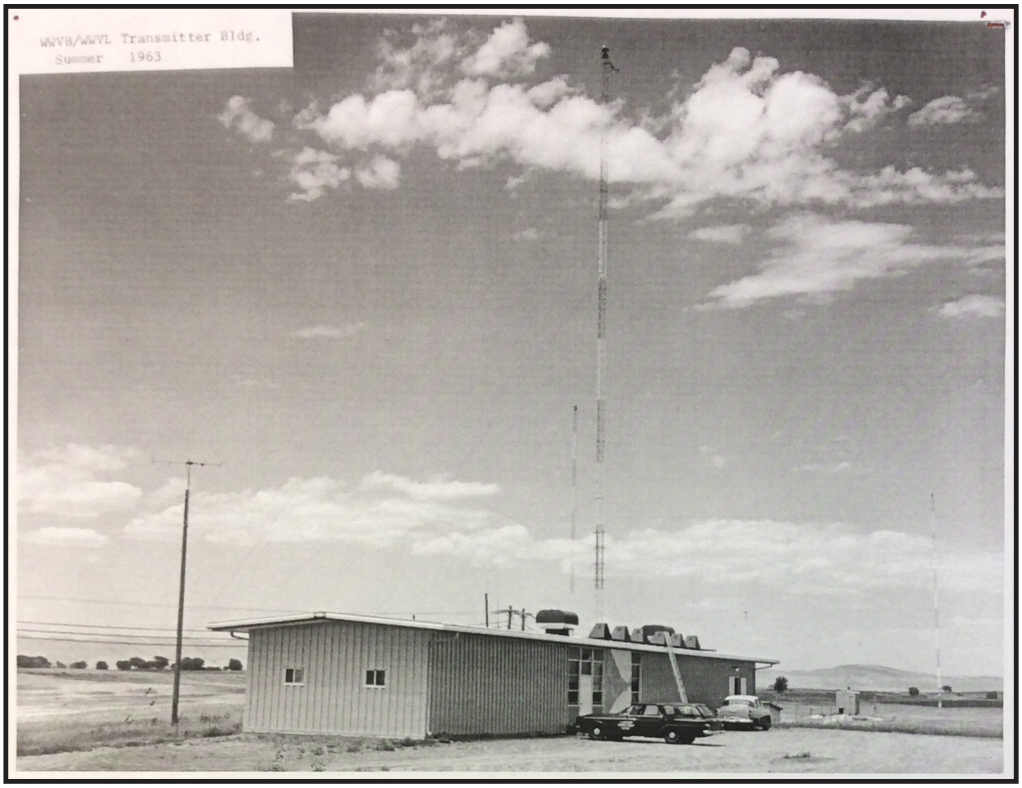

Figure 3.1: Radio Station WWVB at Fort Collins, Colorado, 1963 (courtesy of NIST Fort Collins).

Figure 3.2: Construction of Radio Station WWV at Fort Collins, Colorado, 1966 (courtesy of NIST Fort Collins).

to WWV, WWVH transmitted in code; voice announcements of time were added to the WWVH broadcast in July 1964.

On August 13, 1963, WWVB and WWVL standard broadcast stations went into operation at the new Fort Collins campus. These two stations, one transmitting on LF and the other on VLF, made a total of four stations from which NIST broadcasted standard frequency and time signals (USDOC 1965:1).WWVB (a low frequency 60-kc/s station) and WWVL (a very low frequency 20-kc/s station) initially gave users an opportunity to obtain more accurate standard frequency and time signals than were obtainable with the existing HF services of WWV and WWVH. The HF signals are propagated over long distances by alternate reflections between earth and the ionosphere. Height and density in the ionosphere constantly change affecting the path of radio waves and resulting in a loss of signal accuracy. To overcome this challenge, WWVB and WWVL operated in the LF and VLF regions. Their radio wave transmissions followed the curvature of the earth, with the ground and ionosphere acting as the lower and upper limits of an expansive duct to guide signals around the globe (NBS 1963:178). WWVL ceased operations in 1972.

WWVB has gradually transitioned from a reference source for frequency to a reference source for time. Time codes first were broadcast in July, 1965 and were used generally as time markers in scientific strip chart recordings. Broader application became possible with the introduction of clocks that automatically decoded and displayed WWVB time. Initially limited to scientific and industrial applications, WWVB regulated clocks were introduced to the mass market in the United States in late 1990s. These clocks incorporate single semiconductor chips as WWVB receivers (Lombardi and Nelson 2014:np). From a radio transmission facility emphasizing reference for frequency to one providing time-of-day synchronizations, transmissions from the NIST Fort Collins facility have become increasing important in establishing accurate time that structures the private, public, and work lives of the nation.

3.3. The Kekaha Radio Transmiiter Facility

The Maui Island transmission site was abandoned by NIST in 1971 due to obsolescence, propagation barriers, and an eroding physical site. WWVH had broadcast from the site since 1948 (NBS 1970:137). Assistant Secretary of Commerce for Science and Technology James H. Wakelin, Jr., eloquently recounted the troubled history of the Maui Island campus at the 1971 WWVH Kekaha dedication:

> "In all our services, we try to keep the dissemination mechanism as up-to-date as technology allows. With WWVH, this became a specific and severe problem over the last few years. The equipment, much of which was originally military surplus, has become technically outmoded. The climate has been corroding away the hardware in its un-airconditioned [sic] building. The ocean has devoured two acres of the city. In short, the recent history of WWVH has been a continual battle to stay on the air. This battle ultimately was won, but the outcome of the next skirmish was always in doubt (Wakelin 1971)."

Portions of the Maui station site occupied a man-made peninsula that was degraded by sea erosion. Mountains on both sides of the station interfered with north and east transmissions (NBS 1970:137). The issues leading to the abandonment influenced criteria for a replacement site and the selection of the current location at the Department of the Navy, Barking Sands Missile Range.

A number of islands in the Pacific were considered by NIST as potential sites for the new radio transmitter site, including Guam, the Marshall Islands, American Samoa, and all of the islands in the Hawaiian Chain. The current Kauai site was selected for its level topography and unobstructed location. It also offered commercially available water and power, access to improved roads and access to an airport. In addition, the area is free from electromagnetic interference and the site afforded sufficient space to erect antenna arrays.

Today, the WWVH radio transmitter facility occupies a 30-acre, flat parcel of land near the town of Kekaha, on the western side of the island of Kauai, Hawaii. The land is leased from the U.S. Navy. The parcel is located on the western shoreline of the island—bound to the west by a beach and to the north, east, and south by dense tree lines. The soil on the site is mostly sand.

Chapter 4

Architectural Investigation and Evaluation

Architectural investigations related to the NIST satellite facilities at Fort Collins and Kekaha were undertaken in 2019 to document and to assess each station applying the National Register Criteria for Evaluation (36 CRF 60.4 [a-d]. Data on the appearance and integrity of the buildings, structures, and landscapes were recorded in accordance with Federal standards and the guidelines of the respective states. State inventory forms for Colorado and Hawaii are included in the appendix to this report.

The two facilities receive and transmit the NIST time standard, which originates at Building 1 of Boulder Laboratories. Building 1 of the Boulder Laboratories previously was determined an eligible building under Criterion A (history) and C (architecture). The CO SHPO Survey Form for Building 1 and a concurrence letter from CO SHPO are included in Appendix B of this report.

Both radio transmission facilities are highly scientific and sophisticated engineering complexes that operate in unison to support the primary time measurement mission of NIST. These facilities, historically important for their role in establishing national frequency references, also are responsible for the transmission of time standards that have assumed a greater level of national importance with the introduction of semiconductor chips capable of decoding transmissions directly from the facilities. NIST establishes and transmits the time standard that orders the private, commercial, financial, and public life of the nation.

4.1. Architectural Investigations: Fort Collins

The Fort Collins facility is situated roughly seven miles north of the City of Fort Collins along E. County Road 58 on a level, roughly 390-acre parcel bounded two reservoirs within the viewshed of the foothills of the Rocky Mountains. The location is primarily rural with large residential parcels lining the main thoroughfare. The landscape is generally flat and grassy with a sparse assortment of mature deciduous trees along the roadways and near the primary radio transmitter facilities. The gated facility is accessed by a narrow, paved road and is set back from the main thoroughfare.

The narrow road accessing the facility extends north and terminates at radio transmitter station WWVB. The WWVB station house is a single-story building and occupies an irregular footprint. A small paved parking lot adjoins the south façade; which is delineated by small plant beds with low shrubbery. Two helix houses are located north and south of radio transmitter station WWVB. Both are accessed by dirt roads and are sited at the center of four steel antenna structures. The helix houses are two-story buildings clad in corrugated metal.

A secondary paved road extends eastward from the primary access drive toward radio transmitter station WWV. WWV is a single-story, concrete block building occupying an irregular footprint and terminating in a flat roof. A small paved parking lot adjoins the façade. East of the building are an array of eight steel antennas that occupy a higher grade of terrain. An aerial site plan of the facility is included in Appendix A.

<u>4.1.1. WWVB Components</u>

The Fort Collins complex was constructed by NIST between 1963 and 1966. NIST formalized radio transmissions through the construction of a radio transmitter station to house the WWVB and WWVL transmitters at the new Fort Collins, Colorado, facility in 1963. The WWV transmitter station was relocated to a newly constructed transmitter station in 1966. Today, the Fort Collins district contains the following component resources: WWVB and WWV transmitter stations, two helix houses, and a series of antenna structures all working together to receive and transmit atomic time standards.

Construction of WWVB began in 1962. The single-story WWVB transmitter building (Figure 4.1) is of manufactured steel panel building supported by a concrete slab. The original building, made by Butler Manufacturing, includes a transmitter room, two electrically shielded, copper-lined spaces known as screen rooms, a laboratory area, and a small lavatory. The building was completed in 1963 (Lombardi et al. 2005:23).

The transmitter rooms in the WWVB building are heated during cold weather by the transmitter exhaust air. The exhaust air is recycled using thermostatically controlled ductwork louvers to maintain room temperatures. Backup unit heaters are installed in one of the transmitter rooms. During the warmer months, heated transmitter exhaust air is ducted outside and the rooms are cooled by evaporative coolers (Lombardi et. al. 2005:24).

The WWVB transmitters originally were manufactured for the U.S. Navy by Continental Electronics, Inc. Thus, they are known by their manufacturer model number 218B as well as their military designation as the AN/FRT-72. They were built during the mid-1960s and installed at various naval communications stations around the world. As part of an overhaul program to upgrade and modernize the equipment, the Navy began to close some of the facilities using these transmitters during the 1990s. The equipment then was removed and placed in storage, when it was eventually offered and transferred to NIST in the mid-1990s to replace WWVB's obsolete equipment. Today, three AN/FRT-72 transmitters are installed at WWVB and designated as LF transmitters LFT-1, LFT-2, LFT-2. All have been overhauled as part of the Navy's transmitter overhaul program. Further upgrades have been undertaken by NIST. Each transmitter consists of six cabinets housing different elements of the equipment. The transmitter cabinets are arranged side-by-side, and the entire transmitter is 24-feet long by three-feet deep and 6.5 feet high.

Helix houses also occupy buildings made by Butler Manufacturing and are located northwest and southeast of the WWVB transmitter building. They were assembled along with the transmitter building and strategically placed near the center of two antennas. The helix houses contain equipment to match the impedance of the antennas to that of the transmitters. The electrical connection from transmitter to antenna is made in the helix house (Figures 4.2 and 4.3) (Lombardi et al. 2005:23).

The uninterruptible power supply (UPS) at WWVB, model UT-310, was made by Best Power and installed in 2000. The UPS is utilized only when necessary during poor weather conditions and power outages. The estimated run time with a normal load was more than three hours as of 2005.

The two WWVB transmitting antennas are to the northwest and southeast of the transmitter building, close to their respective helix houses. They are known as the north and south antennas; thus, the helix houses are termed the north and south helix houses in this report (Figure 4.4). While the two top-loaded monopole antenna systems nearly are identical, the north antenna originally was used for the WWVL broadcast, which was taken offline in 1972 (Lombardi et. al. 2005:26). NIST erected these antennas in accordance with designs by W.W. Brown, a NIST consultant, in 1963. Each antenna system consists of three parts: four towers, a capacitance hat or top hat and downlead, and the ground plane.

The four towers in each antenna system are arranged in a diamond pattern. Each tower is held in place by three sets of guy cables[1], with three cables in each set. All towers except tower 2 in the south antenna array stand 400-feet high; tower 2 is 415 feet high. The base of tower 2 is at a lower elevation than the bases of the other towers and is taller as a result. The towers are constructed of welded steel rod in 30-feet increments. Each increment has three sides measuring 4-feet per side. Red flashing beacons and side marker lights are

1 Guy cables, also known as guy-wires or a guy, is a tensioned cable designed to add stability to a free-standing structure.

Figure 4.1: Radio Station WWVB at Fort Collins, Colorado, facing northwest. August 2019.

Figure 4.2: Exterior of the South Helix House at Fort Collins, Colorado, facing south. August 2019.

Figure 4.3: Interior of the South Helix House at Fort Collins, Colorado, facing south. August 2019.

Figure 4.4: South Helix House and Antenna Structures at Fort Collins, Colorado, facing south. August 2019.

installed on each tower. The lights, controlled by a photocell, or light-activated switch, automatically turn on when daylight fades.

4.1.2. WWV Components

The WWV transmitter building was completed in 1966. It is a single-story building constructed of reinforced concrete block (Figure 4.5). The building consists of office and utility areas. Similar to WWVB, the building contains two screen rooms which hold the cesium frequency standards and time code generators that supply the WWV signal to the transmitters. A laboratory area is located adjacent to the screen rooms. The transmitters are located along an operating corridor surrounding the laboratory/screen rooms on three sides. An equipment corridor runs behind the transmitters to allow access for equipment maintenance and repair.

The area containing the transmitters is cooled by a large evaporative cooler mounted on the roof. During the warmer months, exterior air is drawn in and passed through moistened pads, then filtered twice before being distributed through insulated ducts to the transmitters, where it is then used to cool the equipment (Lombardi et. al., 2005:14). From the transmitters, air is exhausted into a ceiling plenum located above the transmitter corridors. Four exhaust fans installed in the roof of the building connect to a pressure sensor; when the plenum static pressure exceeds a certain point, the fans turn on and exhaust the air to the outside. During the cooler months, the washer system is turned off and drained. A thermostatically controlled set of louvers combines outside air with warmed transmitter exhaust to keep the equipment operating and service areas at a moderate temperature while cooling the transmitters. The filters are used year-round.

The original transmitters installed at WWV were manufactured by Technical Materiel Corporation (TMC) during the mid-1960s. They were two types of military transmitters: model GPT-40K, rated at 10kW output power, and model GPT-10K, rated at 2.5Kw output power (Lombardi et. al. 2005:14). Each frequency had a dedicated transmitter and antenna, along with two standby transmitters, T1 and T3, connected to broadband antennas that were capable of operating at any WWV frequency. The 25 MHz service was discontinued during the mid-1970s. At that time, the T6 and 25 MHz antenna were converted for use as a standby transmitter and antenna for the 15 MHz broadcast. During this period, signal sensing and control circuitry was installed to allow standby transmitters to be started automatically in the event of a primary transmitter fault.

New, more efficient transmitters were purchased for the 5, 10, and 15 MHz broadcasts in 1990. The new 10 kW transmitters were made by CCA Corporation and designated T8-A, T7-A and T2-A. At the same time, remote control antenna switches were installed and connected to the outputs of both the new CCA transmitters and the TMC equipment they replaced. The transmitters purchased in 1990 were removed from the WWV building as of 2019.

There are six WWV antennas located along the top of a ridge both north and east of the WWV transmitter building (Figure 4.6). The terrain surrounding the transmitter building slopes upward toward the antenna locations. The location was strategic: the lower building elevation coupled with the higher elevation of the antennas minimizes its impact on the radiation pattern (Lombardi et. al. 2005:17).

The WWV primary antennas were manufactured by Rohn, Inc. and installed in 1966. They are composed of several three-sided tower sections, measuring 18.5 inches per side, mounted on hinged steel bases fastened to concrete foundations, and are fitted with at minimum two sets of guy cables. The antennas were designed to withstand wind speeds up to 112 miles-per-hour (mph). The primary antennas and the 15 MHz standby antennas are half-wave, vertically polarized dipoles. They are center-fed.[2]

Two broadband monopole antennas are installed at WWV, one to the north and one to the south of the building. They are model 437C-2A antennas and were manufactured by the Collins Radio Company and installed when the station was built. They consist of a central tower section 88-feet tall that rests on a ceramic base insulator, surrounded by a wire array. No tuning stubs were used in the broadband antenna installation.

2 Center-fed antennas are connected from the transmission line near the center point of its vertical mast.

Figure 4.5: Radio Station WWV at Fort Collins, Colorado, facing northeast. August 2019.

Figure 4.6: WWV Antenna Systems at Fort Collins Collins, Colorado, facing southeast. August 2019.

All antennas are connected to the transmitters with rigid coaxial transmission lines that are mounted a few inches above the ground on short concrete posts. The lines primarily consist of 20-foot long rigid sections manufactured in the 1960s by Prodelin Corporation. These were installed at the time that the WWV transmission building was constructed and extend from each transmitter to its antenna. All the transmission lines are pressurized with dehydrated air to prevent moisture from entering the lines (Lombardi et. al. 2005:20).

4.2. Architectural Investigations: Kekaha

The Kekaha facility occupies a 30-acre, flat parcel of land near the town of Kekaha, on the western side of the island of Kauai, Hawaii. The facility is accessed through, and fully bounded by, Barking Sands Missile Range on three sides and by the Pacific Ocean on the fourth side. The landscape is flat and consists primarily of low grass and sand with sparse trees at the parcel border. The facility is accessed by a narrow, paved road, which terminates at the WWVH transmitter building. There is no formal paved parking. The WWVH transmitter building (Figure 4.7) is a concrete block, single-story building located at the eastern edge of the site. A loading dock extends from the south elevation. A storage outbuilding constructed of concrete block and wood framing is located just east of the primary transmitter building. Scattered across the WWVH facility are antenna structures. An aerial site plan is included in Appendix A.

Built in 1971, the transmitter building covers an area of 4,482 square feet. The building contains a transmitter room, along with laboratory space, two screen rooms, a reception area, several offices, a small kitchen, and restrooms. A central corridor runs the length of the building, east-west, from the reception area to the transmitter room entrance. A wing off the south elevation contains electrical distribution equipment, a standby generator, and a loading dock (Lombardi et. al. 2005: 32).

The transmitter room is cooled by two split-system air conditioning systems while the transmitters are cooled by outside air that is ducted to the transmitter air intakes. Warm exhaust air is ducted outside. The building contains two screen rooms: the main screen room is where the broadcast time code generators and cesium clocks are located; an adjacent auxiliary screen room is used for monitoring equipment.

WWVH operates on four frequencies: 2.5, 5, 10, and 15 MHz, with a primary transmitter and standby transmitter for each frequency. The first transmitters installed at the current WWVH site were made by AEL Corporation. Seven transmitters of this type were originally installed in 1971; in 1983, two were removed and replaced with three newer, more efficient transmitters made by Elcom-Bauer Corporation. These units became the primary transmitters on 5, 10 and 15 MHz. One of the older units was retained as the primary 2.5 MHz transmitter, while the others were modified to be used as standby transmitters.

The WWVH antennas are of two types: omni-directional and phased array (Figure 4.8). The omni-directional antennas radiate the same power level in every horizontal direction away from the tower, while the phased-array antennas are designed to radiate more power toward the west of the station. The 2.5 MHz antennas as well as the permanent standby antennas are omni-directional towers, while the 5, 10, and 15 MHz primary antennas are phased arrays. The 15 MHz standby antenna is a temporary, prototype phased array consisting of two quarter-wave monopoles. A 41-foot tall grounded steel tower serves as a platform for various HF and National Weather Service receiving antennas. The steel tower is not used for time and frequency broadcasts (Lombardi et. al. 2005:33).

The original omni-directional towers were vertical steel structures made by Rohn, Inc., and Collins Radio Company. Over time, due to the high humidity and salt spray from the nearby ocean, these towers required excessive maintenance. To rectify the issue of constant upkeep, these antennas were replaced by free-standing fiberglass masts (also known as whip antennas) manufactured by Valcom Ltd in 2001 (Lombardi et. al. 2005:34). The new monopole antennas are made up of several hollow, tapered epoxy-fiberglass sections, which are joined together with threaded bronze ferrules. Strips of copper extending the length of each section are embedded in

Figure 4.7: Radio Station WWVH at Kekaha, Hawaii, facing west. September 2019.

Figure 4.8: WWVH Antenna Systems at Kekaha, Hawaii, facing north. September 2019.

the epoxy-fiberglass sections. The top section is capped either with a bronze corona sphere or a hoop shaped capacitive element. The base of the bottom section flares outward to meet the mounting flange. No guy cables are required.

The fiberglass whip antennas have external matching equipment located in a weatherproof box adjacent to the antenna base. The whip antennas are mounted on hinged stainless steel plates, thus the antennas are adjustable and may be lowered for maintenance. Ground planes are installed at each tower, consisting of 120 solid copper wires extending radially outward from a center ring at the tower base. The wires are buried several inches deep, and each wire is terminated to a ground rod, a 10 foot long copper-coated steel rod driven into the earth. The lengths of the ground radials vary, depending on the frequency for which the tower was designed.

4.3. Evaluation Results

Analysis of archival and architectural data applying the NRHP Criteria for Evaluation (CFR 60.4 [a-d]) identified two districts comprising functionally associated buildings, structures, and landscapes. The Fort Collins and Kekaha districts are broadcast facilities for national time standards, which support the NIST mission, and time and frequency standards. The distribution of the national performance frequency standard (NPFS) through these radio transmitter facilities is a critical contribution to national standards that support infrastructure for scheduling, logistics, and public safety. These facilities are responsible for the maintenance of official time and frequency standards for government, private, and commercial operations. Daily the standards broadcast at these facilities are sent to the International Bureau of Weights and Measures in Paris, France, which is averaged with approximately 270 other laboratory-constructed atomic clocks around the globe. This average forms International Atomic Time (TAI).

4.3.1 Fort Collins

The Fort Collins facility is over 50 years of age. The facility is considered a district of component buildings and structures. The district consists of two radio transmitter station buildings, two helix houses, and a total of 16 antenna structures. The district is significant in the area of science. The Fort Collins facility and its component buildings and structures are tasked with relaying the NPFS across the continental United States and to the radio transmitter station located at Kekaha. The district and components are required for national time standards, are further used as a component of TAI, and support the nation's time measurement, scheduling and verification.

4.3.2 Kekaha

The Kekaha facility was constructed in 1971 and consists of radio transmitter station WWVH and nine antenna structures. The Kekaha facility is the second to house radio transmitter station WWVH. From 1948 to 1971, WWVH was located at Kihei on the island of Maui.

Since the Kekaha facility has not reached the generally recommended 50-year age threshold as of this evaluation, Criteria Consideration G was applied in its assessment. Evaluation under Criteria Consideration G is used to determine exceptional significance for buildings, structures, sites, or objects that have not yet reached 50 years of age.

The Kekaha facility demonstrates exceptional significance in the historic themes of science and engineering. Pacific radio transmission has been a component of the NIST mission since the agency constructed the first facility in 1948 on the island of Maui. The Kekaha facility took over Pacific operations in 1971, receiving and relaying the NFPS since it went on-air in 1971. The facility is considered a district of functionally related buildings and structures. The district consists of one radio transmitter station and nine omni-directional antenna structures. The facility receives NPFS transmissions from the Fort Collins facility and further relays these transmissions across the Pacific and to non-contiguous American states and territories. The Kekaha facility also relays other announcements including maritime warnings. The district and components are a required component of maintaining and relaying

NPFS and support the nation's time measurement, scheduling and verification.

4.3.3 Conclusion and Recommendations

The Fort Collins and Kekaha Radio Transmitter Facilities are unique cultural resources significant in science for the transmission of the national NIST time standard. The facilities operate as a unified transmission system; both are functionally related to the atomic clock maintained in the laboratories housed in Building 1 on the NIST Boulder campus. While operation of these highly scientific facilities has necessitated equipment upgrades and modifications since their construction, both retain their overall integrity of location, design, setting, materials, workmanship, feeling, and association. The two facilities possess the significance and integrity required for listing in the National Register of Historic Places under Criterion A for their association with the transmission of the national NIST time standard.

Due to the unique scientific significance and geographic distribution of the resources associated with the atomic clock (Building 1, Boulder campus; Fort Collins Radio Transmitter Facility; and Kekaha Radio Transmitter Facility), consideration of a Multiple Property Format is recommended should NIST consider formal nomination of the resources for National Register listing. Such a format also may accommodate the consideration of new resources in the area of time measurement as the accelerated pace of scientific discovery continues.

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Acknowledgements

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APPENDIX A

SHPO FORMS

Resource Number:
Temporary Resource Number:

OAHP1403
Rev. 9/98

COLORADO CULTURAL RESOURCE SURVEY

Architectural Inventory Form

Official eligibility determination
(OAHP use only)
Date ____________________Initials _______
____ Determined Eligible- NR
____ Determined Not Eligible- NR
____ Determined Eligible- SR
____ Determined Not Eligible- SR
____ Need Data
____ Contributes to eligible NR District
____ Noncontributing to eligible NR District

I. IDENTIFICATION

1. Resource number:
2. Temporary resource number:
3. County: Larimer
4. City: Fort Collins
5. Historic building name: National Bureau of Standards Fort Collins Facility
6. Current building name: National Institute of Standards and Technology Fort Collins Facility
7. Building address: 5703 CO-1, Fort Collins, Colorado 80524
8. Owner name and address: United States Department of Commerce
   1401 Constitution Avenue NW, Washington, DC 20230

II. GEOGRAPHIC INFORMATION

9. P.M. 7th Township T08N Range R68W
   NE ¼ of SE ¼ of NE ¼ of NE ¼ of section 7
10. UTM reference
    Zone 1 3; 4 9 2 8 5 5 mE 4 4 9 2 7 2 2 mN
11. USGS quad name: Fort Collins
    Year:1984 Map scale: 7.5' X 15'___ Attach photo copy of appropriate map section.
12. Lot(s): _________ Block:___________
    Addition: ________Year of Addition: ______
13. Boundary Description and Justification: The district encompasses the entirety of Parcel 8807000907, as recorded in Larimer County Land Records.

III. Architectural Description

14. Building plan (footprint, shape): Irregular
15. Dimensions in feet: Length 143 feet x Width 66.5 Feet
16. Number of stories: One
17. Primary external wall material(s): Metal (Aluminum), Concrete Block
18. Roof configuration: Gabled, Flat
19. Primary external roof material: Asphalt shingles
20. Special features: N/A

Resource Number:
Temporary Resource Number:
21. General architectural description:

The NIST Fort Collins facility is a district with component buildings, structures, and landscapes. The district consists of two primary buildings, Radio Transmitter Stations WWVB and WWV, and associated outbuildings and support structures. Associated outbuildings and support structures include two helix houses and 12 antennas. Transmitters also will be overviewed as these built objects are required to relay cesium atomic time—the primary function of this campus.

<u>WWVB Building</u>
Construction of WWVB began in 1962. The single-story WWVB transmitter building (Figure 4.X) is of manufactured steel panel construction and rests on concrete slab. The original building, made by Butler Manufacturing, includes a transmitter room, two electrically shielded spaces known as screen rooms, a laboratory area, and a small lavatory. The building was completed in 1963 (Lombardi, et al. 2005:23).

The transmitter rooms in the WWVB building are heated during cold months by the transmitter exhaust air. The exhaust air is recycled using thermostatically controlled ductwork louvers to maintain modern room temperatures. There also are backup unit heaters installed in one of the transmitter rooms. During the warmer months, the heated transmitter exhaust air is ducted outside and the rooms are cooled by evaporative coolers (Lombardi, et. al. 2005:24).

There are two smaller buildings located northwest and southeast of the WWVB transmitter building. These buildings are referred to as *helix houses* and also were made by Butler Manufacturing. They were assembled along with the transmitter building and strategically placed near the center of two antennas. The helix houses contain equipment to match the impedance of the antennas to that of the transmitters. The electrical connection from transmitter to antenna is made in the helix house (Figures 4.X and 4.X) (Lombardi, et al. 2005:23).

The uninterruptible power supply (UPS) at WWVB, model UT-310, was made by Best Power and installed in 2000. The estimated run time with a normal load was more than three hours as of 2005.

<u>WWVB Transmitters</u>
The WWVB transmitters originally were manufactured for the U.S. Navy by Continental Electronics, Inc. Thus, they are known by their manufacturer model number 218B as well as their military designation as the AN/FRT-72. They were built during the mid-1960s and installed at various naval communications stations around the world. As part of an overhaul program to upgrade and modernize the equipment, the Navy began to close some of the facilities using these transmitters during the 1990s. The equipment then was removed and placed in storage, where it eventually was transferred to NIST in the mid-1990s to replace WWVB's obsolete equipment.

Today, three AN/FRT-72 transmitters are installed at WWVB and designated as LF transmitters LFT-1, LFT-2, LFT-2. All have been overhauled as part of the Navy's transmitter overhaul program. Further upgrades have been undertaken by NIST. Each transmitter consists of six cabinets housing different elements of the equipment. The transmitter cabinets are arranged side-by-side, and the entire transmitter is 24-feet long by three-feet deep and 6.5-feet high.

<u>WWVB Antennas</u>
The two WWVB transmitting antennas are situated to the northwest and southeast of the transmitter building, close to their respective helix houses. They are referred to as the north and south antennas; thus, the helix houses will be known as the north and south helix houses (Figure 4.X). While the two top-loaded monopole antenna systems nearly are identical, the north antenna originally was used for the WWVL broadcast, which was taken offline in 1972 (Lombardi, et. al. 2005:26). The antennas were erected in 1963 and designed by W.W. Brown, a NIST consultant. Each antenna system consists of three parts: four towers, a capacitance hat or top hat and downlead, and the ground plane.

The four towers in each antenna system are arranged in a diamond pattern. Each tower is held in place by three sets of guy cables, with three cables in each set. All towers except tower 2 in the south antenna at 400-feet high; tower 2 is 415-feet high. The base of tower 2 is at a lower elevation than the bases of the other towers and is taller as a result. The towers are constructed of welded steel rod in 30-feet increments. Each increment has three sides measuring 4-feet per side. Red flashing beacons and side marker lights are installed on each tower. They are controlled by a photocell, or light-activated switch, and automatically turn on when daylight fades.

<u>WWV Building</u>

Resource Number:
Temporary Resource Number:
The WWV transmitter building was completed in 1966. It is a single-story building constructed of reinforced concrete block (Figure 4.X). The building consists of office and utility areas. Similar to WWVB, the building contains two screen rooms which contain the cesium frequency standards and time code generators that supply the WWV signal to the transmitters. A laboratory area is located adjacent to the screen rooms. The transmitters are located along an operating corridor surrounding the laboratory/screen rooms on three sides. An equipment corridor runs behind the transmitters to allow access for equipment maintenance and repair.

The area containing the transmitters is cooled by a large evaporative cooler mounted on the roof. During the warmer months, exterior air is drawn in and passed through moistened pads, then filtered twice before being distributed through insulated ducts to the transmitters, where it is then used to cool the equipment (Lombardi, et. al., 2005:14). From the transmitters, air is exhausted into a ceiling plenum located above the transmitter corridors. Four exhaust fans installed in the roof of the building are connected to a pressure sensor; when the plenum static pressure exceeds a certain point, the fans turn on and exhaust the air to the outside. During the cooler months, the washer system is turned off and drained. A thermostatically controlled set of louvers combines outside air with warmed transmitter exhaust to keep the equipment operating and service areas at a moderate temperature while cooling the transmitters. The filters are used year-round.

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<u>WWV Antennas</u>
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All antennas are connected to the transmitters with rigid coaxial transmission lines that are mounted a few inches above the ground on short concrete posts (Figure 4.X). The lines primarily consist of 20-feet long rigid sections manufactured in the 1960s by Prodelin Corporation. These were installed at the time of the WWV transmission building construction and extended from each transmitter to its antenna. All the transmission lines are pressurized with dehydrated air to prevent moisture from entering the lines (Lombardi, et. al. 2005:20).

22. Architectural style/building type: No Style

23. Landscaping or special setting features: N/A

24. Associated buildings, features, or objects: Radio Transmitter Building, Helix House, and Antennas

IV. Architectural History

25. Date of Construction: Estimate: 1963 to 1966 Actual: 1963 to 1966

    Source of information:

26. Architect: Unknown

    Source of information:

27. Builder/Contractor: Butler Manufacturing

    Source of information:

28. Original owner: United States Department of Commerce

    Source of information:

29. Construction history (include description and dates of major additions, alterations, or demolitions):

30. Original location __X__ Moved ____ Date of move(s):

V. Historical Associations

31. Original use(s): Government
32. Intermediate use(s): N/A
33. Current use(s): Government
34. Site type(s): Government
35. Historical background:

NIST planned its fourth campus (following Gaithersburg, Maryland; Boulder, Colorado; and Kihei, Hawaii) seven miles north of the City of Fort Collins along E. County Road 58, on a roughly 390-acre parcel bound between two lakes and located east of the first foothills of the Rocky Mountains. The site was a strategic choice to accompany its primary use: radio station transmissions. The land is nearly flat and the soil has a high alkali content and a high electrical conductivity. The site was in close proximity to the Boulder campus, which made it easy to staff and manage. However, its distance from the mountains made the location a better choice for broadcasting and omnidirectional signal (U.S. Department of Commerce [USDOC] 1965:12; Lombardi 2002:14).

On August 13, 1963, WWVB and WWVL standard broadcast stations went into operation at the new Fort Collins campus. These two stations, one transmitting on LF and the other on VLF, made a total of four stations which NIST used to broadcast standard frequency and time signals (USDOC 1965:1).WWVB (a low frequency 60-kc/s station) and WWVL (a very low frequency 20-kc/s station) initially gave users an opportunity to obtain more accurate standard frequency and time signals than were obtainable with the existing high frequency (HF) services of WWV and WWVH. The HF signals are propagated over long distances by alternate reflections between earth and the ionosphere. As height and density in the ionosphere change constantly, resulting in changes in the path of radio waves, there is a loss of signal accuracy. To overcome this limitation, WWVB and WWVL were introduced to operate in the LF and VLF regions. Their radio waves followed the curvature of the earth, with the ground and ionosphere acting as the lower and upper limits of an expansive duct to guide signals around the globe (NBS Technical News Bulletin 1963:178).

36. Sources of information:

VI. Significance

Resource Number:
Temporary Resource Number:

37. Local landmark designation: Yes ___ No ___ Date of designation: _________

Designating authority:

38. Applicable National Register Criteria:

_X_ A. Associated with events that have made a significant contribution to the broad pattern of our history;

___ B. Associated with the lives of persons significant in our past;

___ C. Embodies the distinctive characteristics of a type, period, or method of construction, or represents the work of a master, or that possess high artistic values, or represents a significant and distinguishable entity whose components may lack individual distinction; or

___ D. Has yielded, or may be likely to yield, information important in history or prehistory.

___ Qualifies under Criteria Considerations A through G (see Manual)

___ Does not meet any of the above National Register criteria

39. Area(s) of significance: Science

40. Period of significance: 1963-1970

41. Level of significance: National _X_ State ___ Local _______

42. Statement of significance:

Since its creation over a century ago, as the National Bureau of Science (NBS) in 1900, the National Institute of Standards and Technology (NIST) has been at the forefront of scientific standardization and measurement. Work by NIST scientists has resulted in the standardization and measurement of nearly every facet of scientific inquiry. Arguably its most famous asset is NIST-F1, the nation's primary time and frequency standard, housed at Building 1 of the agency's Boulder Laboratories and broadcast from two radio transmitter campuses at Fort Collins, Colorado, and Kekaha, Hawaii. The Fort Collins facility is significant under Criterion A for its association with the development and broadcast of national time frequency standards.

A multiple property approach to documenting holistically the importance of the atomic clock located in the previously determined eligible Building 1 at the Boulder campus and the radio transmitter facilities at Fort Collins, Colorado, and Kekaha, Hawaii is recommended for their collective significance under Criterion A of the NRHP Criteria for Evaluation in science and technology.

43. Assessment of historic physical integrity related to significance:

The NIST Fort Collins campus is not architecturally significant as it lacks a distinct architectural style. Unlike the NIST campuses at Boulder and Gaithersburg, the Fort Collins site is not a research campus and therefore does not exhibit elements of Postwar Research Campus Design.

VII. National Register Eligibility Assessment

44. National Register eligibility field assessment:

Eligible X Not Eligible ___ Need Data _______

45. Is there National Register district potential? Yes ___ No _X

Discuss: This collection of buildings, outbuildings, structures, and objects are not collectively eligible as a

National Register district. This campus is thematically, historically, and functionally related to the cesium atomic clock at NIST Boulder campus and the NIST Kekaha campus, a Pacific radio transmitter campus. There is National Register eligibility between both sites and object as a multiple-property nomination.

If there is National Register district potential, is this building: Contributing ___ Noncontributing ______

46. If the building is in existing National Register district, is it: Contributing ___ Noncontributing ______

VIII. RECORDING INFORMATION

47. Photograph numbers:

    Negatives filed at: History Colorado – Office of Archaeology & Historic Preservation

48. Report title:
49. Date(s): March 2020
50. Recorder(s): Samuel Young
51. Organization: R. Christopher Goodwin & Associates, Inc.
52. Address: 241 E. Fourth Street, Suite 100, Frederick, MD 21701
53. Phone number(s): (301) 694-0428

NOTE: Please include a sketch map, a photocopy of the USGS quad map indicating resource location, and photographs.

Resource Number:
Temporary Resource Number:

Resource Number:
Temporary Resource Number:

Resource Number:
Temporary Resource Number:

Resource Number:
Temporary Resource Number:

Resource Number:
Temporary Resource Number:

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Resource Number:
Temporary Resource Number:

Resource Number:
Temporary Resource Number:

Resource Number:
Temporary Resource Number:

Architectural Resources SIHP Number Request	
A. SIHP Number	
B. Temporary ID	WWVH Radio Station
C. Library Number/Reference	
D. Type of Report	Nomination Form
E. Date Assigned	
F. Resource Name	WWVH Radio Station
G. Site Description	WWVH Radio Station is a district with component buildings and structures located at the terminus of WWVH Road and bound on all sides by Barking Sands Missile Range Facility. The district is composed of a primary radio transmitter building, a storage outbuilding, and nine antenna structures. The site is flat and consists of dirt and grassy knolls.
H. Consultant	R. Christopher Goodwin & Associates, Inc.
I. TMK	412002013
J. Island	Kaua'i
K. District	Waimea
L. Ahupua'a	Waimea
M. Address	WWVH Road
N. City, County, Zip	Kekaha, Kaua'I County, 96752
O. Formal Site Type, Category, or Property	District
P. Site Function or Use	Government
Q. Number of Features	11
R. Year Built	1971
S. Site Period/Period of Significance	1971
T. Condition	Excellent
U. Integrity	Excellent
V. Eligibility	ES
W. Criteria of Significance	A
X. District/Multiple Property	NIST Cesium Atomic Clock and Radio Transmitter Stations
Y. Burials Present?	No
Z. USGS Quad Name/Number	USGS 7.5' Quadrangle, Kauai
AA. UTM Datum/Zone	UTM Zone 4 4
AB. Easting	-159.762702
AC. Northing	21.987836
AD. GPS Point Location Description	Parking Area
AE: Comments	
AF: Preservation Status	Preserved

Q:\Project_Data\Prj_3185_NIST_CO_HI_RadioTowers\MXD\NIST_HI_Quad_Locator.mxdDate: 12/3/2019 Time: 8:50:38 AM User Name: kwest

Service Layer Credits: Copyright:© 2013 National Geographic Society, i-cubed

N
W E
S

Meters
0 400

Scale 1:24,000
Feet
0 2,000

Project Area

Quad Sheet
Boundary

National Institute of
Standards and Technology
Kekaha, HI

USGS 7.5' Quadrangle Map


WWVH
800


WARNING
RADIO-FREQUENCY RADIATION HAZARD
BEYOND THIS POINT:
RADIO FREQUENCY RADIATION
IN THIS ANTENNA FIELD
EXCEEDS FCC RULES
FOR HUMAN
EXPOSURE

APPENDIX B

COLORADO SHPO LETTER 2016

HISTORY Colorado

23 February 2016 HC #67537

Virginia Holtzman-Bell
Boulder Laboratories Site Manager
National Institute of Standards and Technology
325 Broadway
Boulder, CO 80305-3328

RE: National Register Eligibility of Building 1, Boulder Laboratories Campus, Boulder, Boulder County

Dear Ms. Holtzman-Bell:

Thank you for your recent correspondence dated 1 February 2016, concerning the National Register eligibility of Building 1 at the Boulder Laboratories campus. Our office has reviewed the submitted materials, and applied the National Register criteria for listing per 36.CFR.60.4. We believe that Building 1 is eligible for listing on the National Register of Historic Places under Criterion A (History) and possibly for Criterion C (Architecture and Engineering).

If you have any questions, please contact Joseph Saldibar, Architectural Services Manager, at (303) 866-3741.

Sincerely,

Steve Turner, AIA
State Historic Preservation Officer

OAHP1403
Rev. 9/98

COLORADO CULTURAL RESOURCE SURVEY

Architectural Inventory Form

Official eligibility determination
(OAHP use only)
Date ____________________ Initials _______
_____Determined Eligible- NR
_____Determined Not Eligible- NR
_____Determined Eligible- SR
_____Determined Not Eligible- SR
_____Need Data
_____Contributes to eligible NR District
_____Noncontributing to eligible NR District

I. IDENTIFICATION

1. Resource number: 5BL8240
2. Temporary resource number: None
3. County: Boulder
4. City: Boulder
5. Historic building name: Central Radio Propagation Laboratory
6. Current building name: Building 1
7. Building address: 325 Broadway, NIST-Boulder, Boulder, CO 80305
8. Owner name and address: U.S. Government, 325 Broadway, DoC Boulder Labs, Boulder, CO 80305

II. GEOGRAPHIC INFORMATION

9. P.M. 6TH Township T1S Range R70W
   SE ¼ of NW ¼ of SE ¼ of NE ¼ of section 6
10. UTM reference
   Zone 1 3 ; 4 7 7 5 8 2 mE 4 4 2 7 2 5 7 mN
11. USGS quad name: Eldorado Springs
   Year: 1973 (photorevised 1975) Map scale: 7.5' X 15'____ Attach photo copy of appropriate map section.
12. Lot(s): __________ Block: __________
   Addition: __________ Year of Addition: __________
13. Boundary Description and Justification:
   N 1/2 S 1/2 6-1S-70 LESS TRACT 2571 & SE 1/4 NE 1/4 S OF HWY & PT NW 1/4 SW 1/4 SEC 5 & SW 1/4 NW 1/4 5-1S-70 S OF HWY (Legal Description, Boulder County Assessor’s Office)

III. Architectural Description

14. Building plan (footprint, shape): irregular plan
15. Dimensions in feet: Length 625 x Width 823
16. Number of stories: 4
17. Primary external wall material(s): concrete
18. Roof configuration: flat roof
19. Primary external roof material: synthetic

20. Special features: none

21. General architectural description: Building 1 is encircled by Compton Road. It is oriented northeast toward Broadway (State Highway 93). It was designed by the architectural firm Pereira & Luckman. The building comprises a main block with six rear wings. The primary entrance is located on the northeast elevation of the main block, which also houses an auditorium, and a library. A central spine spans from the northeast to the southwest, and creates a circulation network accessing the six wings that extend to the southeast and northwest. The building is constructed of poured concrete and concrete blocks; portions of the concrete are faced in stone. The building has a flat-roof; this, along with the primary use of concrete and the low height of the building accentuate its overall horizontality. The building is constructed into a slight grade. As a result, the building is tiered and elevators or stairs must be used to access each individual wing from the spine of the building.

The façade (northeast elevation) of the building is divided into three sections vertically. The southeastern third houses a library; the northwestern third serves as an auditorium. The central section between the library and auditorium serves as a lobby area and hallway. The library section is one-story and is clad in stone; the roof of this section is flat. Ribbons of windows light the library on the southeast and northwest elevations; the northeast elevation of the library is blind. The auditorium section is one-story and is clad in stone on each elevation; it has a flat-roof, with a slight flat-roof projection to allow for an acoustic ceiling within the interior space. The central section of the façade is recessed behind the northeast wall planes of the library and auditorium. A row of narrow square concrete columns extends between the northeast wall plane of the library and the auditorium. The columns are connected by a horizontal concrete beam. The space between the library and auditorium is only partially roofed, creating an open courtyard in front of the central section. This courtyard area consists of poured concrete walkways around a central planting bed. Currently, a single large tree is located within the planting bed. A narrow area of the space between the library and auditorium is roofed along the northwest and shelters a walkway leading to the main entry. The façade (northeast elevation) of the central section features square concrete columns; glazing extends from grade to ceiling between the columns. The glazing continues along a projecting vestibule that extends northeast and accommodates the main entry to the front of the building. The central section, or spine of the building, is three-stories. The façade of the second and third levels is constructed of concrete and has no openings. The northwest and southeast elevations of the second and third levels feature ribbons of three windows. Each ribbon of windows is separated by a concrete column. Concrete shed-roof awnings, or sunshades, span the window bays.

The lobby area is an open hallway that connects to the library, the auditorium and to steps leading up to the spine of the building and down to the cafeteria area. A reception area is located within the lobby, directly in front of the main entry. The interior of the library is open from wall to wall, with the exception of an office area. The auditorium, although it appears to retain its overall historic configuration, has been modified to accommodate modern seating and modern audio-visual equipment. Steps off of the lobby access a lower-level corridor that leads to the cafeteria area. The cafeteria features an outdoor seating area that is below grade. Steps off of the lobby area also lead upstairs to the spine of the building, which accesses individual wings. Offices and lab spaces line both sides of the spine hallway.

Each wing is similar on the interior, with a corridor flanked by offices and laboratories. The 1952 elevations by Pereira & Luckman depict the layout of each wing.

Wing 1 extends from the northwest side of the spine, directly behind (southwest of) the auditorium. Annex E and Annex F of Building 1 are located along the northeast elevation of Wing 1, partially masking the elevation. The one-story wing has a flat-roof projection on the roof, a clerestory, which features small single-sash windows. The Wing is constructed of poured concrete and features ribbons of windows along the northeast elevation. Each window bay features six sets of windows. Each window bay is divided vertically by a concrete column. A shed-roof sunshade spans the width of the windows. The southwest elevation of Wing 1 is similar to the northeast elevation, with ribbons of windows that feature concrete sunshades.

Wing 2 extends from the southeast side of the spine, directly behind (southwest of) the library. Similar to Wing 1, Wing 2 is one-story and is constructed of poured concrete. It also features ribbons of windows with concrete sunshades. Each window bay features six sets of windows. Each window bay is divided vertically by a concrete column. The Wing also has a clerestory with small, single-sash windows. The southeast elevation of Wing 2 has a dock area that is sheltered by a shed-roof awning that projects to the southeast.

Wing 3 extends from the northwest side of the spine, directly behind (southwest of) Wing 1. Renovations currently are being made to Wing 3 and include sheathing the Wing in new materials. The Wing is one-story, with a clerestory; it originally featured the same materials and openings as Wing 1. The northeast elevation of the Wing is sheathed in narrow metal horizontal panels. The window openings have been modified to accommodate larger modern sashes and the concrete sunshades have been removed. The clerestory also has been altered, with new sheathing and replacement windows that are larger than the clerestory windows remaining on some of the other wings. The stepped building section has been significantly altered by extending the upper roof line to make space for mechanical equipment and ductwork, and the building wing has been widened to create a utility corridor for the labs. The wing now has a rectangular profile on the southwest elevation. The northwest elevation of the Wing features a dock area, which has also been extensively modified. A large opening that accesses the dock on this elevation is recessed within a poured concrete flat-roof projection that extends to the northwest. The southwest elevation of Wing 3 also has been modified. The elevation is clad in vertical panels and the original windows have been replaced with narrow slits. A ribbon of single-sash windows is located above the vertical panels along the eave of the elevation. Unlike Wings 1, 2, 4, and 5, Wing 3 now has an overhanging eave.

Wing 4 extends from the southeast side of the spine, directly behind (southwest of) Wing 2. Similar to Wings 1 and 2, Wing 4 is one-story tall and is constructed of poured concrete. It also has a shallow clerestory. The northeast elevation of the Wing has ribbons of windows and also features a shed-roof sunshade that spans the elevation. Each window bay is divided vertically by a concrete column. The southeast elevation of Wing 4 has a dock area; a large opening with an overhead door pierces the elevation. A pedestrian door southwest of the large opening provides exterior access to the Wing. The southwest elevation is similar to the northeast elevation, with ribbons of windows and a shed-roof sunshade that spans the length of the elevation.

Wing 5 extends from the northwest elevation of the spine, directly behind (southwest of) Wing 3. The Wing is one-story and is constructed of poured concrete. Unlike Wings 1, 2, and 4, Wing 5 does not have sunshades on the northeast and southwest elevations. Each window bay features six sets of windows. Each window bay is divided vertically by a concrete column. The clerestory on Wing 5 is taller than the clerestory on the other wings; unlike the other wings, the clerestory on Wing 5 also features a ribbon of six windows on the northwest elevation. The northwest elevation of the Wing has a dock area, and an extended wheelchair ramp with rails that spans to the northwest. The southwest elevation of the Wing is similar to the northeast elevation; both elevations have the same bay configuration.

Wing 6 extends from the southwest elevation of the spine, directly behind (southwest of) Wing 4. Similar to Wing 3, Wing 6 is undergoing extensive renovations. The northeast elevation has been sheathed in narrow vertical metal panels and the elevation has been altered to accommodate larger modern windows. The clerestory also has been enlarged and sheathed in new materials. Similar to Wing 3, the stepped building section has been significantly altered by extending the upper roof line to make space for mechanical equipment and ductwork, and the building wing has been widened to create a utility corridor for the labs. The wing now has a rectangular profile on the southwest elevation. The southwest elevation of the Wing is clad in vertical panels, similar to those on the southwest elevation of Wing 3. The original windows have been replaced with narrow slits. A ribbon of single-sash windows is located above the vertical panels along the eave of the elevation. The southeast elevation of the Wing features a dock area, which has also been extensively modified. Unlike Wings 1, 2, 4, and 5, Wing 6 now has an overhanging eave.

The *Spine* of the building extends from the central lobby (between the library and auditorium) to the southwest, connecting to each wing and to Building 81. The Spine originally terminated at the location of current-day Wings 5 and 6, even though these wings were not constructed until years after the completion of the first four wings. Recently, the spine was connected to Building 81 to the southwest. The spine originally had features similar to the wings, including window bays separated by concrete columns and concrete sunshades extending above the windows. The majority of the spine retains the window arrangement and materials. One section of the spine, the southeast elevation between Wings 4 and 6, has been clad in metal panels; the sunshades in this section have been removed and the windows have been sheathed in vertical metal rails.

Annex C (construction completed 1989) is connected to the northwest side of Wing 1. It is not fifty years old or older. The one-story building has a rectangular foot print and a flat roof. It is clad in a pebble coat finish and appears to be a modular building. Windows pierce each elevation of the building and have two-light sashes. A poured concrete hyphen connects Annex C to the northwest side of Wing 1. An entry with double-leaf half-light doors is located on the northeast elevation of the hyphen. An additional entry is located on the southwest end of the northwest elevation of Annex C.

Annex D (construction completed 1992) is located on the southeast end of the southwest elevation of Wing 1. It is not fifty years old or older. The annex was not accessible due to ongoing rehabilitation work on Wing 3. The one-story building has a flat roof and a rectangular footprint; it appears to be modular. A pedestrian entry is located on the northwest elevation. Windows throughout have two-light sashes.

Annexes E and F of Building 1 are located along the northeast elevation of Wing 1, partially masking the elevation. Neither annex is fifty years old or older. Both annexes are constructed of metal panels and appear to encircle mechanical equipment. Both rest on poured concrete pads.

22. Architectural style/building type: modern movement

23. Landscaping or special setting features: Grass areas are located along each elevation. Compton Road travels along the northeast, southeast, and northwest elevations. The southwest elevation is directly adjacent to Building 81 (5BL13210). The two buildings are attached by a narrow addition.

24. Associated buildings, features, or objects: 1-Annex C, 2-Annex D, 3-Annex E, and 4-Annex F are located adjacent to the northwest corner of Building 1). *Annex C* (construction completed 1989) is connected to the northwest side of Wing 1. It is not fifty years old or older. The one-story building has a rectangular foot print and a flat roof. It is clad in a pebble coat finish and appears to be a modular building. Windows pierce each elevation of the building and have two-light sashes. A poured concrete hyphen connects Annex C to the northwest side of Wing 1. An entry with double-leaf half-light doors is located on the northeast elevation of the hyphen. An additional entry is located on the southwest end of the northwest elevation of Annex C. *Annex D* (construction completed 1992) is located on the southeast end of the southwest elevation of Wing 1. It is not fifty years old or older. The annex was not accessible due to ongoing rehabilitation work on Wing 3. The one-story building has a flat roof and a rectangular footprint; it appears to be modular. A pedestrian entry is located on the northwest elevation. Windows throughout have two-light sashes. *Annexes E and F* of Building 1 are located along the northeast elevation of Wing 1, partially masking the elevation. Neither annex is fifty years old or older. Both annexes are constructed of metal panels and appear to encircle mechanical equipment. Both rest on poured concrete pads.

IV. Architectural History

25. Date of Construction: Estimate:________ Actual: 1954 (original) 1959, 1962 (additions) 2012-present (renovations)

    Source of information: NIST

26. Architect: Pereira & Luckman; Associate Architects Jesse Earl Stanton and Robert William Ditzen; Architect for Wing 6 James M. Hunter

    Source of information: Architectural Drawings provided by NIST

27. Builder/Contractor: Olson Construction Company

    Source of information: Architectural Drawings provided by NIST

28. Original owner: National Bureau of Standards

    Source of information: NIST

29. Construction history (include description and dates of major additions, alterations, or demolitions): Renovations currently are being made to **Wing 3** and include sheathing the Wing in new materials. The Wing is one-story, with a clerestory; it originally featured the same materials and openings as Wing 1. The northeast elevation of the Wing is sheathed in narrow metal horizontal panels. The window openings have been modified to accommodate larger modern sashes and the concrete sunshades have been removed. The clerestory also has been altered, with new sheathing and replacement windows that are larger than the clerestory windows remaining on some of the other wings. The stepped building section has been significantly altered by extending the upper roof line to make space for mechanical equipment and ductwork, and the building wing has been widened to create a utility corridor for the labs. The wing now has a rectangular profile on the southwest elevation. The northwest elevation of the Wing features a dock area, which has also been extensively modified. A large opening that accesses the dock on this elevation is recessed within a poured concrete flat-roof projection that extends to the northwest. The southwest elevation of Wing 3 also has been modified. The

elevation is clad in vertical panels and the original windows have been replaced with narrow slits. A ribbon of single-sash windows is located above the vertical panels along the eave of the elevation. Unlike Wings 1, 2, 4, and 5, Wing 3 now has an overhanging eave.

Similar to Wing 3, **Wing 6** is undergoing extensive renovations. The northeast elevation has been sheathed in narrow vertical metal panels and the elevation has been altered to accommodate larger modern windows. The clerestory also has been enlarged and sheathed in new materials. Similar to Wing 3, the stepped building section has been significantly altered by extending the upper roof line to make space for mechanical equipment and ductwork, and the building wing has been widened to create a utility corridor for the labs. The wing now has a rectangular profile on the southwest elevation. The southwest elevation of the Wing is clad in vertical panels, similar to those on the southwest elevation of Wing 3. The original windows have been replaced with narrow slits. A ribbon of single-sash windows is located above the vertical panels along the eave of the elevation. The southeast elevation of the Wing features a dock area, which has also been extensively modified. Unlike Wings 1, 2, 4, and 5, Wing 6 now has an overhanging eave.

The Spine originally terminated at the location of current-day Wings 5 and 6, even though these wings were not constructed until years after the completion of the first four wings. Recently, the spine was connected to Building 81 to the southwest. The spine originally had features similar to the wings, including window bays separated by concrete columns and concrete sunshades extending above the windows. The majority of the spine retains the window arrangement and materials. One section of the spine, the southeast elevation between Wings 4 and 6, has been clad in metal panels; the sunshades in this section have been removed and the windows have been sheathed in vertical metal rails.

30. Original location __X___ Moved ____ Date of move(s):

V. Historical Associations

31. Original use(s): government
32. Intermediate use(s):
33. Current use(s): government
34. Site type(s): research facility
35. Historical background: The Los Angeles, California architecture and engineering firm Pereira & Luckman was selected to design Building 1; Robert William Ditzen of Boulder and Jesse Earl Stanton of Beverly Hills, California served as associate architects. The building was completed in 1954. Plans for the building were made available to the public in March 1952. As recounted in *Achievement in Radio, Seventy Years of Radio Science, Technology, Standards, and Measurement at the National Bureau of Standards*, Hugh Odishaw, assistant to the Bureau's director Dr. Edward Condon, was influential in the development of the final design for Building 1. Odishaw encouraged a design that would allow the building to blend into the surrounding landscape, with "terraced sets of low-profiled wings spreading out from a central spine and set upon the sloping terrain with a backdrop of spectacular foothills (the Flatirons)" (Snyder 1986:713).

The final publicized design "called for a reinforced concrete structure with stone facings in the main entrance area. The six wings were one-story structures (with clerestory roof design), three on each side of a central spine. The central unit or spine was four stories high in front and two at the rear, shaped to a sloping terrain" (Snyder 1986:713). In June 1952, the contract for construction of Building 1 was awarded to Olson Construction Company of Denver, Colorado. To reduce the price of construction, two of the wings included in the original design were eliminated from the constructed plans (Snyder 1986:715).

In 1954, *The Boulder Daily Camera* issued a special section "Dedicated to the National Bureau of Standards" to highlight the dedication of the Boulder campus by President Eisenhower. The section featured articles on the dedication and a lengthy description of the Radio Laboratory:

> The building contains more than 200 interior units used for radio laboratory work, administrative offices, service facilities, an auditorium, and a library. It features concrete sun shades over all windows to block off direct rays of sun yet still provides sufficient natural light. Portions of the building built underground are being air conditioned. A four story central spine with four single story wings outlines the design of the laboratory. The building faces northeast, and provision has been made for two additional wings on the southwest end if needed. Since the structure is built on sloping ground Wings 1 and 2,

> lead off the second floor level and Wings 3 and 4 off the third floor level of the central spine. Entrance to the building is made at the north end of the first floor level. Directly ahead the doors is the reception desk, while to the right of the wood-paneled entrance is a 534 seat auditorium to be used for scientific lectures. To the left of the entrance passage is the library. An east-west corridor separates the library and auditorium from the purchasing and personnel offices and lecture rooms. Steps beside the reception desk lead down to the lower level and up to the second floor. The lower level, a space of 10,000 square feet houses the boiler room, transformer room, locker room, and space which may eventually be made into a cafeteria but is used now as a snack bar (*The Boulder Daily Camera* 1954:n.p.).

Pereira, Luckman, Ditzen, and Stanton were awarded the Award of Merit for the design of the building from the AIA in 1954 (Snyder 1986:713). Pereira cited the building as one of his notable works in his nomination form to become an American Institute of Architects (AIA) Fellow in 1957. He included Building 1 as one of ten distinguished designs and elaborated on the most interesting features of the project:

> The development of three kinds of space, each of which had a considerable variation in cost and use, that have been successfully resolved into a contiguous plan. The public facilities (non-security) are at the front in a simple rectangle; the small laboratories and offices for the scientists are located in the spine; and the shops are located in the wings. The grade was used to solve circulation problems of equipment and people (note the connection between the wings and the spine at various levels). In order to make the building work on the site, it was necessary to orient the spine East and West to eliminate glare and provide sun control. The sunshades as shown are formed concrete and are part of the structure (AIA 2015:n.p.).

Two years after the completion of the Radio Laboratory, construction of Wing 6 began. The wing was constructed for the Electronic Calibration Center and was completed in 1959. James M. Hunter of Boulder was the architect for the wing and construction was completed by the Denver Regional Office of the General Services Administration. Wing 5 was completed in 1962 for the Computation Facility (Snyder 1986:716;

36. Sources of information:

American Institute of Architects (AIA)
2015 William L. Pereira Digital Files. Electronic document, http://public.aia.org/sites/hdoaa/wiki/Wiki%20Pages/ahd1034616.aspx. The American Institute of Architects, Washington, D.C, accessed March 2015.
2015 Charles Luckman Digital Files. Electronic document, http://public.aia.org/sites/hdoaa/wiki/Wiki%20Pages/ahd1027392.aspx. The American Institute of Architects, Washington, D.C., accessed March 2015.

Boulder Daily Camera
n.d. "New Wing on NBS Building Will House Center for Coordinating Booming Electronics Field." *Boulder Daily Camera* n.d.: Boulder, Colorado.
1954 Special Section. September. *Boulder Daily Camera*. Boulder, Colorado.

Snyder, Wilbert F., and Charles L. Bragaw
1986 *Achievements in Radio, Seventy Years of Radio Science, Technology, Standards, and Measurement at the National Bureau of Standards*. U.S. Department of Commerce, National Bureau of Standards, Washington, D.C.

Turner, Steve
2016 Correspondence to Virginia Holtzman-Bell regarding the National Register Eligibility of Building 1, Boulder Laboratories Campus, Boulder, Boulder County.

Wilkes, Paul
1964 "Boulder Watches a Growing NBS." *Boulder Daily Camera*. September 13, 1964, p. 3. Viewed at Carnegie Branch Library for Local History, Boulder, Colorado.

VI. SIGNIFICANCE

37. Local landmark designation: Yes ____ No __X___ Date of designation: __

Designating authority:

38. Applicable National Register Criteria:

__X___ A. Associated with events that have made a significant contribution to the broad pattern of our history;

______ B. Associated with the lives of persons significant in our past;

__X___ C. Embodies the distinctive characteristics of a type, period, or method of construction, or represents the work of a master, or that possess high artistic values, or represents a significant and distinguishable entity whose components may lack individual distinction; or

____ D. Has yielded, or may be likely to yield, information important in history or prehistory.

____ Qualifies under Criteria Considerations A through G (see Manual)

____ Does not meet any of the above National Register criteria

39. Area(s) of significance: science, architecture

40. Period of significance: 1954 - 1965

41. Level of significance: National __X___ State ____ Local __

42. Statement of significance:

Building 1 was constructed during a period of NBS growth and expansion. NBS desired new facilities to accommodate expanded research programs and this was not possible at its Washington, D.C. location. A nationwide search was completed in order to locate the new campus in an ideal environment that allowed room for expansion. The citizens of Boulder and the Boulder Chamber of Commerce launched a concerted campaign to secure the new NBS radio laboratory. When it was completed, it was the flagship building of the Boulder site and it was highly visible from the public highway. Through the construction of Building 1, NBS was able to move forward with expanded research, but it also was able to identify themselves as a progressive and modern agency. As a result, Building 1 appears to be eligible for listing under Criterion A for representing the broad patterns of an agency's history.

Building 1 was the only building on the Boulder campus designed by Pereira & Luckman. At the time of its construction, Building 1 was the flagship building of DoC Boulder Labs. The use of elements of the International Style of architecture were considered cutting edge for the period. In addition, the design of the building incorporates elements typically associated with post World War II research buildings, including consolidation of all activities into a single building, low scale, "use module" design for the laboratory wings, and expansive parking. As a result, Building 1 possesses the significance to be individually eligible for listing in the NRHP under Criterion C with a period of significance of 1954 to 1965. This period covers the completion of the main section of the building along with Wings 1 through 6 and also corresponds to the period during which Building 1 was used for its intended purpose as CRPL. The Colorado SHPO found Building 1 "eligible for listing on the National Register of Historic Places under Criterion A (History) and possibly for Criterion C (Architecture and Engineering)" (Turner 2016).

43. Assessment of historic physical integrity related to significance: n/a

VII. NATIONAL REGISTER ELIGIBILITY ASSESSMENT

44. National Register eligibility field assessment:

Eligible __X___ Not Eligible ____ Need Data _

45. Is there National Register district potential? Yes ____ No__X__

Discuss:

If there is National Register district potential, is this building: Contributing ____ Noncontributing ____

46. If the building is in existing National Register district, is it: Contributing ____ Noncontributing ____

VIII. RECORDING INFORMATION

47. Photograph numbers: 5BL8240: 01 - 10

Negatives filed at: CD Submitted to CO SHPO with report

48. Report title: Historic Assessment Department of Commerce Boulder Laboratories for National Institute of Standards and Technology, Boulder, Colorado

49. Date(s): January 2015

50. Recorder(s): Rebecca Gatewood and Katherine Grandine

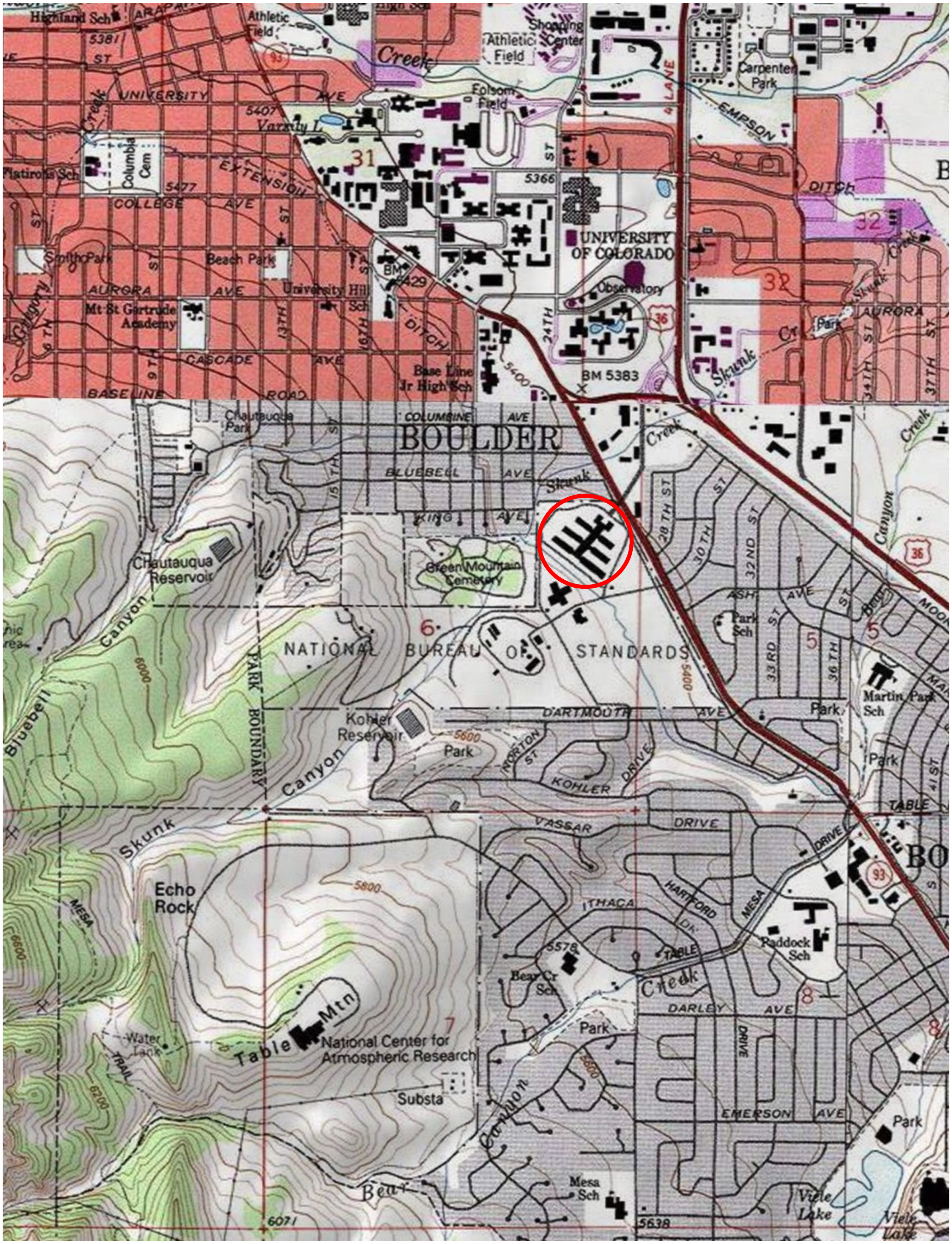
51. Organization: R. Christopher Goodwin & Associates, Inc.

52. Address: 241 East 4th Street, Frederick, Maryland 21701

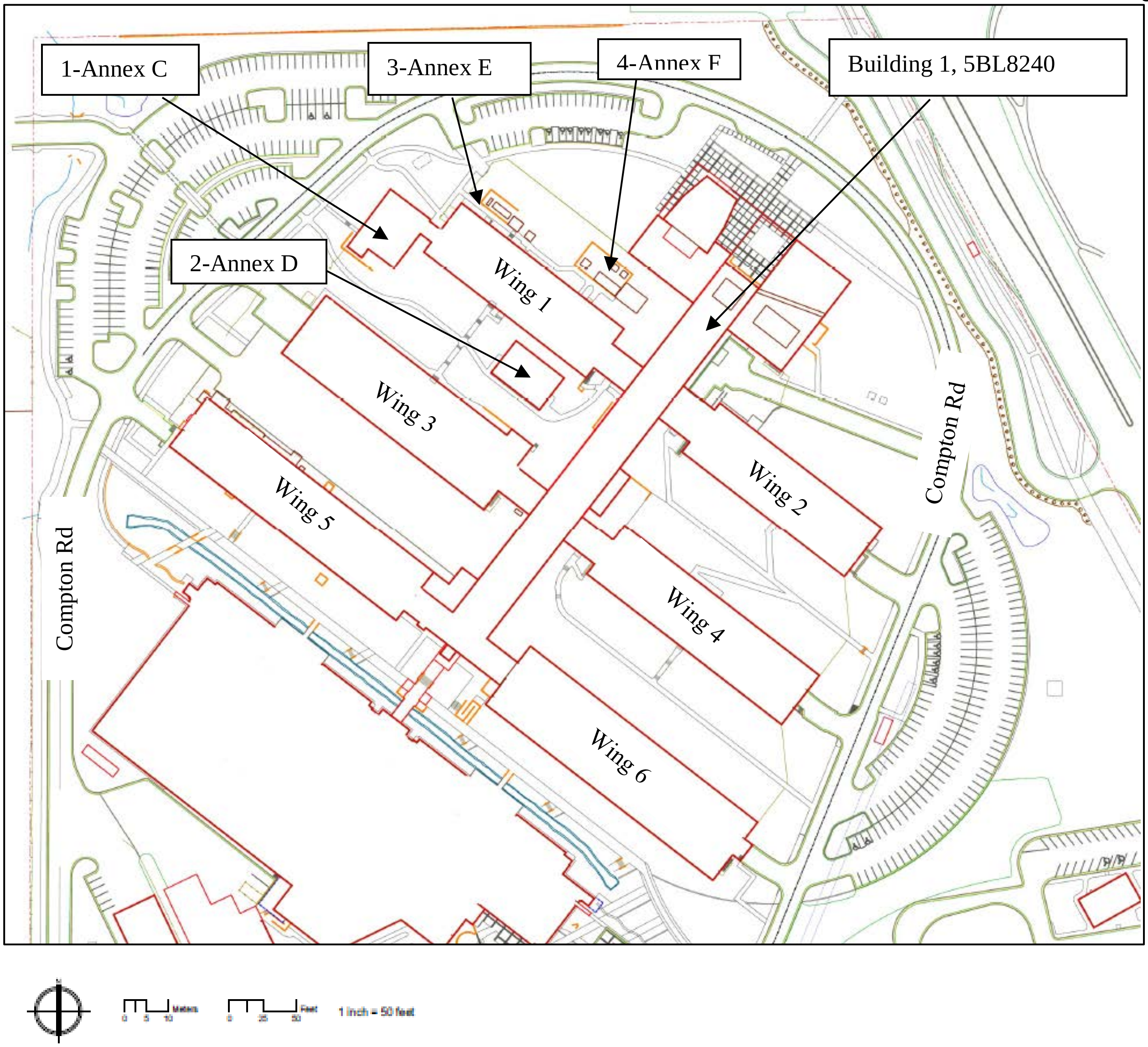
53. Phone number(s):

301.694.0428

NOTE: Please include a sketch map, a photocopy of the USGS quad map indicating resource location, and photographs.



Eldorado Springs, 7.5 Minute Series (Topographic), USGS, 1965 (Photorevised 1971)



5BL8240, 325 Broadway, Boulder, Colorado

5BL8240:01 Building 1, looking southwest

5BL8240:02 Building 1, looking southeast

5BL8240:03 Building 1, Interior lobby

5BL8240:04 Building 1, Interior lobby

5BL8240:05 Building 1, Library interior

5BL8240:06 Building 1, looking southwest

5BL8240:07 Building 1, looking west

5BL8240:08 Building 1, Spine, looking northwest

5BL8240:09 Building 1, Wing 5, looking northeast

5BL8240:10 Building 1, Wing 2, looking northwest