Bonneville Power Administration High Voltage Transmission Testing Historic Context Report

Washington and Oregon

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Cover Photo: BPA's Moro UHV Mechanical Test Line, 1980. (BPA. Photographs of Moro Test Line spanning from 1978 through 1986. Copies on file at Bonneville Power Administration Portland, Oregon).

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Acronyms and Abbreviations

AC	alternating current
BPA	Bonneville Power Administration
ca.	circa
Carey Lab	Charles E. Carey Laboratory
DC	direct current
DOE	determination of eligibility
EHV	extra high voltage
EIS	Environmental Impact Statement
E/MF	electric and magnetic fields
HAER	Historic American Engineering Record
HVDC	high voltage direct current
Hz	Hertz
Intertie	Pacific Northwest–Pacific Southwest Intertie
kV	kilovolt
Mangan Lab	Mangan Mechanical–Electrical Laboratory
MPD	Multiple Property Documentation
NEPA	National Environmental Policy Act
NRHP	National Register of Historic Places
OSU	Oregon State University
PA	Programmatic Agreement
SHPO	State Historic Preservation Office
UHV	ultra high voltage

1. Introduction

1.1 Project Objective

Bonneville Power Administration (BPA) is a nonprofit federal power administration that markets wholesale hydroelectric energy throughout the Pacific Northwest and is part of the U.S. Department of Energy. BPA's transmission system, which provides nearly one-third of the region's electric power, operates primarily in Idaho, Oregon, Western Montana, and Washington; as well as sections of California, Eastern Montana, Nevada, Utah, and Wyoming; and interconnects with systems in British Columbia, Canada.[1] One aspect of accomplishing BPA's mission is the development of technological advancements in high voltage transmission.

In consultation with the Advisory Council on Historic Preservation, the Idaho State Historic Preservation Office (SHPO), Montana SHPO, Oregon SHPO, and Washington SHPO, BPA executed a Programmatic Agreement (PA) to resolve adverse effects resulting from BPA's transmission service undertakings. Programmatic mitigation in the PA included preparation of this historic context statement on BPA's high voltage transmission testing spanning from the 1960s through the 1980s in Washington and Oregon. The following historic context details the chronology of BPA testing facilities, describes individual testing facilities and their unique property types, and explores BPA's contribution to the research and development of ground-breaking new technology in the field of high voltage transmission (Figure 1).

Figure 1. 230-kilovolt breaker at the Lyons Test Facility, September 8, 1977. [2]

[1] BPA.gov, "BPA Facts." https://www.bpa.gov/about/newsroom/fact-sheets.

[2] BPA-provided scanned slides, slide Y212-7.

1.2 Research Methodology

This context was developed through research using a variety of BPA source documents and past documentation. Research used primary and secondary sources, including—but not limited to—internal BPA records, historic newspapers, BPA Annual Reports, engineering technical reports, engineering design manuals, historic photographs and films in BPA's collection, and historic planning documents.

This document relies on the 2012 *BPA Pacific Northwest Transmission System Multiple Property Documentation* (MPD) as a foundation for historic context and expands the historic overview and evaluation framework. However, this document departs from the previously established period of significance in the MPD (1938–1974) and incorporates BPA's testing activities spanning through the 1980s. This document provides a detailed overview of the period of significance and eligibility criteria. This context also incorporates additional research and an expanded identification typology for characterizing BPA's high voltage testing facilities and their components throughout BPA's service area. An identification and evaluation framework addresses significance and integrity considerations that are unique to determining the National Register of Historic Places (NRHP) eligibility of BPA's high voltage testing facilities and lines.

1.2.1 Existing BPA Historic Contexts

Existing BPA Historic Contexts incorporated as secondary materials include the following:

- BPA Pacific Northwest Transmission System MPD[3]
- Corridors of Power: The Bonneville Power Administration Transmission Network Historic Context Statement[4]
- BPA Historic Built Resources Field Guide[5]
- High Voltage Direct Current (HVDC) Test Facility Big Eddy Substation Historic American Engineering Record (HAER)[6]
- Historic Context for the Transmission of Hydroelectricity by the Bonneville Power Administration, 1939–1945[7]
- BPA Transmission Lines Historic Context[8]
- BPA Ross Complex Testing Facilities Historic Context[9]

1.2.2 Key Primary and Secondary Resources

Important primary and secondary resources reviewed for this context include the following:

[3] Kramer, George, *Bonneville Power Administration [BPA] Pacific Northwest Transmission System*. National Register of Historic Places, MPD Form. U.S. Department of the Interior, National Park Service, 2012.

[4] Kramer, George, *Corridors of Power: The Bonneville Power Administration Transmission Network. Historic Context Statement*. Prepared for the Bonneville Power Administration, Portland, Oregon, under Master Agreement #38010, 2010.

[5] AECOM, *Field Guide: Historic Resources.* Portland, Oregon: Prepared for the Bonneville Power Administration, 2020.

[6] Blaser, Andrea. *Historic American Engineering Record: Bonneville Power Administration Big Eddy Substation, HVDC Test Center*, HAER No. OR-186-A, 2016.

[7] Curran, Christine Ann. "*A Historic Context for the Transmission of Hydroelectricity by the Bonneville Power Administration, 1939–1945*." Master's thesis, University of Oregon, 1998.

[8] AECOM, *Bonneville Power Administration Transmission Line Historic Context Report,* Portland, Oregon: Prepared for the Bonneville Power Administration, 2022.

[9] AECOM, *Bonneville Power Administration, Ross Complex Testing Facilities Historic Context,* Portland, Oregon: Prepared for the Bonneville Power Administration, 2023.

Primary sources produced by BPA:

- Proposals and planning documents from 1973 and 1974 regarding the Lyons and Moro testing facilities
- Numerous circa (ca.) 1970s reports authored by Stig A. Annestrand describing the role of test facilities at BPA, test results, and the impact of results on future development
- Documents that note tests performed and subsequent results at several testing facilities
- Lyons Ultra High Voltage (UHV) Test Facilities Electrical Test Program document (1975), which proposes the test program at Lyons and details potential testing, required facilities, and other planning materials[10]
- Photographs of testing facilities and lines
- Electrical Test Program schedules.
- Films from the Moro test facility[11]
- BPA Annual Reports
- Numerous pamphlets produced ca. 1960s–1970s on the need for high voltage testing
- Newspaper articles on BPA testing events and construction

Secondary sources:

- BPA HVDC Test Center exhibit[12]
- BPA and the Struggle for Power at Cost[13]

1.2.3 Research Sources and Repositories

Sources at research repositories throughout the BPA service area were reviewed to aid the development of the historic context. Table 1 summarizes these repositories, their location, and their categorization as a federal, state, or local repository.

Table 1 Repositories and Sources

Repository	Location	Type
Bonneville Power Administration Library	Portland, Oregon	Federal
Bonneville Power Administration Two Park Place	Vancouver, Washington	Federal
National Archives and Records Administration	Seattle, Washington/Online	Federal
University of Washington Library	Seattle, Washington/Online	State
Washington State Archives	Olympia, Washington/Online	State
Washington State Library	Tumwater, Washington/Online	State
Washington State Historical Society	Tacoma, Washington/Online	State
Washington Information System for Architectural and Archaeological Records Data	Online	State
Oregon State Library	Salem, Oregon/Online	State
University of Oregon Library	Eugene, Oregon/Online	State
Oregon Historic Sites Database	Online	State
University of Idaho Library	Moscow, Idaho/Online	State

[10] BPA, *Lyons UHV Test Facilities. Electrical Test Program*, Portland, Oregon, October 1975.

[11] https://river.bpa.gov/galleries/ba53a777-f692-43ee-bf96-9fee01129591_7c78b296-9503-41a8-9f71-eb848445998f-ExternalUser

[12] Burke, Libby, *An Introduction to BPA's HVDC Test Center at Big Eddy [Presentation], September 4, 2019. Accessed September 16, 2025,* https://bonpow2.ent.sirsi.net/custom/web/content/HVDC%20Test%20Center%201963-2017.mp4.

[13] Tollefson, Gene, *BPA and the Struggle for Power at Cost,* Published by BPA, 1987.

Repository	Location	Type
Idaho Cultural Resource Information System	Online	State
University of Montana Library	Missoula, Montana/Online	State
Montana Historical Society	Helena, MT/Online	State
University of California Library	Online	State
California Historical Resources Information System	Online	State
Historic U.S. Geological Survey maps	Online	Federal
Northwest Digital Archives	Online	Local
Newspapers.com	Online	Private
Library of Congress	Online	Federal
U.S. Department of Energy	Online	Federal

1.3 Geographic Boundaries

BPA currently provides service to eight western states: Washington, Oregon, Idaho, Montana, Wyoming, Utah, Nevada, and California. However, the geographic boundary for this context is limited to testing facilities and lines in Oregon and Washington (Figure 2). Although research was conducted on BPA facilities throughout BPA's service territory, no testing facilities or lines were identified in California, Idaho, Montana, Nevada, Utah, or Wyoming. However, all of BPA's service area was impacted by technological advancements that were made possible by the high voltage testing facilities documented in this context.

1.4 Temporal Boundaries

This historic context explores BPA Testing Facilities from 1960 to 1989 and establishes a period of significance from 1961 to 1987. The period begins with the establishment of high voltage testing at the Charles E. Carey Laboratory (Carey Lab) at the Ross Complex in 1961, followed by the HVDC Test Center at the Big Eddy Substation in 1963. The period encompasses testing in the 1970s at the Lyons Test Facility and Moro Mechanical Test Facility. The period of significance ends with the conclusion of testing at the Grizzly Mountain HVDC Research Facility in 1987. Section 2.3 provides a timeline of the development of BPA's testing facilities and highlights key events within the period of significance.

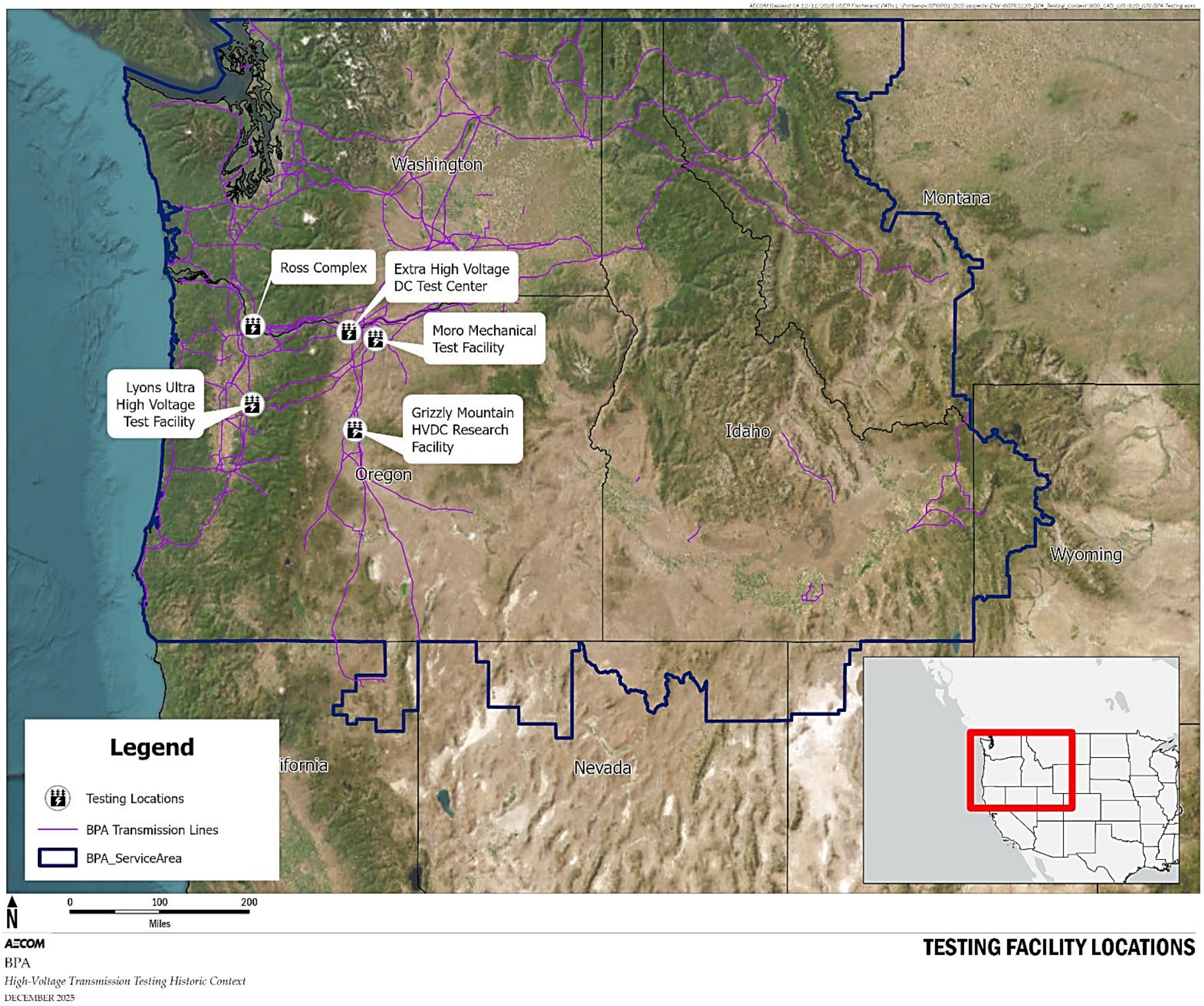

Figure 2. Locations of BPA high voltage testing facilities.

2. Bonneville Power Administration High Voltage Testing Historic Context

2.1 Brief History of Bonneville Power Administration

BPA was created in 1937 by an Act of Congress as part of President Franklin Roosevelt's "New Deal" to market power from the Bonneville Dam, the Columbia River's first federal dam. Since its inception, BPA has impacted the development of technology, industry, and community throughout the Pacific Northwest. The construction of the Master Grid transmission network (1938–1945) provided affordable power to urban and rural communities, transmitted from the Bonneville and Grand Coulee Dams in Oregon and Washington, and brought major industries to the region (Figure 3).[14] During World War II, BPA's Master Grid network advanced the region's significant wartime industries by supplying power to support shipyard production and to aluminum manufacturing sites for aircraft production. BPA also powered the Hanford site, where the United States produced plutonium used in the atomic bombs dropped on Japan in 1945.

Figure 3. Workers installing a transmission structure at Grand Coulee Dam, 1949.[15]

During BPA's System Expansion Period (1946–1974), BPA connected new power generation facilities on the Columbia River and its tributaries to help accommodate the region's post-war growth.[16] The Columbia River Treaty (1964) between the United States and Canada and development of the Pacific Northwest–Pacific Southwest Intertie (Intertie) enabled BPA to further expand its network and begin marketing excess power to southern California.[17] BPA continued to facilitate the development of the region's aluminum, agriculture, and timber industries. By the 1960s and 1970s, the need for higher voltage and more power resulted in the development of testing facilities, as well as ground-breaking new technology and research.

[14] Curran, Christine Ann, *A Historic Context for the Transmission of Hydroelectricity by the Bonneville Power Administration, 1939-1945,* Master's thesis, University of Oregon, 1998*;* Kramer, *BPA Pacific Northwest Transmission System MPD.*

[15] National Archives and Records Administration (NARA), "Grand Coulee Dam-49-10-6-(E20026)," Seattle, WA: NARA, 1949.

[16] The federal government implemented an aggressive construction program to develop dams throughout the Pacific Northwest for hydroelectric power, flood control, and irrigation. Following the end of World War II in 1945, Congress authorized six new federal dams on the Columbia River. Seven more dams were approved in 1950 and two more in 1954. These dams supported the BPA transmission network by generating power, supporting industries, connecting with underserved markets, and fostering community development and growth.

[17] Kramer, *BPA Pacific Northwest Transmission System MPD*; Kramer, *Corridors of Power*; The Columbia River Treaty allowed for the construction of four dams, which released water to produce additional power as needed in the United States. The Intertie allowed for the transmission of surplus power from the Pacific Northwest to be transported over long distances to California. Testing facilities were utilized to develop technology for the Intertie.

Since its inception, BPA has continually adapted to evolving regional and national priorities by incorporating new electric distribution, management, and communication technologies through system upgrades and expansion.[18]

2.1.1 Areas of Service

BPA's service area includes 300,000 square miles across eight states in the northwestern U.S.: Washington, Oregon, California, Idaho, Montana, Wyoming, Utah, and Nevada. In total, BPA provides one-third of the electric power generated in the Northwest and operates and maintains more than 15,000 circuit miles of high voltage transmission (Figure 4).[19] Table 2 details the number of high voltage transmission lines per state within BPA's service area. The electrical power that BPA provides is sourced from 31 federal hydroelectric dams operated by the U.S. Army Corps of Engineers and the Bureau of Reclamation, one nonfederal nuclear powerplant operated by Energy Northwest, and several small nonfederal powerplants.[20] Although research on high voltage testing facilities was conducted for all states within the BPA service area, only Washington and Oregon were found to contain testing facilities.

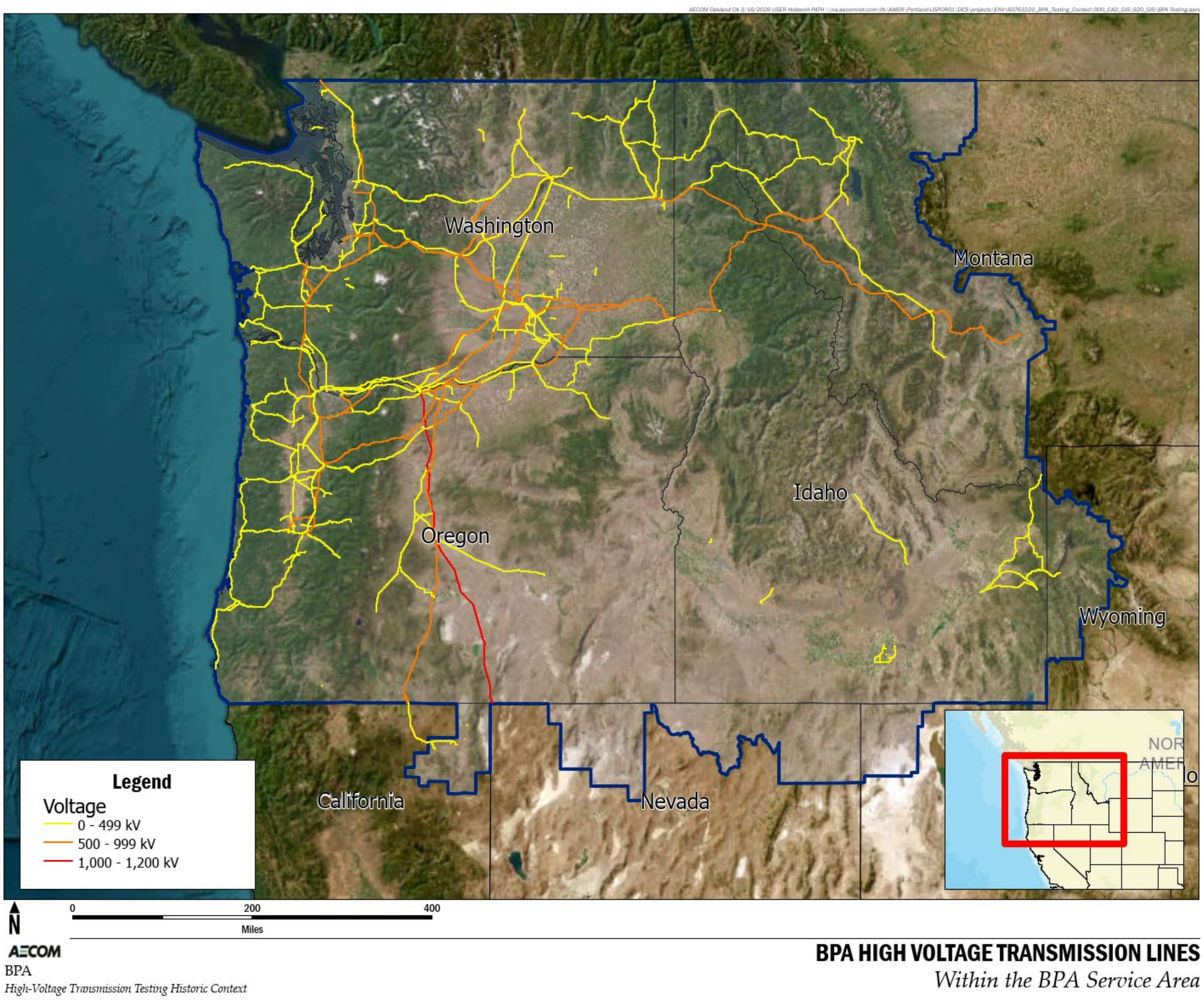

Figure 4. High voltage transmission lines within the BPA service area.

[18] Kramer, *BPA Pacific Northwest Transmission System MPD.*

[19] BPA.gov, "BPA Facts," https://www.bpa.gov/-/media/Aep/about/publications/general-documents/bpa-facts.pdf.

[20] BPA.gov, "Power Services," https://www.bpa.gov/energy-and-services/power.

Table 2 Distribution of BPA High Voltage Transmission Lines Per State

State/District	Miles of High Voltage Transmission Line
Oregon	4,894
Washington	7,899
California	78
Idaho	844
Wyoming	27
Montana	1,212

2.2 High Voltage Electricity

According to the *American National Standards Institute C84.1 Electric Power Systems Voltage Ratings*, high voltage electricity is generally categorized as 100 kilovolt (kV) to 230 kV.[21] Medium voltage is greater than 1,000 volts and less than 100 kV, whereas low voltage is typically 1,000 volts or less.[22] BPA began operating high voltage transmission lines as early as 1939. High voltage electricity was the preferred method to move electricity across greater distances because less electricity was lost in transit.[23] High voltage electricity is too powerful to be used in traditional consumer methods, like to operate household appliances, and therefore must be transformed into a lower voltage prior to distribution to consumers.[24] High voltage electricity is transmitted using direct current (DC), which does not require as much equipment in comparison to alternating current (AC). AC requires more substations, whereas DC can travel greater distances before requiring a substation to transform the power. DC towers are also smaller and lighter, thus requiring less materials and less cost to construct.[25]

Voltage requirements have increased over time due to greater consumer requirements. BPA has been at the forefront of developing technology to transmit electricity at continually increasing voltages. The first high voltage DC transmission line completed in the United States was BPA's Intertie, which transported high voltage power from the Columbia River at The Dalles, Oregon, to Los Angeles, California.[26, 27] By the early 1970s, the need for development of even higher voltage was recognized, and BPA testing facilities were constructed to provide solutions. BPA began researching and testing extra high voltage (EHV) and UHV transmission levels. EHV is generally 345 kV to 765 kV, and UHV is 800 kV to 1,000 kV.[28] BPA began transmitting EHV in the 1960s and UHV in the 1970s. Compared to high voltage, UHV offered more energy savings across transmission lines and greater savings to consumers.[29] With support from the Department of the Interior and Congress, BPA began a program in 1975 to construct a new outdoor facility and develop and test prototype UHV transmission equipment using the Carey

[21] Mohammed, Tara, and Robert Magsipoc, *Definitions, Codes and Standards for Medium-Voltage Systems*, *https://www.csemag.com/definitions-codes-and-standards-for-medium-voltage-systems/#:~:text=Throughout%20the%20United%20States%2C%20several,NEC%202023%20edition*.

[22] Ibid.

[23] BPA.gov, *Transmission: From Dam to Doorstep*, *https://www.bpa.gov/learn-and-participate/community-education/hydropower-101/transmission*.

[24] Annestrand, Stig A., and Alvin R. Batiste, "Bonneville Power Administration's High Voltage and Mechanical Test Facilities," Reprinted from *Proceedings of the American Power Conference 38*, 1976.

[25] Ibid.

[26] Burke, *An Introduction to BPA's HVDC Test Center at Big Eddy;* Annestrand and Batiste, "Bonneville Power Administration's High Voltage and Mechanical Test Facilities."

[27] BPA operates and maintains this line up until the Nevada-Oregon border. South of the Nevada-Oregon border, the line is managed by the Los Angeles Department of Water and Power.

[28] Saldana, Ryan, *The Difference Between High Voltage and Ultra-High Voltage*, https://www.hvmtech.com/post/the-difference-between-high-voltage-and-ultra-high-voltage; Appalachian Power, "How the System Works," https://www.aeptransmission.com/westvirginia/Kenna/docs/open_house/HowtheSystemWorks_Poster_AP.pdf.

[29] Annestrand and Batiste, "Bonneville Power Administration's High Voltage and Mechanical Test Facilities."

Lab.[30] A 1979 publication discussing the savings of UHV stated that BPA "would save 8,000 acres of land for every 200 miles of [UHV] constructed, and power [losses] would only be one fifth as great per megawatt-mile," which is equivalent to saving 1.75 million barrels of oil per year (Table 3).[31]

UHV continued to be a primary area of study at BPA throughout the late 1980s. Three areas of UHV were studied through BPA's 1,100 kV test program at the Lyons and Moro test facilities: electrical performance, mechanical performance, and environmental effects.[32] UHV research findings from BPA's test facilities were shared with utility corporations around the world.[33]

Table 3 Right-of-Way Requirements for Varying Voltage Levels of Transmission Lines

	230 kV Single-Circuit Line	500 kV Single-Circuit Line	500 kV High-Capacity Double-Circuit Line	1,100 kV High-Capacity Single-Circuit Line
Right-of-way width required	125 feet	125 feet	135 feet	170 feet
Transmission capacity per circuit	300	1,500	5,000	10,000
Acres of land required per mile of right-of-way for 10,000 MW capacity	510	105	32	21
Number of lines required for 10,000 MW capacity	37	7	2	1

Notes: kV = kilovolt; MW = megawatt

Source: BPA, *Proposal for 1,100-kV Transmission Line Prototype, Branch of System Engineering,* August 6, 1973. Revised September 6, 1973, and June 11, 1974.

2.3 Development of BPA's High Voltage Testing Program

The earliest documented laboratory testing at BPA occurred in 1939.[34] These tests included the calibration and scaling of switchboard instruments and the testing of meters, instrument transformers, and relays used within the BPA system. Over the next five years, testing operations grew to include acceptance and maintenance testing, as well as field testing 150 kV transmission. By the early 1950s, research and development work became a primary function of BPA laboratories. The development of a 1,200 kV impulse generator in 1952 prompted the expansion of BPA's testing abilities, and by 1954, chemical, materials, and mechanical testing began.[35] BPA's high voltage testing program evolved over the following decades to meet the needs of high voltage, EHV, and UHV programs. Section 2.4.1 provides an overview of the history of high voltage electricity. The following subsections detail BPA's high voltage testing program in the 1940s and 1950s (Section 2.4.2), 1960s and 1970s (Section 2.4.3), and 1980s to present (Section 2.4.4) (Table 4).

Beginning in the mid-1950s and through the mid-1960s, BPA labs focused on three main areas: dielectric tests and insulation evaluation, construction materials inspection, and preventive maintenance programs for substations.[36] The first dedicated EHV test facility was the Carey Lab, built at the Ross Complex in 1961. The Carey Lab facilitated a testing program for BPA's

[30] BPA, *1975 Annual Report*, Washington, D.C.: U.S. Department of the Interior, 1975.

[31] "More Power to Us," *The Columbian*, April 15, 1979.

[32] BPA, *1980 Annual Report*, Washington, D.C.: U.S. Department of the Interior, 1980.

[33] "More Power to Us" *The Columbian*.

[34] U.S. Department of Energy, *Bonneville Power Administration's Test Facilities*, Washington D.C., 1979.

[35] Ibid.

[36] Annestrand and Batiste, "Bonneville Power Administration's High Voltage and Mechanical Test Facilities."

500 kV transmission lines—a voltage that almost quadrupled in the span of less 20 years. The lab tested elements like insulation, conductors, and hardware needed to produce the high voltage line.[37] Three years later, the BPA HVDC Development Program was established, and new facilities like the HVDC Test Center at the Big Eddy Substation were constructed. The Intertie was a large focus of this program, and lines were studied to determine conductor and insulation requirements. By the mid-1970s, multiple additional testing facilities were constructed, including the Fog Test Chamber (1972), the Mangan Mechanical–Electrical Laboratory (Mangan Lab; 1972), and the Carey UHV Lab (1972). Two facilities were constructed in 1976: the Lyons Test Facility (Lyons, Lynn County, Oregon) and the Moro Mechanical Test Facility (Moro, Sherman County, Oregon), which both evaluated 1,100 to 1,200 kV transmission and various mechanical, electrical, and environmental factors. The Grizzly Mountain HVDC Research Facility was built in 1984 and was utilized to research the effects of 500 kV DC transmission lines on cattle and crops. BPA developed modern mechanical, electrical, and chemical laboratories to verify the adequacy of new and improved transmission facility designs and in turn, reduce the risk of power system failures. Over the past 88 years, BPA's testing facilities have shaped how transmission lines are designed, have increased production while decreasing costs, maintenance, and land acquisitions, and have provided groundbreaking data on the environmental impacts of high voltage lines. As a result of high voltage testing, BPA designed and built one of the world's largest networks of high voltage transmission lines.[38]

Table 4 BPA High Voltage Testing Facilities Development Timeline

Date	Event
1937	BPA was created by an act of Congress as part of President Roosevelt's New Deal.
1939	First laboratory-type functions occurred at BPA in the form of calibration and scaling of switchboard instruments and testing of meters, instrument transformers, and relays used on the BPA system.[1]
1947	Current testing processes began at Ross Complex (Vancouver, Washington), and a broad range of maintenance and acceptance testing was completed.[2]
1946–1950	BPA's transmission line system became the largest in the nation.[3]
1954	BPA's first EHV tower was built and tested, followed by the construction of the first 345 kV transmission lines in BPA's transmission grid (Chief Joseph-Snohomish and McNary-Ross).[4]
1955	The High Current Test Lab, BPA's first dedicated testing facility, was constructed at the Ross Complex in Vancouver, Washington.[5]
1961	Construction of the Carey Laboratory at the Ross Complex, was completed to facilitate a testing program to define the insulation, hardware, and conductor requirements for BPA's 500 kV transmission lines.[6]
1962	Congress appropriated funding for the HVDC Development Program, which established experimental testing facilities in The Dalles, Oregon.[7]
1963	Construction of the HVDC Test Center began at the Big Eddy Substation in The Dalles, Oregon, advancing BPA's high voltage research.[8]
1964	The Columbia River Treaty between the United States and Canada is ratified; development begins on the Intertie.[39]

[37] U.S. Department of Energy, *Bonneville Power Administration's Test Facilities.*

[38] Annestrand, Stig A., et al. *Report on the BPA Demonstration Center at Lyons UHV Test Facilities,* June 1, 1979.

[39] Kramer, *BPA Pacific Northwest Transmission System MPD*; Kramer, *Corridors of Power.*

Date	Event
1965	Construction of BPA's first 500 kV lines began.[9]
1968	BPA completed its largest construction of high voltage lines ever, constructing over 913 miles of 500 kV lines that year.[10]
1970	BPA completed construction of the Pacific Northwest–Pacific Southwest Intertie through Oregon and California.[11]
1971–1975	"The Dalles Project" is funded at the HVDC Test Center in The Dalles, Oregon, to study electrical characteristics of insulators, conductors, and hardware for HVDC systems up to 600 kV.[12]
1972	The HVDC Test Center at The Dalles, Oregon, received a Fog Test Chamber.[13]
1972–1973	Construction of the Fog Test Chamber and the Mangan Lab at the Ross Complex in Vancouver, WA, was completed.[14]
1972	The Carey High Voltage Laboratory was added to the existing Carey Lab at the Ross Complex.[15]
1975	Supported by the Department of the Interior and Congress, BPA began a program to develop and test prototype UHV transmission.[16]
1975–1976	BPA constructed the UHV Outdoor Test Yard at the Ross Complex and installed a $1 million impulse generator designed to simulate irregularities and other characteristics of existing and future transmission lines.[17]
1976	An Environmental Impact Statement was completed in preparation for two new 1,100 kV test facilities: an Electrical Prototype Test Line (Lyons) and a Mechanical and Ice Test Prototype Test Line (Moro).[18]
1976	The Moro Mechanical Test Facility and Lyons Test Facility (Moro, Oregon, and Lyons, Oregon) were constructed.[19]
1979	A Visitor Center opened at the Lyons test facility, informing visitors about the newest UHV technology.[20]
1984	The Grizzly Mountain HVDC Research Facility was established in Madras, Oregon.[21]
1987	Study at Grizzly Mountain HVDC Research Facility concluded, marking the end of BPA's testing programs.[22]
1996	HVDC Test Center in The Dalles, Oregon, closed.[23]
2017	HVDC Test Center was demolished.[24]

Notes: BPA = Bonneville Power Administration; EHV = extra high voltage; HAER = Historic American Engineering Record; HVDC = high voltage direct current; kV = kilovolt; UHV = ultra high voltage

[1] U.S. Department of Energy, *Bonneville Power Administration's Test Facilities*.

[2] Kramer, *BPA Pacific Northwest Transmission System MPD*.

[3] BPA, *1950 Report on the Columbia River Power System*, U.S. Department of the Interior, 1950.

[4] Osipovich, "Full Scale Tests Prove BPA's 345-Kv," *Electrical World*, February 8, 1954.

[5] Williams, Carl, *Z0329, BPA Ross High Current Test Lab*, Historic Property Report. Olympia, WA: Washington Department of Archaeology and Historic Preservation, 2015.

[6] Annestrand and Batiste, "Bonneville Power Administration's High Voltage and Mechanical Test Facilities."

[7] BPA, *1962 Report on the U.S. Columbia River Power System*, U.S. Department of the Interior, 1962.

[8] Blaser, *Historic American Engineering Record: Bonneville Power Administration Big Eddy Substation HVDC Test Center*.

[9] Annestrand and Batiste, "Bonneville Power Administration's High Voltage and Mechanical Test Facilities."

[10] BPA, 1968 Annual Report*: Federal Columbia River Power System*, U.S. Department of the Interior, 1968.

11 BPA, "Pacific Intertie Map, The Oregon History Project," 1964, https://oregonhistoryproject.org/articles/historical-records/pacific-intertie-map/#.XGWkuJXrvZN

12 Annestrand and Batiste, "Bonneville Power Administration's High Voltage and Mechanical Test Facilities"; U.S. Department of Energy, *Bonneville Power Administration's Test Facilities.*

13 Blaser, *Historic American Engineering Record: Bonneville Power Administration Big Eddy Substation HVDC Test Center.*

14 BPA, *1973 Annual Report,* Washington, D.C.: U.S. Department of the Interior, 1973.

15 U.S. Department of Energy, *Bonneville Power Administration's Test Facilities.*

16 BPA, *1975 Annual Report*.

17 BPA, *1976 Annual Report*, Washington, D.C.: U.S. Department of the Interior, 1976.

18 BPA, *Supplement to the Environmental Statement, Fiscal Year 1976 Proposed Program, Prototype 1100 kV Test Facilities,* U.S. Department of the Interior, October 22, 1974.

19 U.S. Department of Energy, *Bonneville Power Administration's Test Facilities.*

20 *Albany Democrat-Herald*, "Come Visit Us, Urges BPA," October 5, 1979.

21 Lee et al. "The Grizzly Mountain HVDC Transmission Research Facility," *Right of Way*, April 1986, https://eweb.irwaonline.org/eweb/upload/web_0486_Grizzly_Mountain.pdf.

22 BPA, *1981 Annual Report: Bonneville Power Administration.* U.S. Department of Energy, 1981.

23 Blaser, Historic American Engineering Record: Bonneville Power Administration Big Eddy Substation HVDC Test Center.

24 Ibid.

2.3.1 Early Development of High Voltage (1940s to 1950s)

BPA's Master Grid (1938–1945) transmission network, composed of transmission lines and substations in Oregon and Washington, ushered in a new era of high voltage power distribution to the Pacific Northwest. The Master Grid transmitted high voltage power between generation facilities and major load centers as early as 1939. The cities of Portland, Seattle, and Spokane were connected by a 230 kV transmission line circuit with radiating 115 kV transmission lines reaching smaller cities, towns, industrial plants, and utilities.[40] Although BPA continued to maintain and develop transmission lines operating below 115 kV during the Master Grid period, more circuit miles of high voltage transmission lines were constructed. Comprised predominately of high voltage transmission lines, the Master Grid was designed to facilitate rapid expansion of BPA's transmission network to broaden its geographic reach in the ensuing decades. As part of the development and maintenance of the Master Grid transmission network, BPA began calibrating switchboard instruments and testing meters, instrument transformers, and relays used throughout the BPA system in 1939.[41] Testing capabilities increased throughout the early 1940s, and by 1945, field testing up to 150 kV was possible in BPA facilities.[42]

BPA's development of the transmission grid after World War II during the System Expansion Period (1946–1974), is characterized by transitioning away from war industries, diversifying revenue sources, and focusing on expanding BPA's transmission line network.[43] Between 1946 and 1950, BPA's transmission line system became the largest in the nation, expanding from two to five states and from 2,737 to 4,040 circuit miles of transmission lines with 70 substations (Figure 5).[44]

As BPA expanded its transmission and communication network during the 1950s, it implemented technological innovations to increase capacity and reliability. Although testing of transmission equipment at the Ross Complex began as early as 1939, the first dedicated testing facility, the High Current Test Lab, was constructed in 1955 at the Ross Complex.[45] Additional facilities at the Ross Complex were developed in the late 1950s, 1960s, and 1970s.[46] Testing during the early years of the System Expansion Period included materials testing in a dedicated materials laboratory, as well as increased staff expertise in the areas of chemical and

40 Kramer, *BPA Pacific Northwest Transmission System MPD*.

41 Annestrand and Batiste, "Bonneville Power Administration's High Voltage and Mechanical Test Facilities."

42 Ibid.

43 Williams, *BPA Ross High Current Test Lab.*

44 BPA, *Report on the Columbia River Power System*.

45 Williams, *BPA Ross High Current Test Lab.*

46 BPA, *1973 Annual Report*.

mechanical testing.[47] Between 1954 and 1964, BPA laboratories began implementing dielectric tests, preventative maintenance programs, and insulation evaluations.[48]

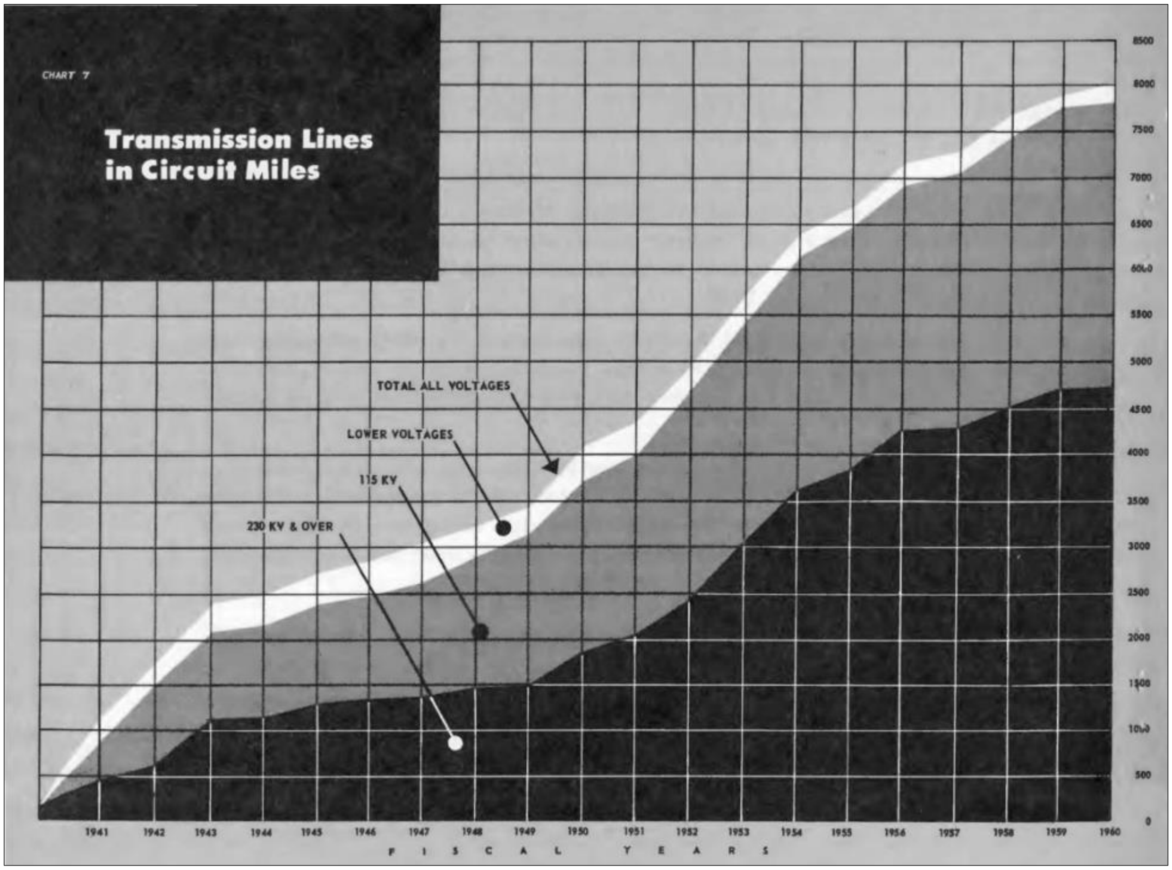

Figure 5. Comparison of BPA transmission lines' mileage by voltage (1941–1960).[49]

Completion of BPA's first EHV 345 kV test tower in 1954 facilitated the construction of the first 345 kV transmission lines (Chief Joseph-Snohomish and McNary-Ross) in the BPA transmission grid later that year.[50] BPA continued testing the limits of high voltage transmission in the following decades.

2.3.2 High Voltage Testing (1960s to 1970s)

The 1960s and 1970s were the most influential decades for high voltage testing in BPA's history During these 20 years, four testing facilities were developed, the world's largest HVDC transmission line was constructed, and BPA completed several "firsts" in high voltage technology, contributing greatly to the transmission line industry. BPA's high voltage testing led to improved designs based on environmental factors, increased transmission loads, reduced land requirements, reduced mechanical failure and maintenance costs, and a stronger understanding of the potential environmental impacts of high voltage transmission.

1960s and the Pacific Northwest-Pacific Southwest Extra-High Voltage Intertie

During the 1960s, growing electricity demand increased the need for high voltage testing. Increasing collaboration between government entities was also on the rise, as the sale and usage of power began to be negotiated across state lines. BPA, in cooperation with the Bureau

[47] Annestrand and Batiste, "Bonneville Power Administration's High Voltage and Mechanical Test Facilities."

[48] Ibid.

[49] BPA, *1960 Annual Report on the U.S. Columbia River Power System,* U.S. Department of the Interior, 1960.

[50] Osipovich, "Full Scale Tests Prove BPA's 345-kV."

of Reclamation, completed a study of a proposed intertie between the U.S. Columbia River Power System and Northern California.[51] Submitted to the Senate Committee on Interior and Insular Affairs on February 17, 1960, the report determined the feasibility of selling surplus energy from the Pacific Northwest to California.[52] Negotiations among BPA, the Senate Committee on Interior and Insular Affairs, and other federal and state agencies on the proposed Intertie project would continue for several years.

As the demand for higher transmission voltages continued to increase, BPA experimented with different tower designs and stringing methods to support this increased need.[53] BPA determined older stringing methods were inadequate for higher transmission voltages, and in 1961, new machinery for stringing conductors was put into use on all high voltage lines.[54] Later that year, the Carey Test Laboratory was constructed, making it possible for BPA to conduct a greater number of tests and investigations on high voltage.[55]

No HVDC transmission lines had been developed in the United States by the early 1960s. Seeing the expanding need for transmitting power at a higher voltage in the United States and a lack of existing data on the topic, a Department of the Interior task force funded a study of HVDC electricity.[56] In June 1962, Congress authorized the funding for the HVDC Development Program, which established experimental testing facilities.[57] The intent of the program was to fund working groups to conduct full time studies on six specific areas of interests: DC Flashover, DC Ground Current, Inductive Coordination, Insulator Leakage, Safe Working Procedures, and Radio Noise and Instrumentation (Table 5).[58] The testing facilities provided data on DC transmission that was later used to prepare for the construction of the Intertie.[59]

Table 5 Six Areas of Interest Studied during the HVDC Development Program[1]

Area of Interest	Purpose
DC Flashover	Study insulators and airgaps and their DC flashover characteristics, as well as line and station insulation requirements. Determine line and station insulation design criteria. Examine how insulation efficiency is affected by weather and other phenomena.
DC Ground Current	Determine the effects of DC ground current on underground metallic structures and railway signals. Evaluate soil properties and changes due to current passage. Investigate the effect of ground electrodes on adjacent systems.
Inductive Coordination	Evaluate the effects of harmonic currents on converter–inverter systems and communication networks, and how to mitigate effects.
Insulator Leakage	Examine insulator shape and surface composition and effects on surface leakage and contamination. Develop contamination simulation tests and measuring procedures. Study how DC insulation efficiency is impacted by contamination.
Safe Working Procedures	Investigate the physiological and psychological effects of intense DC fields. Establish protective measures, procedures, and tools required during DC hotline maintenance.

[51] BPA, *1960 Annual Report.*

[52] Ibid

[53] BPA, *1961 Annual Report on the U.S. Columbia River Power System,* U.S. Department of the Interior, 1961.

[54] Ibid.

[55] BPA, *1963 Annual Report on the U.S. Columbia River Power System,* U.S. Department of the Interior, 1963.

[56] Blaser, *Historic American Engineering Record: Bonneville Power Administration Big Eddy Substation, HVDC Test Center*.

[57] Ibid

[58] Ibid.

[59] BPA, *Extra High Voltage Direct Current Test Center,* By Stewart L. Udall, U.S. Department of the Interior, and Charles F. Luce, BPA. Big Eddy Substation, The Dalles, Oregon, 1963.

Area of Interest	Purpose
Radio Noise and Instrumentation	Observe the effects of radio and television interference in close proximity to EHV DC lines. Investigate corona loss characteristics of DC transmission lines. Observe and analyze conductor aging processes and conductor corona sources.

Notes: DC = direct current; EHV = extra high voltage; HVDC = high voltage direct current

[1] Blaser, *Historic American Engineering Record: Bonneville Power Administration Big Eddy Substation, HVDC Test Center*.

Two key steps were taken to advance the technology of high voltage power transmission in 1963: construction began on the first 500 kV AC transmission line from John Day Dam to the Oregon-California border, and ground broke on a $2 million DC transmission test center.[60] The test center, later named the HVDC Test Center, was built at the Big Eddy Substation in The Dalles, Oregon, in fall 1963, and was the first of its kind in the United States (Figure 6). The high voltage transmission study was scheduled to be a 2-year test program and was an important piece of America's contribution to technology leadership in DC power transmission.[61]

Figure 6. Test line at the HVDC Test Center, September 26, 1963.[62]

In 1964, BPA continued to study DC current at the HVDC Test Center in preparation for the Intertie construction.[63] The facility experienced a collapse in the dome that housed the testing equipment on May 20, 1964, pausing testing until the facility was rebuilt in fall 1964.[64]

Tests conducted at the HVDC Test Center gave BPA the information it needed to build the Intertie and transmit power from what would become BPA's Celilo Converter Station, near The Dalles, Oregon, to the Los Angeles Department of Water and Power–operated Sylmar Converter Station, north of Los Angeles, California. Once built, the Intertie used an 846-mile-long DC line, which at the time was heralded as the longest of its kind in the world.[65]

The Intertie was a monumental engineering achievement that connected the West Coast's main power grids (Figure 7). The largest transmission project in U.S. history, the Intertie was built to

[60] BPA, *1963 Annual Report*.

[61] Ibid.

[62] BPA-provided National Archives scan, E7086.

[63] BPA, *1964 Report on the U.S. Columbia River Power System, U*.S. Department of the Interior, 1964.

[64] Ibid.

[65] BPA, *Extra High Voltage Direct Current Test Center.*

"balance power needs in the West" and permit the Northwest and Southwest to share surplus electrical power.[66] BPA's 1967 annual report described the project:

> When complete, the Intertie will represent an investment of $660 million with $273 million coming from private utilities, $298 million from the Federal government, and $89 million from the City of Los Angeles. BPA's share of the Federal cost is $167 million and the Bureau of Reclamation's $131 million.[67]

Intertie construction lasted from 1965 to 1970; upon completion, two 500 kV/AC transmission lines extended approximately 940 miles from the John Day Dam on the Columbia River southward through the Central Valley of California, terminating at the Lugo substation near Los Angeles. The third transmission line, an 800 kV DC (1970), extended from the Celilo Converter Station, near The Dalles Dam on the Columbia River, southward through Central Oregon and Nevada before terminating at the Sylmar Converter Station near Los Angeles (Figure 8). At the time of completion, it was the United States' first and the world's largest DC transmission power line. The project allowed BPA and other Northwest utilities to sell surplus energy to the Pacific Southwest, generating extra revenue and, in 1975 alone, saved the Southwest utilities the "equivalent to more than 31 million barrels of costly, substantially imported oil."[68]

Figure 7. Map of the proposed Intertie, September 1964.[69]

[66] BPA, "Pacific Intertie Map, The Oregon History Project."

[67] BPA, *1967 Annual Report: U.S. Columbia River Power System,* U.S. Department of the Interior, 1967.

[68] BPA, *1976 Annual Report.*

[69] Oregon History Project, Pacific Intertie Map. https://www.oregonhistoryproject.org/articles/historical-records/pacific-intertie-map/; Oregon Historical Society Research Library, 48789.

Figure 8. Illustration of the BPA Grid and future Intertie, 1966.[70]

Testing continued on DC transmission throughout the mid-1960s, and results were used to extrapolate tower and conductor designs.[71] The construction of BPA's first 500 kV lines after 1965 resulted in some of the first hardware failures.[72] These failures were primarily caused by subconductor oscillation and vibration. BPA had experienced minimal transmission system mechanical failures in the past.[73] Most failures were fatigue-type failures, which were primarily caused by defective materials.[74] To solve these reoccurring problems, BPA built its own test and development facilities, and 7 years later, the Mangan Lab was constructed at the Ross Complex to test fatigue-type failures.[75] At the HVDC Test Center in The Dalles, the High Voltage Test Line was absorbed into the John Day-Keeler line. By 1967, BPA joined Project UHV, a research program sponsored by the Edison Electric Institute, an association that represented all U.S. investor-owned electric companies.[76] Project UHV aimed to explore UHV AC transmission, running between 1967 and 1971.[77] In 1968, BPA completed its largest construction of high voltage lines ever, totaling over $110 million in construction costs and resulting in the construction of 913 miles of 500 kV lines.[78]

1970s and the Establishment of Additional Testing Facilities

On May 21, 1970, the Intertie went into commercial operation, transporting high voltage electricity from the Pacific Northwest to California.[79] At the start of the 1970s, BPA anticipated that power requirements in the Pacific Northwest would greatly increase over next 30 years, with a 75 percent increase occurring on the western side of the Cascades.[80] The concept of UHV transmission was determined by BPA to be the most feasible plan to meet growing needs.

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[70] BPA, *1966 Report: U.S. Columbia River Power System,* U.S. Department of the Interior, 1966.

[71] BPA, *1964 Report.*

[72] Annestrand and Batiste, "Bonneville Power Administration's High Voltage and Mechanical Test Facilities."

[73] Ibid.

[74] Ibid.

[75] Ibid.

[76] BPA, *1967 Annual Report.*

[77] BPA spent $800,000 (in 1967) to participate in the joint research program with other private utility companies, scheduled to span 5 years of research. The program was utilized to explore voltages above 750 kV and how to modify techniques to be able to safely transmit higher voltages (BPA, *1967 Annual Report*). Project UHV evolved from a research facility, also named "Project UHV," that was built by General Electric ca. 1958–1964 to perform research on extra high voltage transmission. Additional information is available in BPA's *Transmission Line Reference Book HVDC to ±600kv* (Electric Power Research Institute 1977)

[78] BPA, *1968 Annual Report.*

[79] BPA, *1970 Annual Report*, Washington, D.C.: U.S. Department of the Interior, 1970; U.S. Department of Energy, *Bonneville Power Administration's Test Facilities;* Burke, *An Introduction to BPA's HVDC Test Center at Big Eddy.*

[80] BPA, *Determination and Findings to Negotiate a Class of Contracts Required for the Construction of an 1,100-kV Prototype Project for Research and Development*, March 1974.

Compared to high voltage, UHV offered more energy savings across longer transmission lines, resulting in greater savings to consumers.[81]

At the HVDC Test Center in The Dalles, a research project with the Edison Electric Institute was funded in joint partnership with BPA. The project provided operating information on HVDC up to 600 kV and resulted in additional facilities being constructed at the HVDC Test Center. A fog test chamber was built, and line and fog chamber tests began in the fall of 1972.[82] Construction of other BPA facilities increased throughout the decade. In 1975, with support from the Department of the Interior and Congress, BPA began a program to construct a new outdoor facility and develop and test prototype UHV transmission equipment using the Carey High Voltage Lab.[83] At the Ross Complex, the UHV addition to the Carey Lab and an associated Outdoor Test Yard were completed in 1975 and 1976, respectively.

In the late 1970s, two additional test facilities were constructed to meet the expanding need for UHV research: Lyons Test Facility and Moro Mechanical Test Facility. BPA's ability to make reliable judgement and advance planning of the next higher voltage overlay in the BPA system was limited by lack of knowledge and experience of overhead AC transmission in the 1000–1,200 kV range, thus testing was needed to determine the environmental, technical, and economic acceptability of UHV transmission (Figure 9).[84]

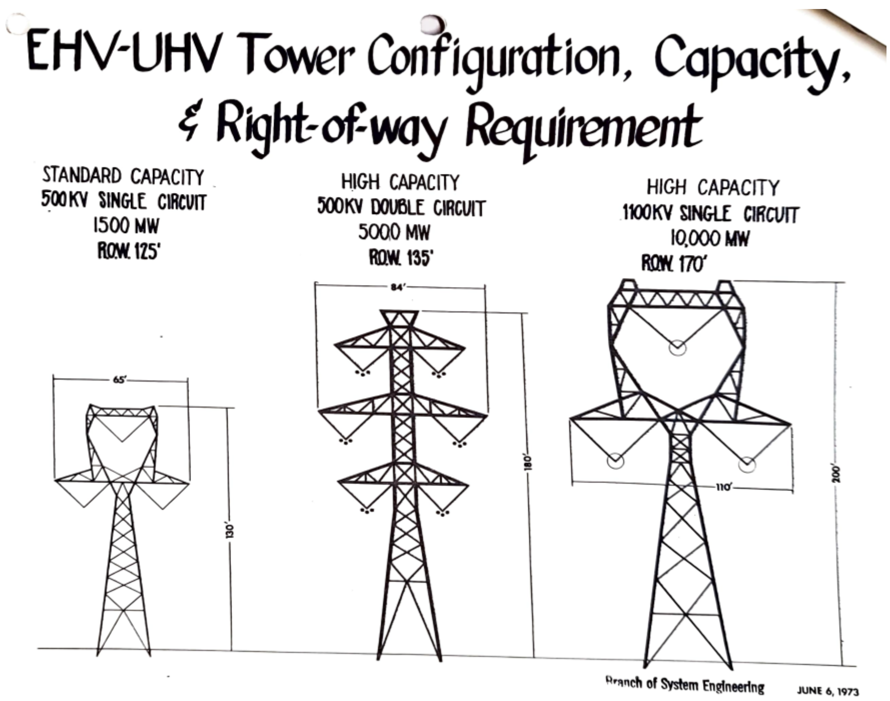

Figure 9. Image showing tower configurations holding increasingly higher voltage, 1973.[85]

A 1976 Environmental Impact Statement (EIS) was compiled in preparation for the two prototype 1,100 kV test facilities.[86] The EIS justified the need for exploring UHV transmission, stating "the future [of electrical transmission] requires higher loads within a reasonable amount of right of way. Long-range planning indicated that to meet expected demand for power, suitability of ultrahigh voltage (1,100 to 1,200 kV) designs must be approved."[87] BPA stated in

[81] Annestrand and Batiste, "Bonneville Power Administration's High Voltage and Mechanical Test Facilities."

[82] BPA *1972 Annual Report.*

[83] BPA, *1975 Annual Report*.

[84] BPA, *Determination and Findings to Negotiate a Class of Contracts*.

[85] BPA. Branch of System Engineers. *Proposal for 1,100-kV Transmission Line Prototype.*

[86] BPA, *Supplement to the Environmental Statement, Fiscal Year 1976 Proposed Program.*

[87] Ibid.

the EIS that the operation of 1,100 kV prototype line would provide information on environmental impacts, safety aspects, electrical aspects, and construction and maintenance techniques.[88] In order to begin construction of UHV lines, finalizing the design of a UHV transmission system would require performance of mechanical and electrical tests. The Moro Mechanical Test Facility and the Lyons Test Facility were both constructed to fill this data gap on UHV transmission (Figure 10). The facilities received funding in 1975 for approximately $5.5 million under the Department's Research and Development budget.[89] The two facilities were ultimately completed in 1976.

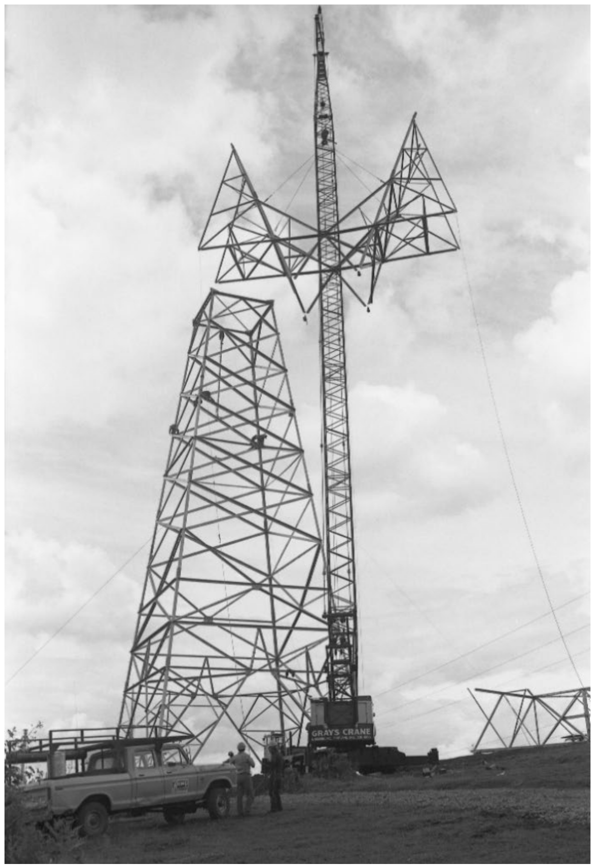

Figure 10. Construction of the Lyons Test Facility, July 1976.[90]

A 1979 newspaper article discussing the savings of UHV stated that BPA “would save 8,000 acres of land for every 200 miles of [UHV] constructed, and power [losses] would only be one fifth as great per megawatt-mile,” which is equivalent to saving 1.75 million barrels of oil per year.[91] Research and testing on high voltage transmission continued, and additional testing facilities were constructed in the 1980s.

2.3.3 High Voltage Testing (1980s to Present)

In the 1980s, BPA’s high voltage testing focused on improving HVDC systems, uprating 500 kV AC transmission, and studying environmental impacts. By 1980, the BPA high voltage transmission grid was the largest in the world, containing approximately 13,000 circuit-miles of transmission lines and 357 substations. Fiscal year 1981 was one of the busiest construction years in BPA’s history. BPA reported the completion of 497 circuit-miles of high voltage

[88] BPA, *Supplement to the Environmental Statement, Fiscal Year 1976 Proposed Program;* BPA, *Prototype 1100 kV Test Facilities Project – Progress Report,* October 8, 1974.

[89] U.S. Department of Energy, *Bonneville Power Administration’s Test Facilities.*

[90] BPA-provided slide scans, slide I0908-28.

[91] “More Power to Us,” *The Columbian*.

transmission lines and the addition of seven substations to the BPA grid. BPA's 1,100 kV test program was preparing for the advent of commercial UHV transmission. Beginning in 1982, electrical studies at the Lyons Test Facility put less emphasis on corona characteristics and more emphasis on substation equipment, particularly gas-insulated equipment (Figure 11). The environmental studies at Lyons facility continued to evaluate the effects of electrical fields on natural vegetation, crops, mammals, birds, livestock, and honeybees.

Figure 11. Workers on a test line at the Lyons Test Facility, October 4, 1982.[92]

In July 1982, BPA began building its portion of the Colstrip transmission system through western Montana. The system was one of the world's largest and most reliable networks of long-distance high voltage lines.[93] In 1983, BPA designed, tested, and installed new master control systems for the Celilo and Sylmar Converter stations at each end of the Intertie. This effort was part of an upgrading of the Intertie from 1,600 megawatts to 2,000 megawatts.[94]

In 1984, BPA led the development and testing of the world's first EHV DC circuit breaker. The breaker allowed the operation of long-distance, multi-terminal DC transmission lines. This new EHV DC circuit breaker was a significant breakthrough in transmission technology. Regional operations saved 600 labor-hours in 1984 through the introduction of a new program to test static single-pole relays. The relays were used to sense electrical disturbances and switch off

[92] BPA-provided scanned slide, slide P390B-22.

[93] BPA, *1982 Annual Report: Bonneville Power Administration,* U.S. Department of Energy, 1982.

[94] BPA, *1983 Annual Report: Bonneville Power Administration,* U.S. Department of Energy, 1983.

valuable equipment before it suffered extensive damage. BPA planned to expand this new relay testing program and anticipated it may save as much as 10,000 hours of labor in a single year.[95]

BPA and a group of 10 utility companies co-sponsored an agricultural study near the Intertie's DC line in central Oregon in 1984. The study aimed to determine whether operating the line at 1,000 kV resulted in any significant effects on cattle or crops and was also utilized to learn more about possible environmental effects from electrical fields associated with HVDC transmission lines. As a result of the study, BPA established the Grizzly Mountain HVDC Research Facility.[96] The study took place under the 500 kV Celio-Sylmar line, which was part of the Intertie, and consisted mostly of cattle pens with minimal built facilities.[97] Research conducted at the facility was done in joint partnership between BPA and Oregon State University.[98] The facility operated from 1984 to 1987, and the study found no unusual differences between the exposed group of cattle and crops and the control group. At the site, BPA engineers made significant advances in the measurement and characterization of the electrical environment near the HVDC line.[99]

In 1985, design work for the final 99-mile transmission line segment from Taft Substation across northern Idaho to Bell Substation near Spokane, Washington, was nearly finished. All sections of the line were equipped with the world's first application of high-speed single-pole relaying and grounding equipment. This equipment made it possible to transfer higher levels of power and maintain stable system operations. Advances in technology permitted the installation of new gas-insulated EHV equipment at Taft Substation. The substation's seven 500 kV gas-insulated circuit breakers required much less space than conventional equipment, an innovation made possible by BPA testing facilities.[100]

Responding to emerging environmental issues, BPA was involved in evaluating the concerns about the health hazards from electric and magnetic fields (E/MF). BPA's interim guideline for new transmission lines was to not increase exposure of the population to these fields where practical alternatives existed. In 1989, BPA contributed to national research on the subject, continued its own research, and created publications to inform the public. A high voltage AC transmission E/MF study, initiated by BPA in 1989, was anticipated to bring $500,000 of co-funding to Pacific Northwest universities.[101] UHV continued to be a primary area of study at BPA throughout the late 1980s. Three areas of UHV continued to be studied through BPA's 1,200 kV test programs at Lyons and Moro: electrical performance, mechanical performance, and environmental effects.[102] UHV research findings from BPA's test facilities have been shared with utility corporations around the world via in-person conferences and publications.[103]

As BPA's transmission system complexity and maximum voltage increased, test requirements changed.[104] Laboratory facilities with improved functions and new test methods were added to the Ross Complex, and new measuring techniques were developed.[105] Today, the Ross Complex is BPA's primary testing facility. BPA testing facilities accommodate most electrical testing required on systems extending from low voltage into the UHV range.[106]

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[95] BPA, *1984 Annual Report: Bonneville Power Administration,* U.S. Department of Energy, 1984.

[96] Raleigh, Robert J., *Joint HVDC Agricultural Study: Final Report,* September 30, 1988. https://fic.oregonstate.edu/sites/agscid7/files/eoarc/attachments/336.pdf.

[97] Ibid.

[98] BPA, *1985 Annual Report: Bonneville Power Administration,* U.S. Department of Energy, 1985.

[99] BPA, *1987 Annual Report: Bonneville Power Administration,* U.S. Department of Energy, 1987.

[100] BPA, *1985 Annual Report.*

[101] BPA, *1989 Annual Report: Bonneville Power Administration,* U.S. Department of Energy, 1989.

[102] BPA, *1980 Annual Report.*

[103] "More Power to Us," *The Columbian.*

[104] Annestrand and Batiste, "Bonneville Power Administration's High Voltage and Mechanical Test Facilities."

[105] Ibid.

[106] Ibid.

2.4 BPA High Voltage Testing Facilities and Transmission Lines

Historically, BPA operated five testing facilities; four of the facilities were in Oregon, and one was in Washington. The facilities provided space for exploring opportunities for development in design and technologies, specifically regarding the expanding need for more power in the Pacific Northwest. These facilities played pivotal roles in the creation of high voltage, EHV, and UHV transmission lines, and the testing results impacted the transmission industry. The testing facilities overall reduced consumer costs, increased safety standards, led to important technological advancements, provided insight on potential environmental impacts on animals and plants, and led to greater transmission capacity at BPA, within the United States, and around the world. Tests performed at the facilities included mechanical, electrical, and chemical testing (Figure 12). Each facility and specific tests conducted at the facility are detailed in the following subsections.

Figure 12. Staff members performing tests at the Moro Mechanical Test Facility, November 1979.[107]

2.4.1 Ross Complex

The Ross Complex is a 250-acre facility located north of Vancouver, Washington (Figure 13). Construction of testing facilities at the Ross Complex began in 1955 with the High Current Test Lab where tests were conducted on high voltage switch gears to improve equipment design. The Carey Lab was built in 1961 and focused on improving BPA's 500 kV transmission lines.[108] Additional testing facilities added in the late 1960s-early 1970s include the Blacksmith Shop/Medium Voltage Testing Building, the Fog Test Chamber, and the Mangan Lab.[109] Two facilities were added to the Carey Lab; the High Voltage Lab (1972) and the UHV Outdoor Test Yard (1976) (Figure 14). A chemistry lab was established in the nearby Ampere South building in 1979 and it collaborated with several other BPA labs for testing oil form breakers and transformers.[110] The Ross Complex currently has the only laboratories of its kind on the Pacific Coast, and BPA tests almost all of its supplies and materials in the Carey or Mangan Lab.

[107] BPA-provided scanned slide, slide I0975-17

[108] Ibid.

[109] BPA, *1973 Annual Report*.

[110] Dizon, Rolando, and Joshua Powers, interview with AECOM at BPA Ross Complex Testing Facilities, Vancouver, WA, February 14, 2023; U.S. Department of Energy, *Bonneville Power Administration's Test Facilities.*

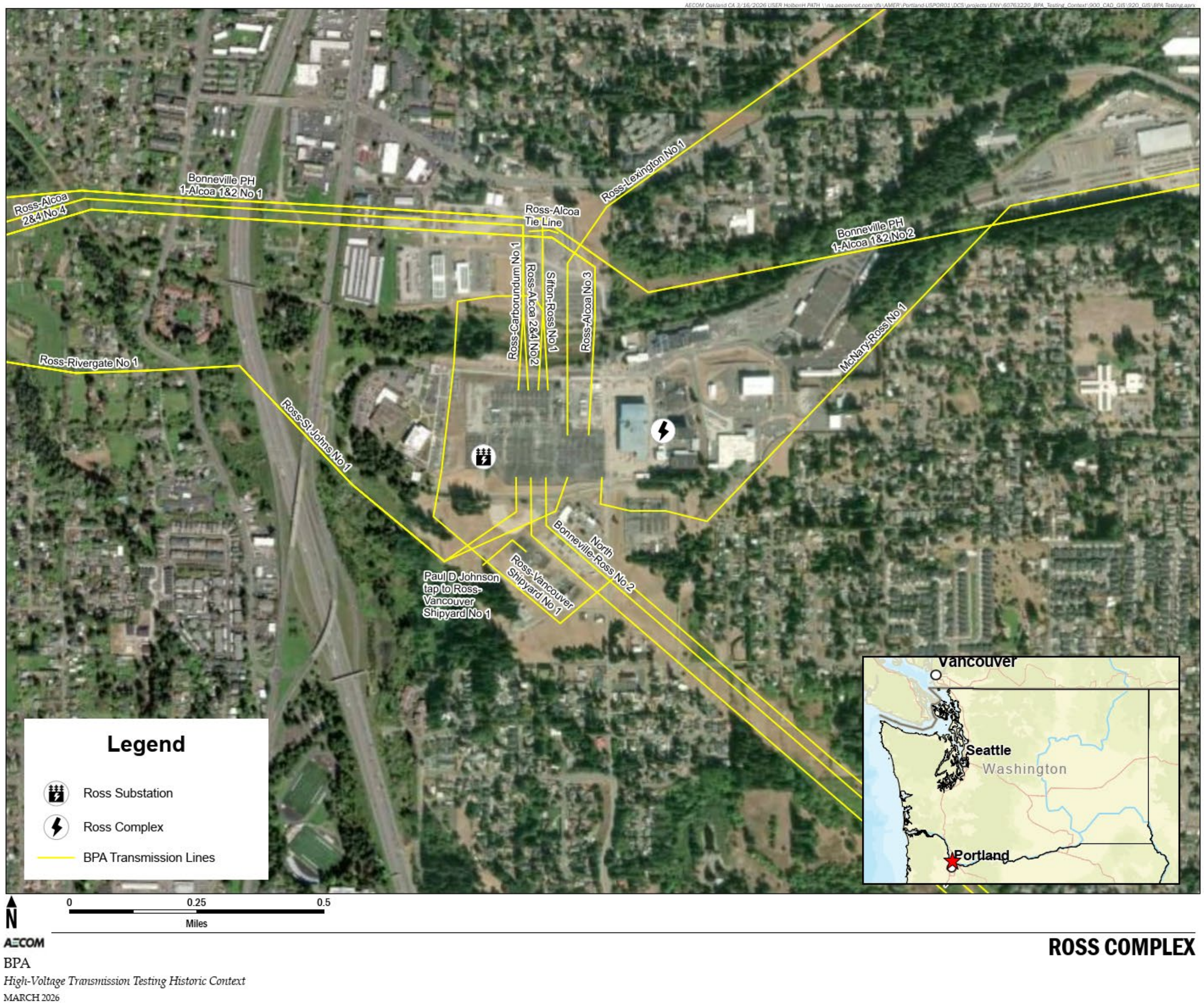

Figure 13. Map of the Ross Complex, Ross Substation, and associated transmission lines.

Laboratory tests at Ross were generally divided into electrical tests and mechanical tests. The Carey High Voltage Lab historically was the main electrical laboratory. In the late 1970s, the lab included a High Voltage Impulse Test Facility, a UHV 60-Hertz (Hz) Test Facility, an EHV 60 Hz Test Facility, a Fog Test Chamber, a High Current Test Facility, a Chemistry Lab, an Instrumentation and Standards Lab, and a Capacitor Test Facility (Figure 14).[111] The Mangan Lab was the main mechanical test facility and was supported by a short outdoor transmission line test facility.

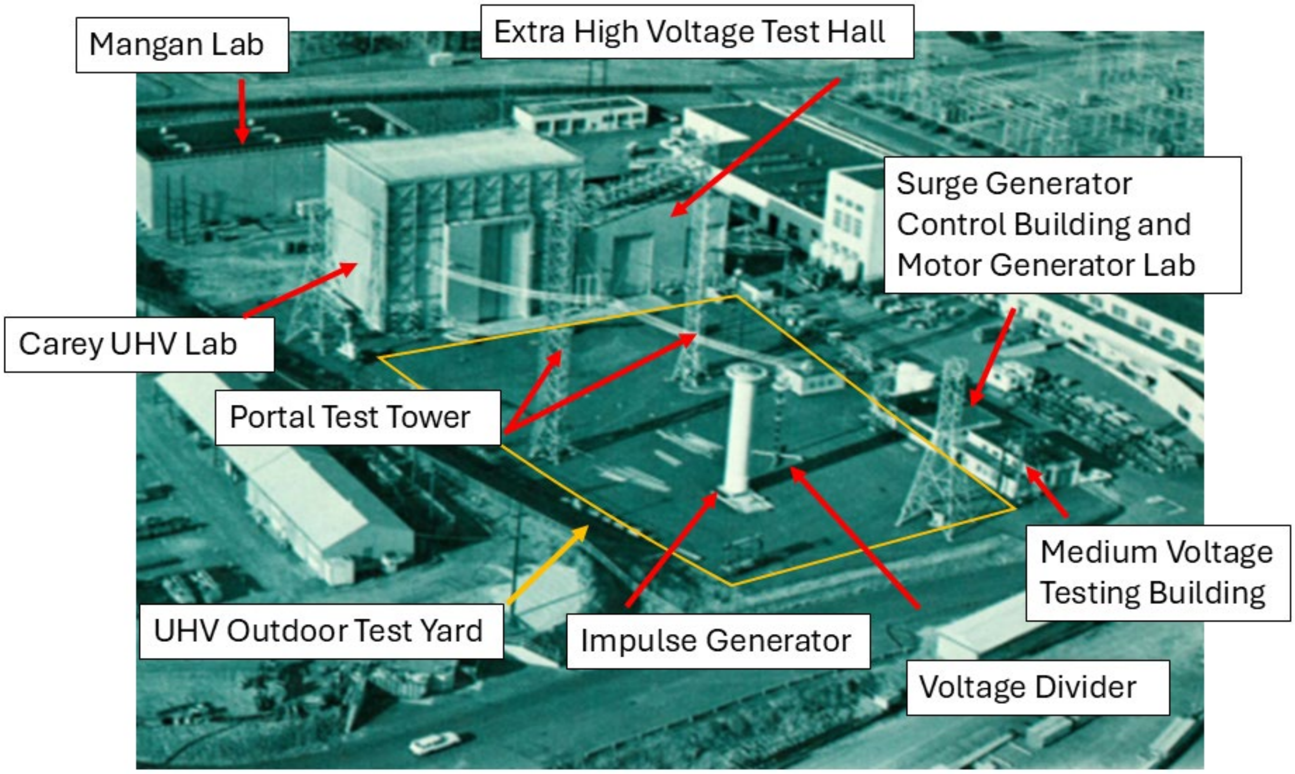

Figure 14. Aerial view of BPA Ross Complex Testing Facilities in 1979.[112]

Testing Facilities at the Ross Complex

Charles E. Carey Lab and High Voltage Test Laboratory

The Carey Lab was constructed by BPA in 1961 for maintenance electrical testing of 345 kV equipment. BPA purchased a 4-million-volt impulse generator for the purpose of conducting test projects and investigations in 1965.[113] The High Voltage Laboratory was added to the Carey Lab in 1972 to conduct testing on BPA's new 500 kV transmission lines.[114] Machinery found in the Carey Lab included the cascade transformer, impulse generator, and a splice shunt, which remain in operation today. The High Voltage Lab was also used to test for corona, an electrical discharge from conductors carrying high voltage that is both visible and audible.

Also referred to as the UHV Test Hall in the late 1970s, the Carey Lab had an unobstructed vertical clearance of 25 meters, allowing for large-scale testing.[115] Historically, a bridge crane moved test equipment throughout the hall. The hall walls were designed to attenuate sound and reduce electromagnetic interference. Massive doors on either side of the lab provided access to the adjoining outdoor UHV test lab and a storage yard (Figure 15). The EHV Test Hall is also

[111] Annestrand and Batiste, "Bonneville Power Administration's High Voltage and Mechanical Test Facilities."

[112] U.S. Department of Energy, *Bonneville Power Administration's Test Facilities.*

[113] BPA, *1965 Report: U.S. Columbia River Power System,* U.S. Department of the Interior, 1965.

[114] U.S. Department of Energy, *Bonneville Power Administration's Test Facilities.*

[115] Ibid.

housed within the Carey Lab. This test hall had a shorter vertical clearance of 15 meters, when compared to the 25-meter UHV Test Hall, and was equipped with a bridge crane. Doors faced out into the UHV Outdoor Test Yard, and the hall held two 350 kV test transformers. A special feature of the EHV Test Hall was an oil pit that was utilized for bushing tests. The hall was damaged by a fire in the 1990s and converted to a training area, classroom, and library.[116]

Figure 15. Exterior of the Carey Lab.[117]

UHV Outdoor Test Yard

The UHV Outdoor Test Yard, developed in 1976, supported both the Carey and Mangan Labs and tested UHV transmission. Equipment within the test yard included an impulse generator, portal test tower, and voltage divider (Figure 16). The outdoor yard was able to handle higher voltage testing than the indoor test facilities due to the level of clearance and outdoor environment.

Measuring 13,000 square meters, the UHV Outdoor Test Yard's impulse generator is enclosed in glass-laminated polyester to allow for operations in all weather.[118] The impulse generator features 28 stages, which can be connected in series or parallel to simulate transmission line irregularities. The Carey Lab featured a similar indoor impulse generator with a staircase generator with 12 stages, which are charged capacitors that are utilized to increase voltage and provide controlled, high voltage outputs during tests. The portal test tower had adjustable ground plane panels and a water spray rack to simulate realistic environmental conditions on transmission lines (Figure 17).

[116] Dizon and Powers, Interview.

[117] AECOM 2022

[118] Annestrand and Batiste, "Bonneville Power Administration's High Voltage and Mechanical Test Facilities."

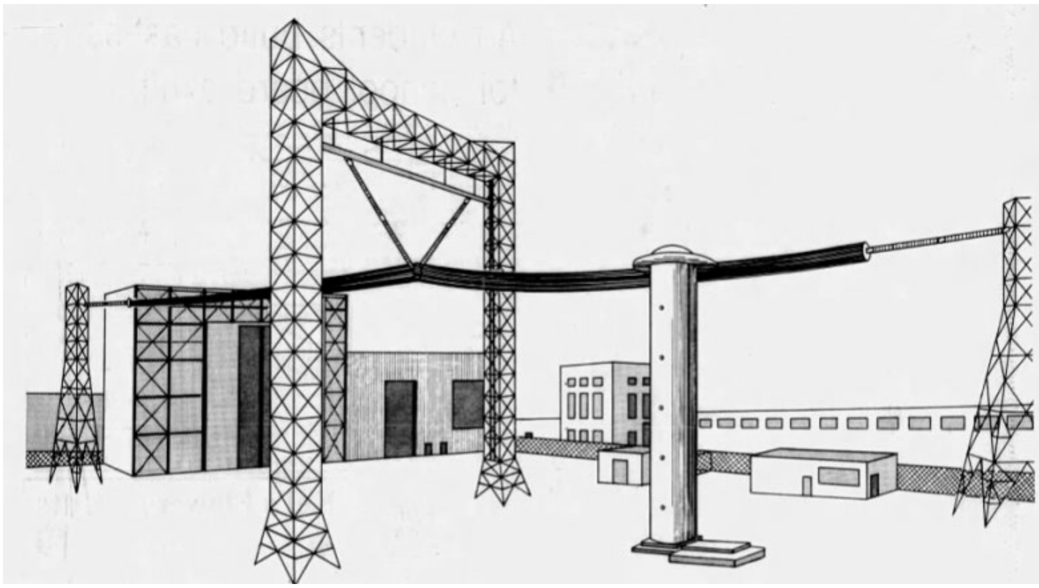

Figure 16. Historic drawing of the UHV Outdoor Test Yard prior to completion.[119]

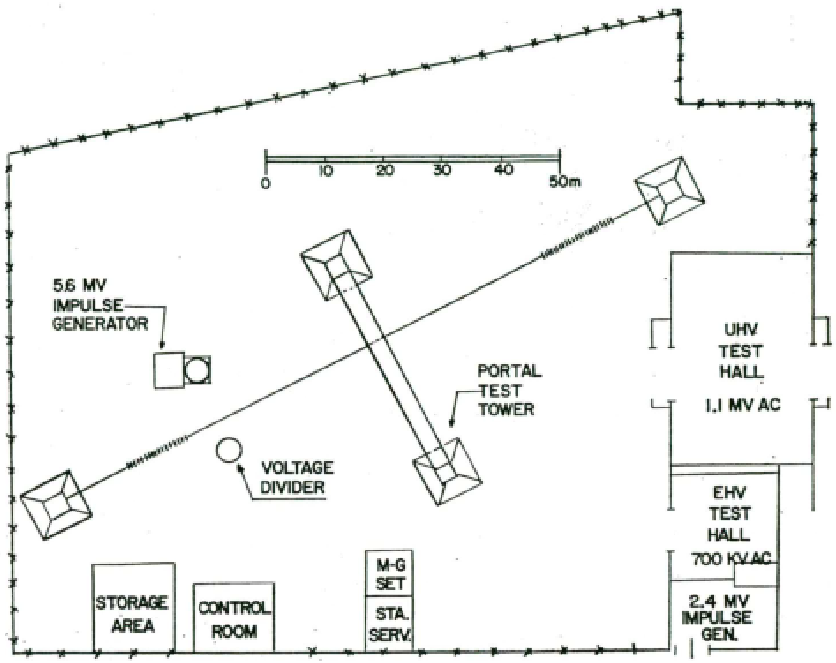

Figure 17. 1976 diagram of the UHV Outdoor Test Yard.[120]

Fog Chamber and Associated Infrastructure

Designed for testing contaminated insulators in rain and fog conditions, the Fog Test Chamber had an associated test yard and voltage regulator (Figure 18).[121] The system also had the capability to change the resistivity of the water by utilizing mineralizing and mixing processes. The Fog Test Chamber was powered by a transformer with variable voltage, which could supply a single-phase 1.5-mega volt-ampere steady state load, as well as an 18.5-mega volt-ampere fault. The Fog Test Chamber was also equipped with a steam and spray fog system, and an overhead rain rack to simulate rain and fog conditions.

[119] *The Columbian*, "BPA Engineers Simulate Lightning Bolts."

[120] U.S. Department of Energy, *Bonneville Power Administration's Test Facilities.*

[121] Ibid

Figure 18. The Fog Test Chamber and attached Test Yard.[122]

Mangan Lab

The Mangan Lab was built in 1972 and housed mechanical and electrical test facilities that helped prevent and troubleshoot mechanical failures on transmission systems (Figure 19). The assorted lab equipment provided conditions to test static and dynamic mechanical loads and electric currents. Within the lab, a horizontal tension test machine was able to test transmission equipment up to 125 feet in length, simulating weather conditions and allowing engineers to stretch and compress various materials. The lab also contained an environmental test chamber, which produced temperatures from -49ºF to +203ºF with variable humidity levels. Tests of hardware compression tension were completed using a fatigue test machine. An outdoor transmission line test span facility was developed for testing suspension and dead-end insulators and hardware. The test facility has also been utilized as a training tool for apprentice line workers and to test maintenance tools. Studies conducted at the facility include tests on ice buildup on conductors and fatigue resistance of line hardware fittings.

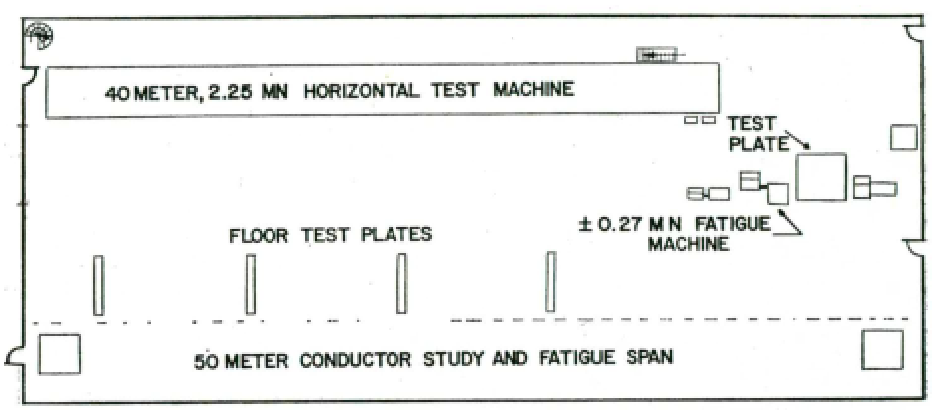

Figure 19. 1976 floorplan of Mangan Lab.[123]

[122] AECOM, *Updated J.D. Ross Complex Determination of Eligibility,* Portland, Oregon. Prepared for the Bonneville Power Administration, 2023.

[123] Annestrand and Batiste, "Bonneville Power Administration's High Voltage and Mechanical Test Facilities."

Chemistry Lab

The Chemistry Lab at the Ross Complex performed a variety of tests on insulating oils, industrial and domestic water, paint, adhesives, wood pole inspection, asphalt and concrete, and metallic compounds.[124] Equipment at the lab included several spectrophotometers (infrared, atomic absorption, and UV-visible light), as well as a gas cell, emission spectrograph, gas chromatograph, and carbon furnace.

Instrumentation and Standards Lab

The Instrumentation and Standards Lab primarily repaired, maintained, calibrated, and supplied BPA instruments used at electrical and microwave installations, and laboratories.[125] A majority of the instruments were portable and used to test equipment like telemetering devices and meters. The lab also used a measurements systems unit that developed instruments that are not available from commercial sources but that are needed for special tasks or abnormal, BPA-specific measurements. Many pieces of instrumentation remain in operation. The lab's standards are in ordinance with the National Bureau of Standards.

Tests Performed

Tests performed at the Ross Complex's seven testing facilities included a wide variety of electrical, mechanical, chemical, and environmental tests. Testing capabilities can be largely categorized into two categories: Laboratory Testing and Prototype Testing. Laboratory Testing includes impulse, mechanical, low frequency, and direct voltage tests. Prototype Testing includes low-frequency, high voltage tests, such as those performed in the UHV Outdoor Test Yard, as well as vibration tests, tensile and compression tests (like those performed in the Mangan Lab), and stress analyses. The size of the Ross Complex and the plethora of resources on site enhanced the capabilities of the testing facilities on site in terms of the sheer number and types of tests performed. Furthermore, the presence of multiple testing facilities and staff at the Ross Complex established a central location for BPA high voltage testing. Table 6 summarizes the types of tests performed at several of the Ross complex's testing facilities. Today, testing still occurs at the Ross Complex, and BPA tests almost all supplies and materials in the Carey or Mangan Lab prior to installation.

Table 6 Tests Historically Performed at Different Ross Facilities

Facility	Types of Tests Performed	Purpose and Impacts of Tests
High Current Test Lab (demolished 2016)	Exposing high voltage switch gears to large magnitudes of current.	Avoid failures on a complex system; obtain design data and verify the adequacy of new designs[1]
Carey Lab	Testing on insulation, hardware, and conductor requirements for BPA's 500 kV transmission lines.	Test and improve safety conditions, including bucket truck boom lifts; improve functionality of hardware; test new designs prior to field implementation, improve overall functionality; potentially reduce costs and/or materials
Mangan Lab	Evaluating the tensile, compressive, shear and impact strength, vibration characteristics, and mechanical-electrical-thermal characteristics of a broad range of static and dynamic loads at various current and voltage levels under various controlled weather conditions.	Prevent hardware failures; predict how materials may react within certain environmental conditions; prevent power outages due to material failure; increase safety for BPA line workers by testing lifeline strength

[124] U.S. Department of Energy, *Bonneville Power Administration's Test Facilities.*

[125] Ibid.

Facility	Types of Tests Performed	Purpose and Impacts of Tests
Chemistry Lab	Testing oil from breakers and transformers for performance under high voltage conditions, inspecting wood poles, consulting on asphalt and concrete designs.	Understand current conditions of BPA transformers and other materials; prevent failures from arising and evaluate effectiveness of materials and their longevity

Notes: BPA = Bonneville Power Administration; kV = kilovolt

[1] U.S. Department of Energy, *Bonneville Power Administration's Test Facilities.*

Distinguishing Features

The Ross Complex testing facilities are characterized by their adaptability. For example, the Mangan Lab was designed with flexible spaces to allow for the movement of large pieces of testing equipment and completion of many types of tests. Large, purpose-built utilitarian doors at both the Carey and Mangan Labs have allowed for the movement of large machinery, cranes, and testing equipment to adjacent facilities. Another unique feature is the Carey UHV Lab's built-in faraday cage, which was designed to be incorporated into the floors and ceilings and provides a safer environment for staff working with high voltage.

Associated Test Lines

The Ross Complex has one associated test line; a short test span that is housed within the UHV Outdoor Test Yard. The short test span in the yard measures 46 meters long and passes through a portal test tower, interacting with a nearby impulse generator and voltage divider. Historically, the Outdoor Test Yard provided a unique opportunity to test higher voltages due to the greater clearance capabilities of an exterior yard. The 36-by-36-meter portal test tower was equipped with adjustable ground plane panels and a water spray rack (Figure 20).[126] The testing line was smaller in comparison to other testing facilities and included a shorter test span. Testing performed on the line included impulse tests, switching tests, and lightning tests on line insulators and air gaps.[127] As a result of these tests, BPA made significant improvement of transmission line designs, including reducing the number of insulators used per line, resulting in cost savings.

Figure 20. Portal Test Tower and Test Span with Carey UHV Lab visible in the background.[128]

[126] U.S. Department of Energy, *Bonneville Power Administration's Test Facilities.*

[127] Ibid.

[128] AECOM, *Updated J. D. Ross Complex Determination of Eligibility*.

2.4.2 High Voltage Direct Current Test Center at the Big Eddy Substation

The HVDC Test Center was located at the Big Eddy Substation complex in The Dalles, Oregon (Figure 21 and Figure 22). The Test Center was built in 1963 for collecting data to aid in the design and construction of the Pacific Intertie.[129] As discussed in Section 2.3.2, the Intertie was the first HVDC transmission line in the United States. To prepare for construction of the Intertie, the Department of the Interior authorized the creation of a task force, whose role was to explore and experiment with HVDC. In 1962, Congress authorized BPA to create a HVDC Development Program and test center, with the goal to find and prevent potential issues that may occur with DC electricity distribution. As summarized in a 1963 BPA publication on the HVDC Test Project, "this test program will provide much needed basic information on corona and radio interference phenomena."[130] The program planned to establish groups to conduct research on six areas of interest: DC Flashover, DC Ground Current, Inductive Coordination, Insulator Leakage, Safe Working Procedures, and Radio Noise and Instrumentation.[131] These investigations were subsequently carried out at the HVDC Test Center between 1963 and 1968, and the mission of the program was completed.[132] The HVDC Test Center was energized on November 5, 1963, with construction costs totaling $2 million.[133] The HVDC test installation was specifically designed for the study of insulation coordination, insulator design, and radio interference.[134]

Figure 21. View of HVDC Test Center, including Insulator Leakage Line and Power Supply Building, 1964.[135]

[129] Blaser, *Historic American Engineering Record: Bonneville Power Administration Big Eddy Substation HVDC Test Center.*

[130] BPA. *Extra High Voltage Direct Current Test Project,* Big Eddy Substation, The Dalles, Oregon, 1963.

[131] Blaser, *Historic American Engineering Record: Bonneville Power Administration Big Eddy Substation HVDC Test Center.*

[132] Ibid

[133] Ibid.

[134] BPA, *Extra High Voltage Direct Current Test Project.*

[135] BPA Library, sourced 2025.

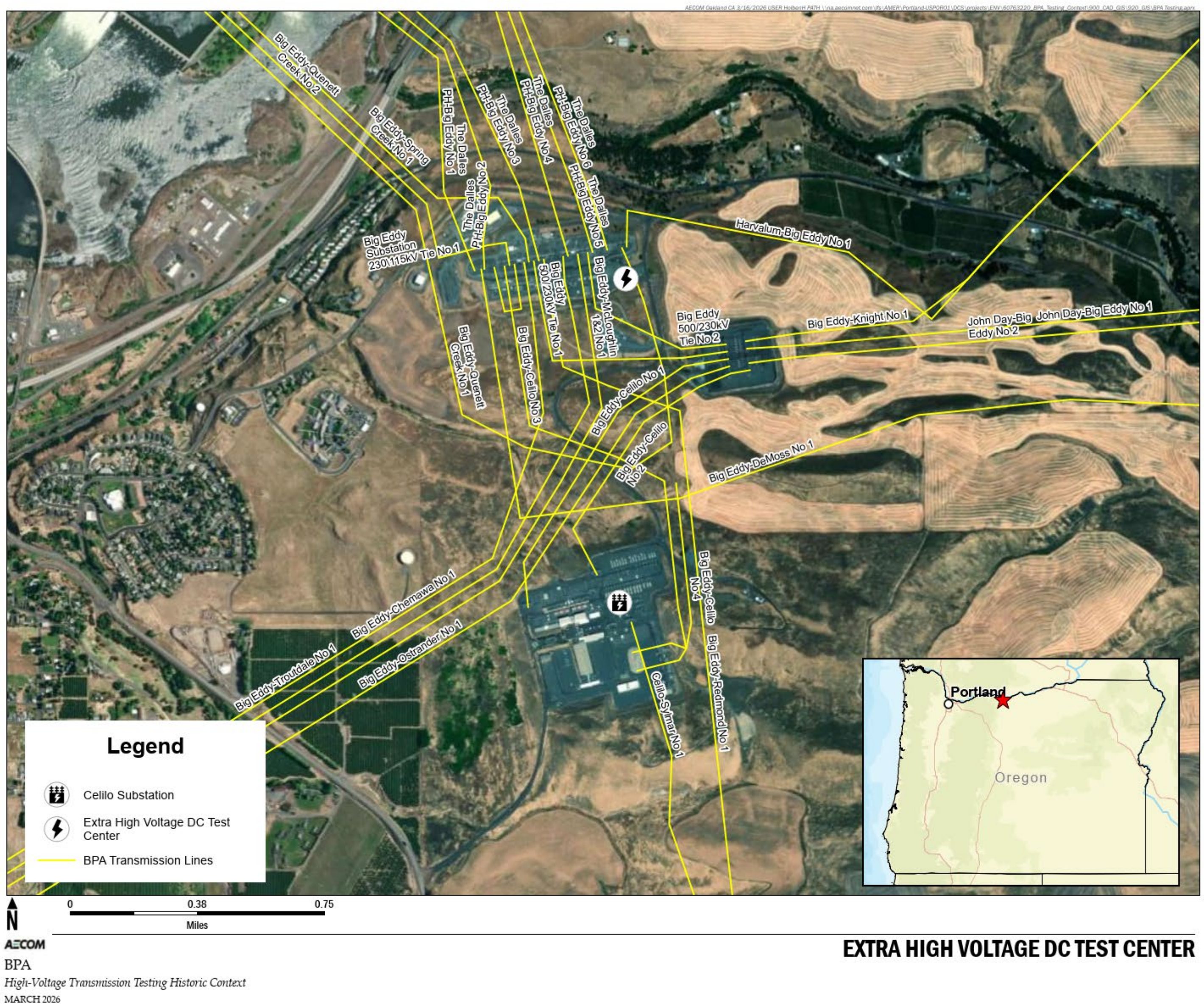

Figure 22. Map of the EHV DC Test Center, Celilo Substation, and associated transmission lines.

The HVDC Test Center conducted tests for the development of the Intertie from 1963 to 1968 and was the first facility of its kind in the United States to study conversion between AC and DC.[136] In 1965, BPA proposed to move the high voltage testing equipment to the Charles E. Carey Test Center at the Ross Complex.[137] This move was proposed due to the 5-mile test line being absorbed into the John Day-Keeler transmission line.[138] Seeing a growing need to test AC techniques, BPA planned to continue testing at the Ross Complex to optimize AC designs and operations, including proving the capability and performance of switchgear, transformers, and insulation.[139]

However, after the energization of the Intertie in 1970, the HVDC Test Center continued to be used for high voltage testing. Having served its original function, the center was revived to explore better ways to carry more power longer distances.[140] BPA partnered with the Electric Power Research Institute, a national organization of utilities, to research and develop even higher voltage transmissions.[141] To further explore these new research initiatives, the test center was upgraded to provide design criteria for lines rated up to 600 kV.[142] A cooperative test program known as The Dalles Project was funded from 1971 to 1975. The program, funded by the Edison Electric Institute, the American Public Power Association, and BPA, studied electrical characteristics of insulators, conductors, and hardware for HVDC systems up to 600 kV.[143] As described in the 2016 HAER documentation of the HVDC Test Center, The Dalles Project had several objectives:

- Study performance and insulation requirements of line and station insulators under various environmental conditions.
- Study radio interference, television interference, audible noise, and corona loss characteristics of typical overhead transmission lines in the ±400 kV to ±600 kV range.
- Determine clearance requirements for DC lines up to ±600 kV.
- Evaluate DC hotline maintenance.
- Investigate ionization phenomena such as ion migration, charge accumulation, and generation of oxidants, and investigate other phenomena or effects that may create nuisance, discomfort, or hazard.
- Attempt to correlate DC laboratory data with operating line data and with 60 Hz and impulse data obtained in BPA's Ross Testing Complex at Vancouver, Washington, and in other projects and laboratories.

A unique feature of the HVDC Test Center was the amount of marketing material that was produced for the facility. Numerous promotional pamphlets were produced throughout the 1960s and 1970s that described the goals of the facility and explained the concept of high voltage to the general public. The brochures include detailed, highly visual drawings and photographs of the facilities (Figure 23). The benefits of high voltage, including energy saving costs and planning for future consumption, were also discussed in the pamphlets.

[136] BPA, "High Voltage Exhibit Comes Home," 2022, https://www.bpa.gov/about/newsroom/news-articles/2022/20220629-high voltage-exhibit-comes-home.

[137] BPA, *Bonneville Power Administration Justification for Appropriations*, 1965.

[138] Blaser, *Historic American Engineering Record: Bonneville Power Administration Big Eddy Substation HVDC Test Center.*

[139] BPA, *Bonneville Power Administration Justification for Appropriations*.

[140] BPA. *Extra High Voltage Direct Current Test Center,* The Dalles, Oregon, 1974.

[141] Ibid.

[142] Ibid.

[143] U.S. Department of Energy. *Bonneville Power Administration's Test Facilities*.

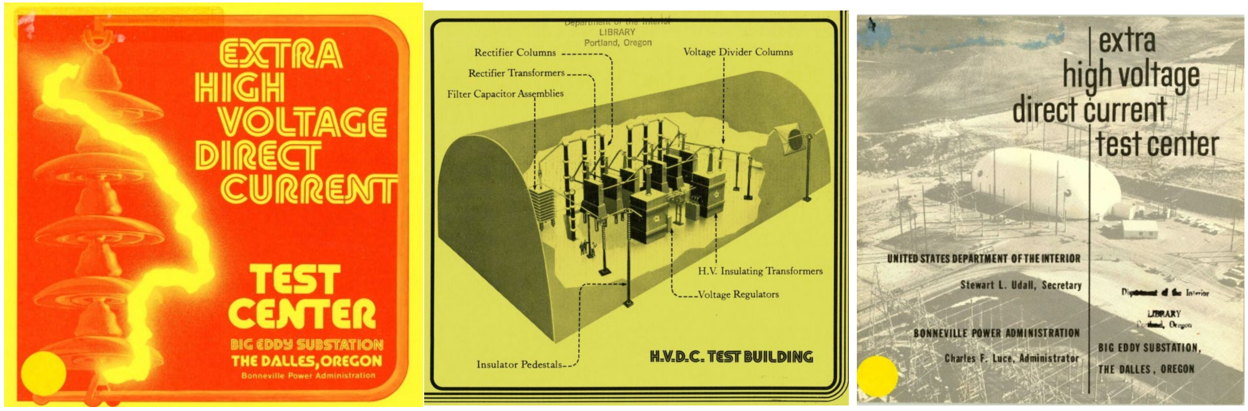

Figure 23. Examples of the pamphlets and drawings produced, 1963–1974.[144]

By the late 1970s, numerous publications referred to the site as the "EHV DC Test Center at The Dalles." The test center was powered by two three-phase solid state bridge rectifiers. BPA used the site until 1996 then stopped due to the presence of hazardous and outdated materials. The HVDC Test Center was demolished in 2017 to make way for future development around the Big Eddy Substation.[145] The HVDC Test Center comprised three buildings, two test lines, and a test tower (Figure 24). The three buildings included the Power Supply Building, the Control House, and the Fog Chamber.

Figure 24. Photograph of the original air bubble and greater facilities at the HVDC Test Center, 1963.[146]

[144] BPA, *Extra High Voltage Direct Current Test Center,* 1974.

[145] Blaser, *Historic American Engineering Record: Bonneville Power Administration Big Eddy Substation HVDC Test Center.* The HVDC Test Center was determined eligible for the NRHP in 2013 under Criteria A and C. The facility received HAER documentation in 2016.

[146] Ibid.

HVDC Test Center Buildings

Power Supply Building

The Power Supply Building was built in 1963 and housed the conversion equipment that converted AC into DC for test usage. The building was the “heart of the complex” and contained the HVDC power supply that transported electricity to several other test components throughout the facility.[147] The building was initially constructed with an external inflated nylon air bubble that encased the electrical power supply. The bubble tore on May 20, 1964, and was later replaced by a timber arch structure with a similar oval shape. The power supply housed within the building produced DC output ratings of 500 kV to 825 kV. Other materials within the building included insulating transformers, voltage regulators, rectifier columns, and voltage dividers. In 1965, an interior fog test chamber was added and was used to test insulators (Figure 25). A High Voltage Test Line, Insulator Leakage Line, and Flashover Test Tower were connected to the Power Supply Building. The test lines are discussed in detail in the Associated Test Lines section below. The Flashover Test Tower was used to test the capabilities of insulation to withstand surges in various environments and to facilitate flashover testing for line-to-tower air gaps.[148] The tower utilized a maximum test voltage of 825 kV and was ultimately removed in 1996 after the closure of the facility.

Figure 25. Interior fog test chamber within the Power Supply Building, ca. 1965.[149]

[147] Blaser, *Historic American Engineering Record: Bonneville Power Administration Big Eddy Substation HVDC Test Center.*

[148] U.S. Department of Energy. *Bonneville Power Administration's Test Facilities*.

[149] Blaser, *Historic American Engineering Record: Bonneville Power Administration Big Eddy Substation HVDC Test Center.*

Control House

The Control House was built in 1963 and was the epicenter at which testing equipment was monitored and controlled (Figure 26). The building housed a control panel and was located west of the Power Supply Building. The building provided office space for researchers and workers, and, prior to its demolition in 2017, contained numerous testing reports, data, and blueprints.

Fog Chamber

The Fog Chamber was built in 1972 and was the last addition to the HVDC Test Center. The 60-foot-tall Fog Chamber was located on the southwest corner of the Power Supply Building. The construction of the Fog Chamber was necessary due to the lack of data regarding the impact of environmental factors on high voltage line insulation and airgap clearances.[150] The interior of the chamber contained nozzles and racks that simulated fog and rain (Figure 27). Four hoists were present in the chamber and supported suspension assemblies. A control room on the west elevation of the chamber contained a control panel and fog-proof windows for viewing tests. Metal tubs placed on the floor were used to generate fog to test insulator performance in wet conditions. Like the Fog Test Chamber at Ross, the water utilized in the Fog Chamber could be controlled to meet specific testing needs, and the resistivity of the water could be altered using demineralizing and mixing systems present on site.[151] These tests provided valuable data that BPA used to fine-tune the components of its high voltage transmission lines, such as selecting and developing various shapes and sizes of insulators based on whether they were to be used in areas of high incidence of rain or fog, in dry desert climates, or in areas of high industrial contamination.[152]

Figure 26. The Control House (right foreground), as documented in the 2016 HAER. The Fog Chamber (right background) is also visible.[153]

[150] BPA, *Extra High Voltage Direct Current Test Center,* 1974.
[151] U.S. Department of Energy, *Bonneville Power Administration's Test Facilities*.
[152] BPA, *Extra High Voltage Direct Current Test Center,* 1974.
[153] U.S. Department of Energy, *Bonneville Power Administration's Test Facilities*.

Figure 27. Interior of the Fog Chamber showing the metal tubs and hoists, ca. 1970s.[154]

Tests Performed

Tests performed at the HVDC Test Center changed over time due to evolving research needs (Table 7). At the inception of the center, testing was primarily to aid in the development of the Intertie (1963–1968). A second wave of testing occurred in the early 1970s with the funding of The Dalles Project (1971–1975). Testing primarily focused on the study of insulators, radio and TV interference, corona, and environmental impacts to equipment (specifically insulators). Testing continued at the HVDC Test Center until its closure in 1996, although details on tests performed during this time period were not readily available in historical documents.

Table 7 Tests Historically Performed at HVDC Test Center Facilities

Facility	Types of Tests Performed	Impact of Tests
Facility-wide testing goals	1963–1968 (Intertie-era): Study of insulation coordination, insulator design, and radio interference, conversion between alternating and direct current. 1971–1975+ (The Dalles Project and beyond): Study of electrical characteristics of insulators, conductors, and hardware for HVDC systems up to 600 kV.	Aided development of Intertie design; provided previously unknown knowledge regarding how HVDC operates under stress, wind, and stormy conditions.
Power Supply Building	Exposing high voltage switch gears to large magnitudes of current. Flashover tests.	Determined line voltage capabilities; determined most economical and environmentally sound operation of lines with least amount of power loss during transmission.
Fog Chamber	Test insulator performance in simulated weather conditions, including various types of fog and rain.	Informed insulator design based on geographic location and environmental factors. By using the most successful insulator for individual biomes, BPA reduced repair costs and improved material longevity and resiliency.

[154] U.S. Department of Energy, *Bonneville Power Administration's Test Facilities*.

Facility	Types of Tests Performed	Impact of Tests
High Voltage Test Line	Research TV and radio interference, corona losses, noise; space charge effects of DC transmission lines; flashover tests.	Prevented unintended consequences and impacts to people and the surrounding environment. By studying potential noise pollution and disruption of daily activities like TV and radio, BPA prevented costly or uncomfortable scenarios before they occur.
Insulator Leakage Line	Compare and test insulators under various conditions, including exposure to moisture and other environmental factors.	Similar to the tests performed in the Fog Chamber, these tests determined the ideal insulators for varying weather conditions, preventing mechanical failures and minimizing maintenance costs.
Flashover Test Tower	Test capabilities of insulation to withstand surges in various environments; facilitate flashover testing for line-to-tower air gaps.	Allowed BPA to better understand what will occur during power surges and helped prevent loss of power during future environmental conditions.

Notes: BPA = Bonneville Power Administration; DC = direct current; HVDC = high voltage direct current; kV = kilovolt

Distinguishing Features

Similar to the Mangan Lab at the Ross Complex, the HVDC Test Center contained several adaptable components that were movable to allow for flexible, customizable testing. The test equipment at the HVDC Test Center was arranged so that the power supply could feed any of the three test areas at any DC voltage.[155] Planning documents from 1963 also indicate that a portable high-current DC power supply cable was planned for the facility. The facility was also the first of its kind in the United States in regard to high voltage testing, thus its design elements were unique and groundbreaking. For example, BPA used innovative construction methods to build a nonconductive structure large enough to contain the testing equipment. The original large air-supported bubble was designed and erected to cover the power supply and control center.

Associated Test Lines

Two testing lines were present at the HVDC Test Center, a High Voltage Test Line and an Insulator Leakage Line (Figure 28 through Figure 30). The High Voltage Test Line was nearly 5 miles long and could carry a capacity of 750 kV.[156] The line originated south of the power supply and traveled in an east–northeast direction. The line consisted of six wood pole towers that delivered power to the 25 steel transmission towers used for tests. The line was utilized to research TV and radio interference, as well as corona losses, noise, and space charge effects of DC transmission lines (Figure 28).[157] In 1965, the 5-mile High Voltage Test Line was proposed to be absorbed into the John Day-Keeler transmission line.[158] The Insulator Leakage Line was 585 feet long and extended south from the power supply (Figure 29).[159] The line was used to compare and test insulators under various conditions. A drawing of the facility shows the numerous intersecting lines (Figure 30). Both lines were removed in 1996.

[155] BPA, *Extra High Voltage Direct Current Test Center,* 1963.
[156] Blaser, *Historic American Engineering Record: Bonneville Power Administration Big Eddy Substation HVDC Test Center.*
[157] U.S. Department of Energy. *Bonneville Power Administration's Test Facilities*.
[158] Blaser, *Historic American Engineering Record: Bonneville Power Administration Big Eddy Substation HVDC Test Center.*
[159] Ibid.

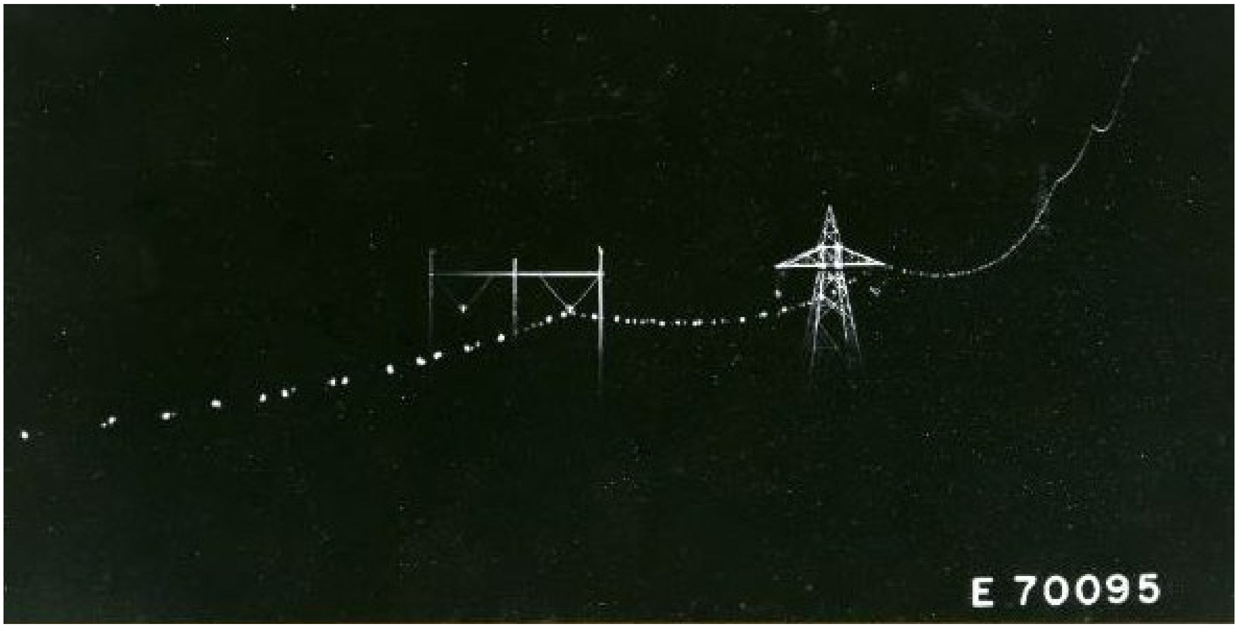

Figure 28. Dry weather corona formation on the HVDC Test Line, 1964.[160]

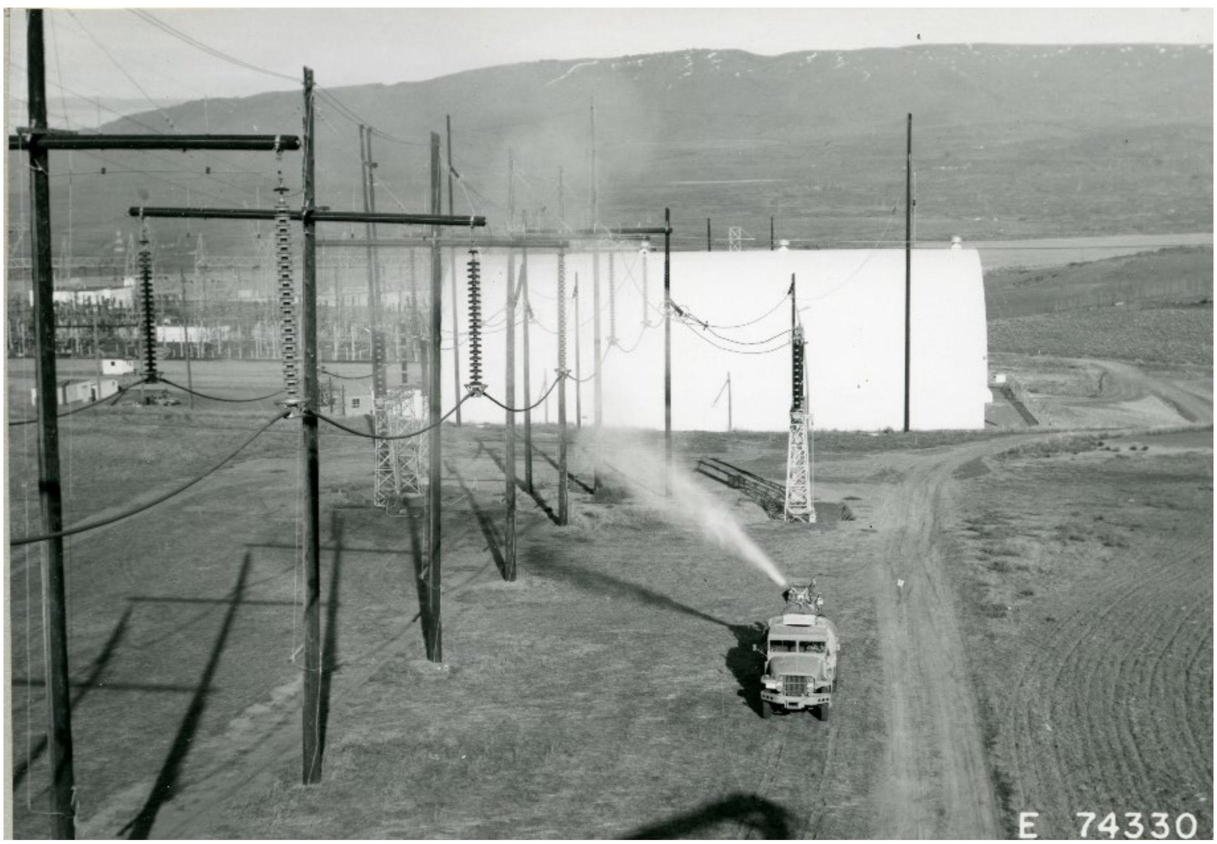

Figure 29. Contamination equipment operating on the Insulator Leakage Line, 1965.[161]

160 BPA Library, sourced 2025.
161 Ibid.

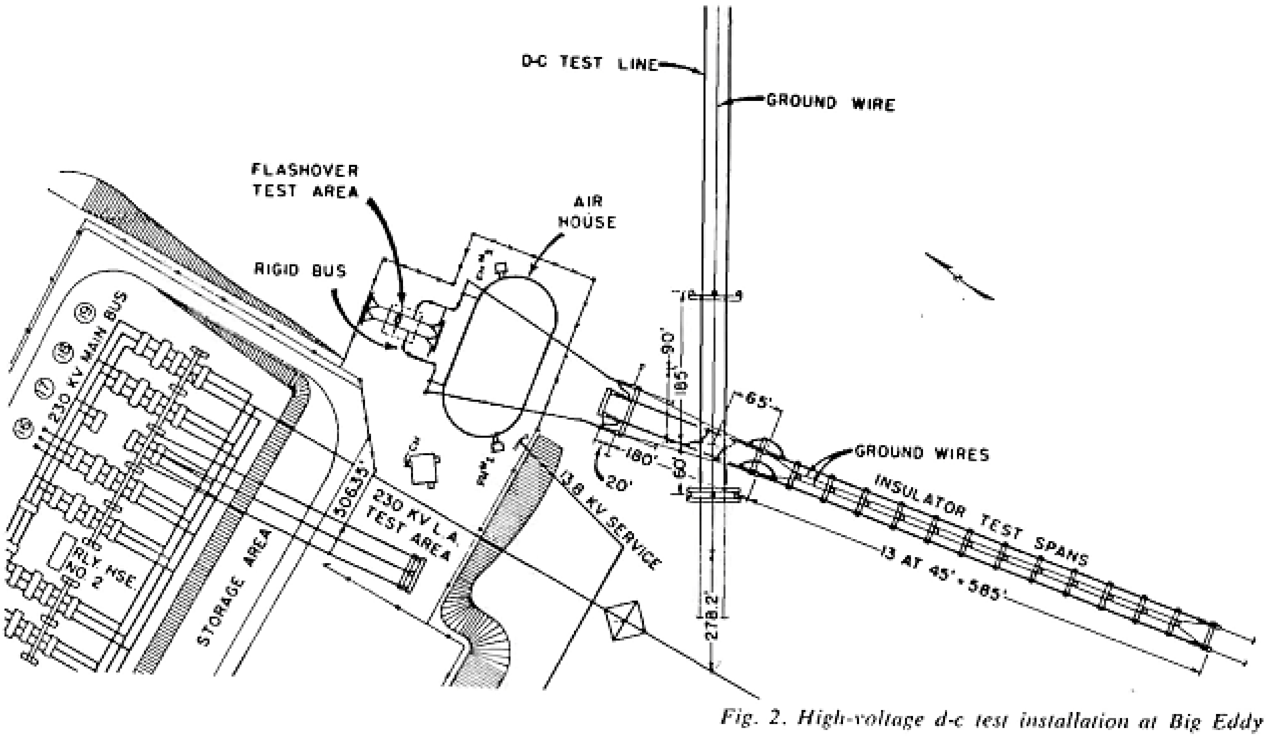

Figure 30. 1963 drawing of the HVDC Test Center at Big Eddy.[162]

2.4.3 Lyons Test Facility

The Lyons Test Facility was located in Linn County, Oregon (Figure 33). Initially developed as the "Lyons Project," the facility was given the name the "Lyons UHV Test Site" by the BPA Naming Committee on September 20, 1974.[163] The facility was built in 1976 and energized in 1977. The main goal of the test facility was to evaluate the electrical effects of 1,100 and 1,200 kV transmission and verify the electrical, mechanical, and environmental acceptability of 1,200 kV designs.[164] Specific areas of study included the impact on radio and television interference as well as ecological effects on plants and animals.[165] The electrical test site had a proposed cost of $650,000 in 1975, which is equal to almost $4.2 million in 2025. The cost breakdown included $187,000 for site development, $280,000 for instrumentation and transducers, and $183,000 for data, communications, and control acquisition. Staffing of the site was proposed to include at least two individuals permanently assigned to the site: an engineer and an instrument craftsman. Planning documents indicate that the facility would consist of a 1.8-mile electrical test line, incorporate an existing 230 kV breaker to energize the test facility, and add three single-phase 1,100/230 kV transformers near the Santiam Substation.[166]

The layout of the Lyons Test Facility, as proposed in 1975, included an instrumentation control house, parking and storage facilities, transducer locations, and general testing areas (Figure 31). The Control House included space for offices, a conference room, instrumentation storage, and the data acquisition system. The Control House was proposed as two industrial type house trailers connected by a covered walkway (Figure 32). The instrument transducers were located at the midway point of the electrical test span. The transducers read radio and TV interference,

[162] BPA, *Extra High Voltage Direct Current Test Center*, 1963.

[163] BPA, *Laboratory Report, Prototype 1100 kV Test Facilities Project – Progress Report No. 9,* Authored by Stig. A. Annestrand, January 13, 1975.

[164] Annestrand et al. *Report on the BPA Demonstration Center at Lyons UHV Test Facilities*.

[165] BPA, *1976 Annual Report*.

[166] BPA, *Supplement to the Environmental Statement, Fiscal Year 1976 Proposed Program.*

audible noise, and included additional instrumentation like antennas and microphones to capture data. Plans indicated that a weather tower would be located near the controls house, and remote recording of noise and ozone would be made at the midspan of the line. Original proposals included a plan to use guyed suspension structure; however, this idea was later dropped from the project due to the extended length of time needed to properly develop the structure.[167] Instead, three single and separate guyed mast dead-end structures were scheduled to be used. This afforded the facility more flexibility than the previous connecting bridge concept and resulted in a lighter tower.

Figure 31. Overview of the Lyons Test Facility, December 1981.[168]

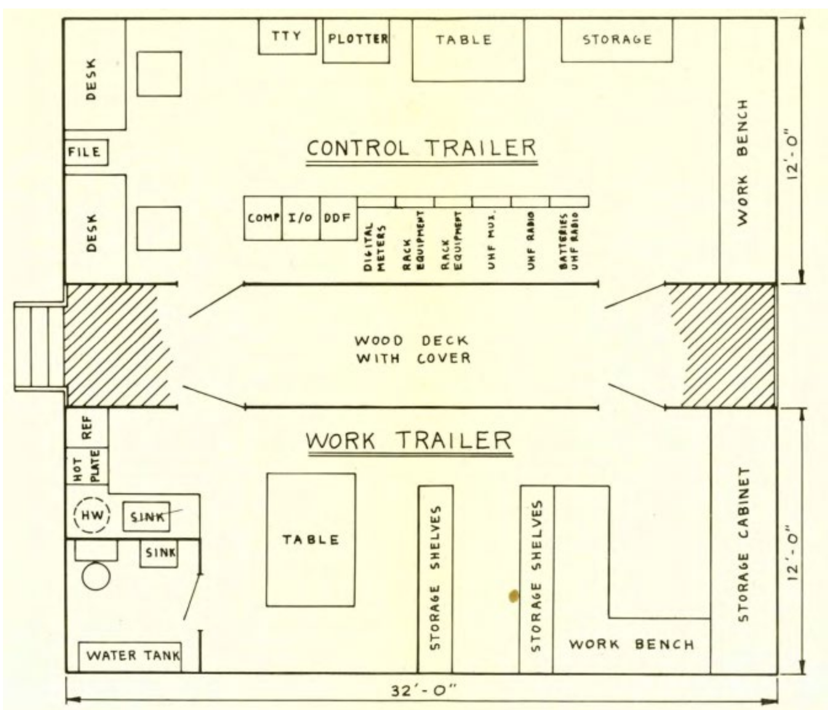

Figure 32. Layout of the Control House, ca. 1975. [169]

[167] BPA, *Santiam Electrical Test Line, Prototype 1100kV Project,* July 23, 1974.

[168] BPA Library, sourced 2025.

[169] BPA, *Lyons UHV Test Facilities.*

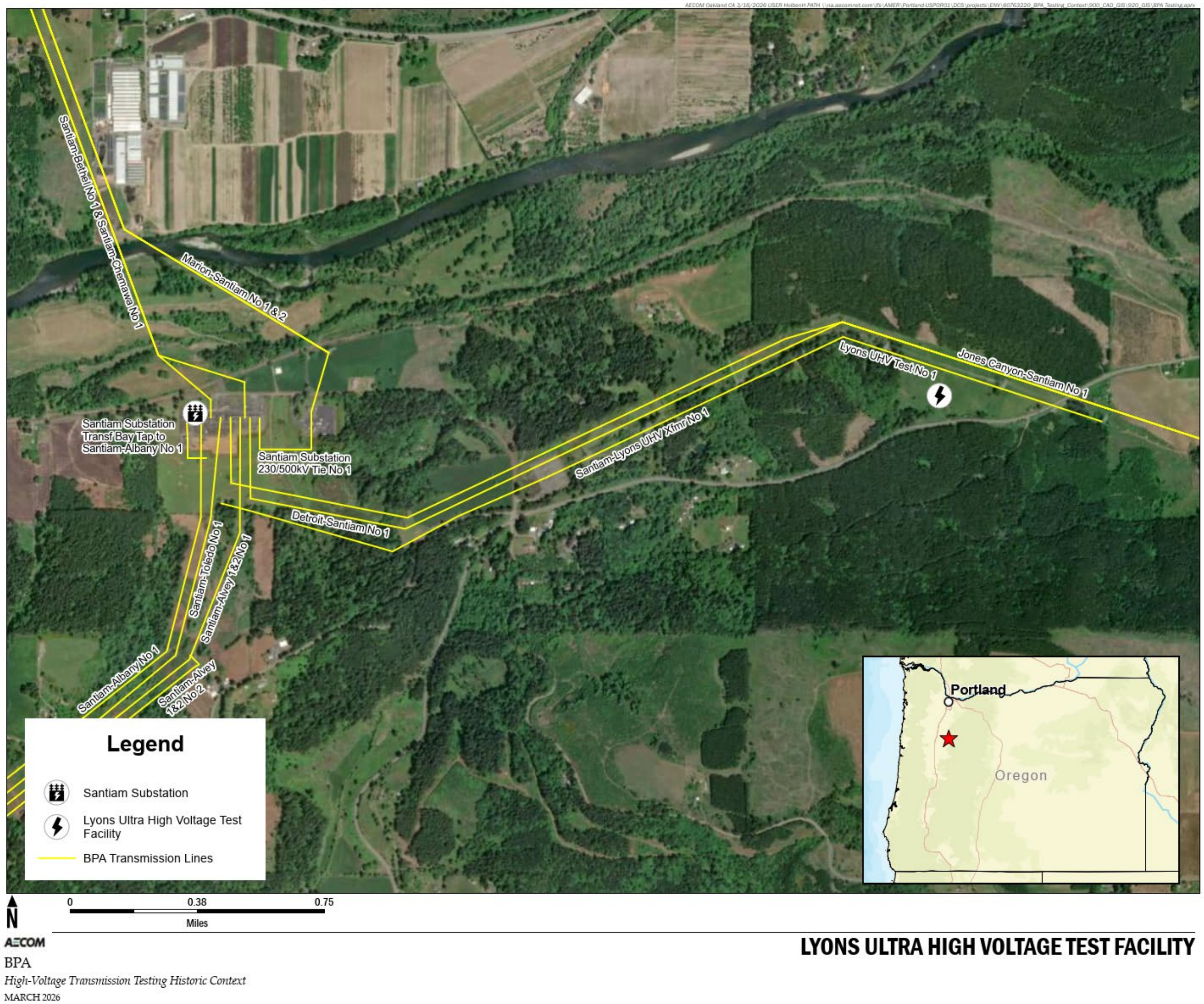

Figure 33. Map of Lyons Ultra High Voltage Test Facility.

When the facility was energized in 1977, it contained a full-scale, three-phase 1,200 kV prototype line and was the first transmission line to operate 1,200 kV using 1,200 kV towers and hardware.[170] At the site, data on electrical phenomena were recorded. In addition, radio and TV interference, as well as ambient and audible noise, were continuously monitored near the line.

One of the most important components of this test program was gathering long-term data. The test program was divided into two functions: long-term continuous data collection and short-term staged tests. The long-term data collection was completed by using mostly automated systems. Data from long-term tests were transmitted to Portland via microwave and were stored on tape at the Portland facility. Long-term data studies included analysis of large data populations to determine mean and standard deviations, trend plotting, and regression analysis. Short-term staged tests were performed on site using portable instrumentation. These short-term tests included frequency spectrum analysis of audible noise, induced voltage and current studies, and annoyance studies of radio interference, TV interference, electric fields, and audible noise. Data gathered at this facility helped to inform BPA of potential issues that might occur when transmitting high voltage and assisted in preventing discomfort and disturbances to humans, animals, and plants alike.

In 1979, a $100,000 visitor center opened at the Lyons Test Facility.[171] The overall goal of the Visitor Center was to inform, educate, and involve the public, technical persons, and personnel from BPA and other agencies.[172] The building consisted of a 12-meter-x-9-meter structure and had a capacity of 40 persons for viewing films or lectures.[173] An opening day ceremony was held on September 24, 1979 with a group of Mari-Linn Grade School students and BPA and state officials.[174] The ceremony was successful, with photos taken of children interacting with engaging exhibits and BPA staff providing tours of the facility. The Visitor Center featured interactive exhibits including “slide shows, push-button quizzes, and demonstration equipment,” as well as an outdoor exhibit allowing visitors to feel the presence of an electric field. A Van De Graaph machine was present in the center, allowing visitors to experience high voltage in a method that was safe to the touch (Figure 34). Another piece of demonstration equipment was a bicycle attached to an electric generator, which gave visitors the opportunity to discover how long it took to manually create enough energy to power a lightbulb or TV set (Figure 35).[175] Several months after its opening, BPA project engineer Lynn Gabriel stated that the Visitors Center was receiving between 60 and 90 people a month during the summer, with numbers “dropping off during the rest of the year.”[176] Most visitors to the site were from the electric power energy, although newspaper articles from the time period encouraged local school groups to tour the facility.[177]

Testing at the Lyons Test Facility in the late 1970s through early 1980s included similar themes such as testing the effects of high voltage transmission on cattle, honeybees, plants, and other wildlife.[178] In 1982, the Lyons Test Facility transitioned its testing to include a greater emphasis on substation equipment, specifically gas-insulated equipment, which would aid in the development of more cost effective and reliable equipment.[179] Historic aerial photographs reveal that the Lyons Test Facility and associated Visitors Center were demolished between 1982 and 1992. As of 2026, the only remains of the Lyons Test Facility are impressions in the earth indicating where the buildings and paved roads once stood.

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[170] U.S. Department of Energy. *Bonneville Power Administration’s Test Facilities*.

[171] *Albany Democrat-Herald*, “Come Visit Us, Urges BPA.”

[172] Annestrand et al. *Report on the BPA Demonstration Center at Lyons UHV Test Facilities*.

[173] Ibid.

[174] *Albany Democrat-Herald*, “Come Visit Us, Urges BPA.”

[175] “BPA Testing high-voltage energy-saving lines,” *The Lebanon Express*, October 4, 1979.

[176] *Albany Democrat-Herald*, “Come Visit Us, Urges BPA.”

[177] Ibid

[178] U.S. Department of Energy. *Bonneville Power Administration’s Test Facilities*.

[179]“BPA: Voltage Risk Unfounded,” *The Columbian,* October 4, 1977.

Figure 34. A child experiences the hair-raising effects of the Van De Graaph machine while learning about high voltage at the Lyons Visitor Center, 1979.[180]

Figure 35. A child tests generating power on a bicycle on opening day of the Lyons Visitor Center in 1979.[181]

Tests Performed

The testing performed at the Lyons Test Facility was designed to examine the performance of a 1,100 and 1,200 kV line. Testing components included the line's audible noise, radio and TV interference levels, electrostatic effects, effects on other utilities, and corona loss. Special tests were also planned for towers and footings, specifically to evaluate surge impedance and footing resistance. The facility was designed as a prototype line for stringing an 8-bundle Thrasher conductor configuration. This line did not test effects of phase arrangement, phase spacing, and gradient voltage, which was expected to be determined at other UHV research facilities.[182] Figure 36 depicts a proposed testing schedule.

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[180] BPA Library, sourced 2025.

[181] Ibid

[182] Annestrand and Batiste, "Bonneville Power Administration's High Voltage and Mechanical Test Facilities."

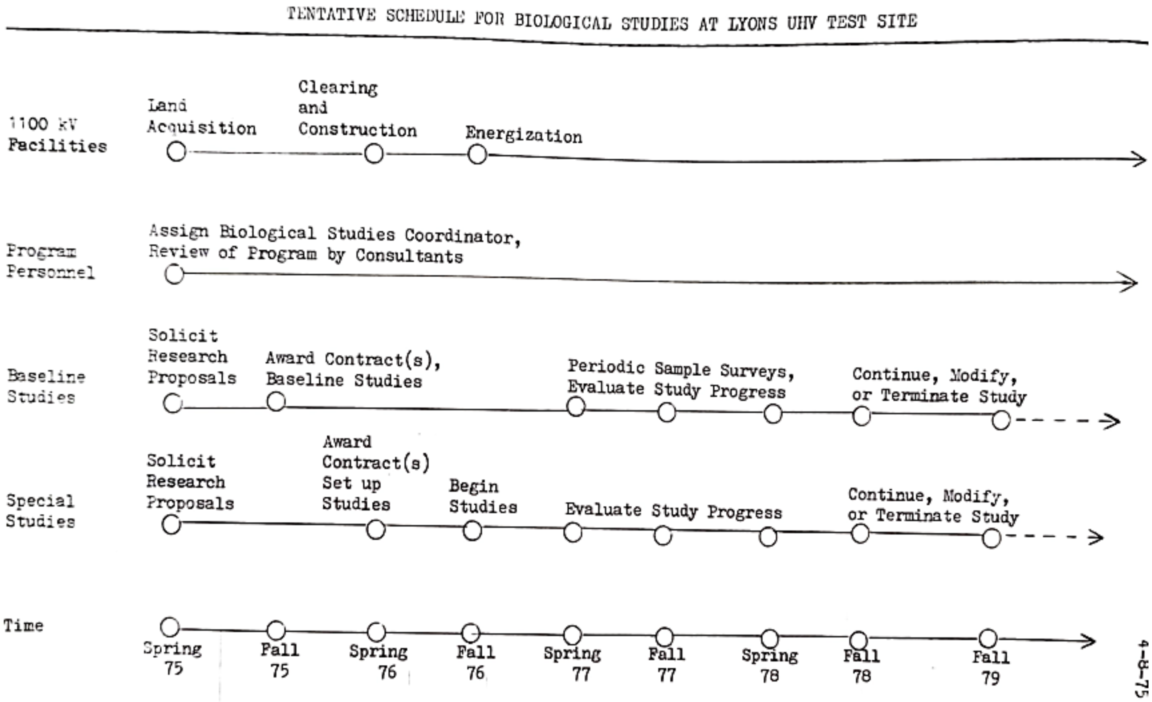

Figure 36. Schedule for Biological Studies at the Lyons Test Facility, April 1975.[183]

The facility was designed to maximize data analysis while minimizing manual data handling, with the assumption that long-term data analysis would be done on a CDC 6500 computer in Portland. The facilities on site were designed to scan and transmit data to Portland.[184] To procure appropriate instrumentation for the test facility, various government organizations and other testing facilities were contacted for recommendations. A 106-page report, authored in 1975, presented an estimate of the test facility cost, staffing requirements, as well as technical specifications and required instrumentation for the Lyons Test Facility.[185]

The facility also tested possible electrical effects of high voltage transmission on plants and animals (Figure 37). Although BPA's experience with 500 kV systems indicated that there were likely no adverse electrical-related biological impacts from high voltage, the majority of previous research did not simulate a transmission line environment during testing.[186] Studies involving plants were anticipated to explore possible effects on pollination, seed production, mortality rates, and response to environmental stress.[187] Studies on animals included determining possible effects on behavior, health and grown, and response to environmental stress.

The facility conducted a greater number of environmental tests in comparison to previous testing facilities, specifically on plants and animals. Previous studies did not simulate a transmission line environment during testing; thus, Lyons was the first facility to provide long-term data on the effect of transmission lines on the environment. Another unique feature of the site was its use and transmission of data. Long-term data analysis of testing results was performed on a computer approximately 70 miles northwest of the facility in Portland. Tests were able to be conducted at the facility during critical weather conditions by monitoring the online data from the Portland headquarters, a technological advancement in testing facilities.

[183] BPA. Branch of Substation Design, *Project Outline: Lyons UHV Test Site*, 1975.

[184] BPA, *Lyons UHV Test Facilities*.

[185] Ibid.

[186] Ibid.

[187] Ibid.

Figure 37. Bee hives observed at the Lyons Test Facility in July 1977.[188]

Distinguishing Features

Distinguishing features of the Lyons Test Facility include its adaptable space, simplistic design, use of microwave technology to transmit data, and testing line. The facility had a utilitarian, simplistic design in comparison to previous testing facilities. Comprised of a testing line, storage, and a Control House made of modular trailers, the design facilitated testing purposes and was minimal in comparison to the Ross Complex and HVDC Test Center (Figure 38). The facility's open, expansive areas under the test lines provided adaptability for the varying environmental tests conducted. The facility also transmitted data via microwave technology to BPA headquarters, a technological advancement not seen in previous facilities. The test line at the Lyons Test Facility was also distinctive, equipped with transducers and other equipment to perform various measurements and tests.

The most distinct feature of the Lyons Test Facility was the 1979 Visitor Center. Although some components of the Ross Complex were initially designed for public visitors, the Lyons Test Facility was the only testing facility in BPA's network to have a dedicated Visitor Center with passive and interactive displays.[189] The center focused on educating the public on the usage of high voltage in their day-to-day lives and featured interactive exhibits and opportunities to view high voltage testing. Similar to the pamphlets produced for the HVDC Test Center discussed in Section 2.4.2, this invitational approach to public involvement in high voltage testing is distinguishing and noteworthy. The Lyons Test Facility captures a unique level of public involvement that is not present at other test facilities.

[188] BPA Library, sourced 2025.

[189] The public was encouraged to visit the Ross Substation and other substations, with landscaping made "an integral part of the design of the substations to achieve natural, dignified, and pleasing structures." At the Ross Complex, the control house fronted a central courtyard. At the center of the courtyard, the Cooling Pond (1939) served the dual purpose of providing both an interesting focal point for visitors and a cooling pond for up to four condensers. The public's access and connection to the complex was lost over time due to increased security concerns (excerpt taken from AECOM's 2023 *Updated J.D. Ross Complex District Determination of Eligibility*).

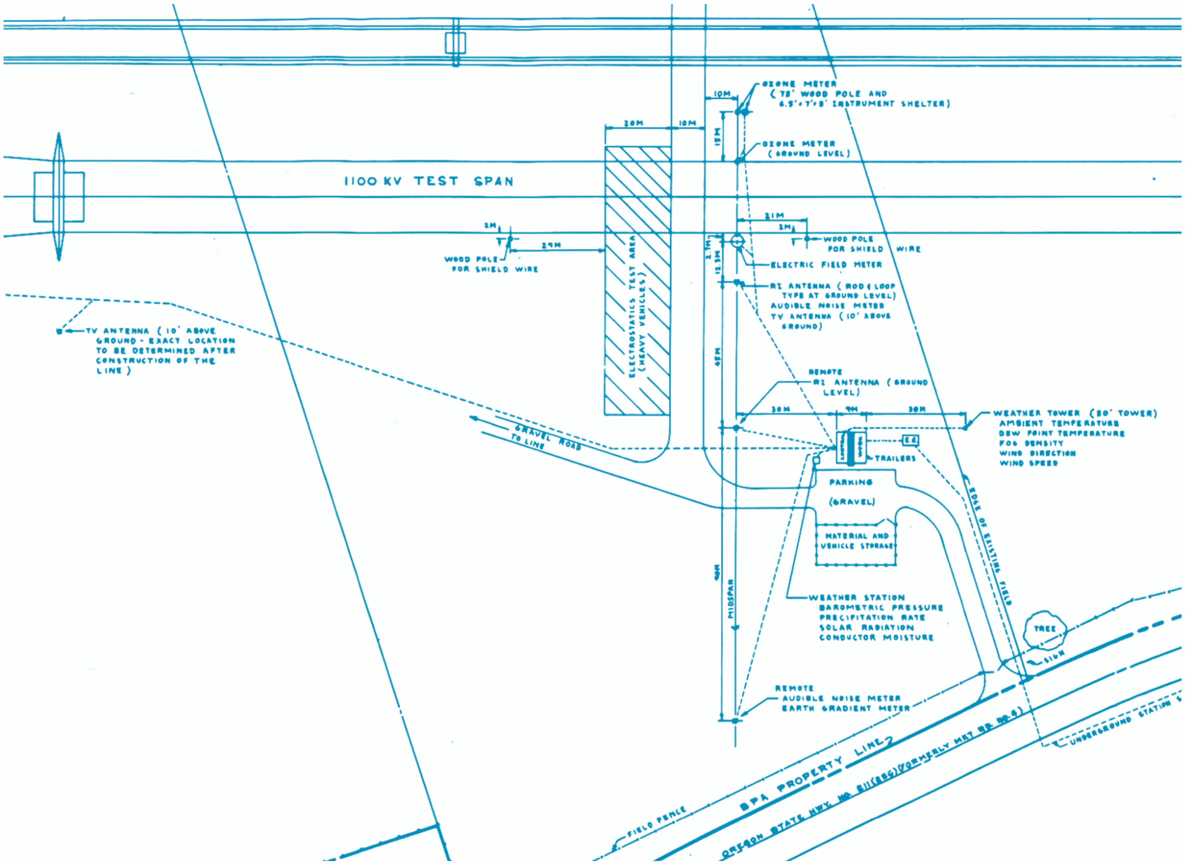

Figure 38. Layout of the Lyons Test Facility, ca. 1979.[190]

Associated Testing Lines

The Lyons Test Facility contained a full-scale, three-phase 1,200 kV prototype line.[191] The 1.3-mile line was installed to prepare for testing the high capacity (10 million kilowatts per circuit) needed to transmit power in the late 1980s and beyond. [192] Towers averaged 200 feet tall and were strung with two overhead ground wires and eight conductor lines for each of three phases of 1,100 kV AC. The line traveled east to west and was north of the Control House. The areas beneath the lines were used to test environmental impacts on plants and animals. The line was the first transmission line to operate 1,200 kV using 1,200 kV towers and hardware.[193]

2.4.4 Moro Mechanical Test Facility

The Moro Mechanical Test Facility was located in Sherman County, Oregon, and was built to evaluate the effects of high winds and severe icing on towers, conductors, conductor bundles, spacers, dampers and other hardware (Figure 39).[194] Constructed in 1976, the facility used a 1,200 kV, 1.8-kilometer-long transmission line for testing.[195] Also on site at the facility was a storage shed, as well as a prefabricated building that housed an office space and the data acquisition system (Figure 40). After a review of historic aerial photographs, it appears that the Moro Mechanical Test Facility may have been demolished between 1987 and 1994. The current condition of the facility is unknown.

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[190] BPA, *Lyons UHV Test Facilities. Electrical Test Program.*

[191] Annestrand and Batiste, "Bonneville Power Administration's High Voltage and Mechanical Test Facilities."

[192] BPA, *1976 Annual Report*.

[193] U.S. Department of Energy, *Bonneville Power Administration's Test Facilities*.

[194] BPA, *Supplement to the Environmental Statement, Fiscal Year 1976 Proposed Program.*

[195] U.S. Department of Energy, *Bonneville Power Administration's Test Facilities;* BPA, *Supplement to the Environmental Statement, Fiscal Year 1976 Proposed Program.*

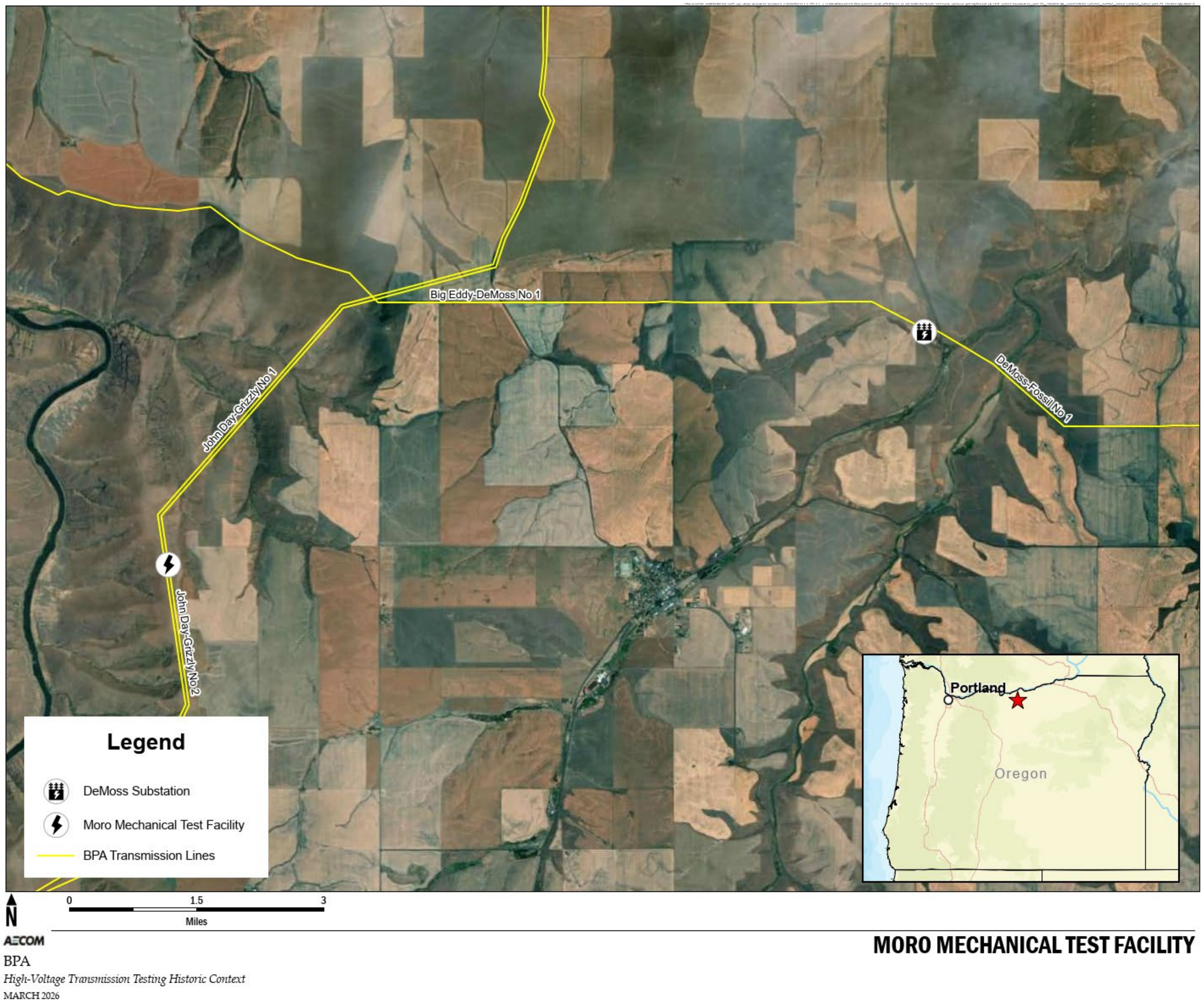

Figure 39. Map of the Moro Mechanical Test Facility, DeMoss Substation, and associated transmission lines.

Figure 40. Moro Mechanical Test Facility in November 1978.[196]

The transmission line was parallel to the John Day-Grizzly 500 kV lines, and its location was specifically chosen due to hardware failures attributed to conductor motion occurring there in the past.[197] The transmission line consisted of two dead-end and four suspension towers that were specially modified to accommodate the testing program.[198] The towers were self-supporting and designed to allow simultaneous mechanical testing and the handling of special hardware.[199] Towers also included extra structural components not generally found on normal suspension towers, including a small elevator, platforms, and special hardware (Figure 41). Staffing was proposed to include two senior technicians—both a mechanical and an electrical technician—due to the complexity of the work.[200]

The major objectives of the Moro Mechanical Test Facility were to better understand structural and mechanical aspects of UHV transmission design and to advance transmission design at all voltage levels.[201] The 1.1-million-volt test facility performed comprehensive mechanical tests for "worst case" environmental conditions like wind-induced oscillations, ice impacts, vibrations on hardware, and load capacity.[202] Data collected at this facility included movie and video tapes of tests, as well as data on wind velocity, snow and rain rate, and structural responses to instrumentation.[203] Test results were acquired using minicomputers and were sent via microwaves to BPA's headquarters in Portland, where the majority of data analysis was completed using a large computer.

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[196] BPA Library, sourced 2025.

[197] BPA, *Moro Test Program Primary Objectives* document, ca. 1980.

[198] BPA, *Structural – Mechanical Test Program, Moro UHV Mechanical Test Line*, July 1975.

[199] Annestrand and Batiste, "Bonneville Power Administration's High Voltage and Mechanical Test Facilities."

[200] BPA, *Structural – Mechanical Test Program.*

[201] Ibid.

[202] BPA, *1975 Annual Report*; BPA, *1976 Annual Report*.

[203] BPA, *Supplement to the Environmental Statement, Fiscal Year 1976 Proposed Program.*

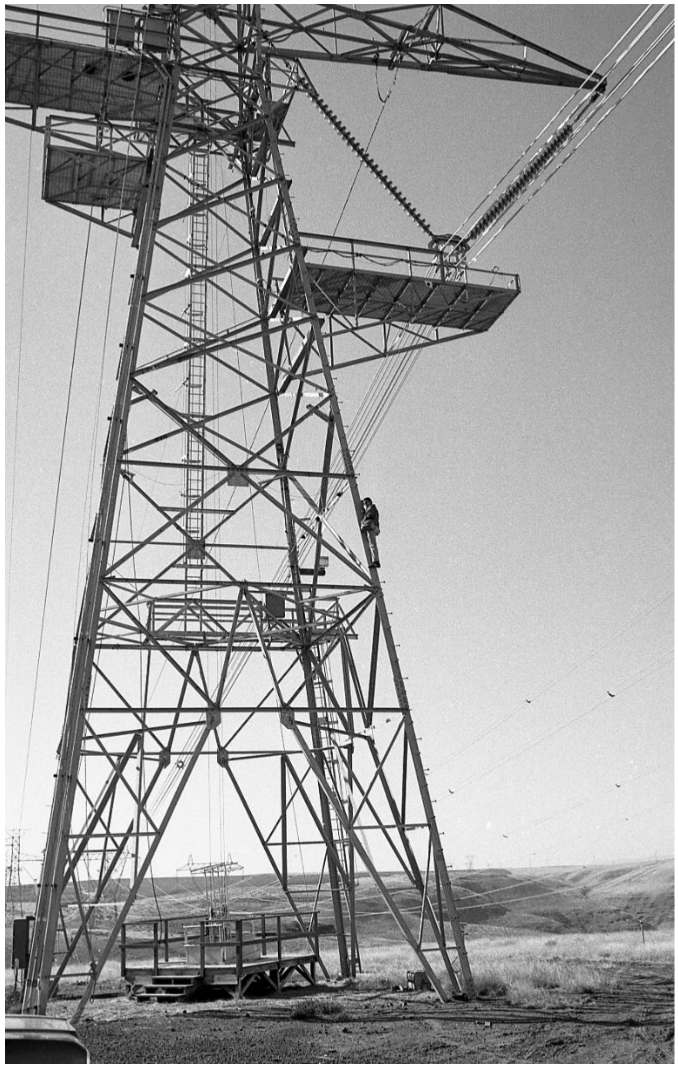

Figure 41. Photograph from ca. 1980 showing the unique platform feature (top right) present on testing towers at the Moro Mechanical Test Facility, which allowed workers to have easier access to equipment.[204]

Tests Performed

The test program at the Moro Mechanical Test Facility had four main research goals: to optimize mechanical design of UHV transmission lines, to develop and verify analytical procedures, to refine design loads and criteria, and to develop construction and maintenance techniques for UHV lines.[205] Testing consisted of monitoring and analyzing performance of conductor bundles, insulator hardware, and tower structures when exposed to both artificially induced and naturally occurring weather.[206] An example of the proposed test schedule for the facility is provided in Figure 42. The results of the tests conducted at this facility informed future line design and improved overall functionality of the lines and their hardware. These improvements overall reduced mechanical failure and improved functionality of the lines and hardware during severe weather.

[204] BPA Library, sourced 2025.

[205] Annestrand and Batiste, “Bonneville Power Administration’s High Voltage and Mechanical Test Facilities.”

[206] Ibid.

2.3 TEST SCHEDULE

Test No.	Test Conditions	Objective	Estimated Time
1	Transient Testing - Tower 4 without conductors and ground wires strung	Determine resonant frequencies, mode shapes and structural damping of the tower	1 Month
2	Initiate Test Program	Instrumentation installation, adjustment and calibration	2 Months
3	Transient Testing - Transmission Line System. Rigid spacers, uniform spacing, vary bundle tilt. Natural and staged bundle excitation. Vary tower stiffness and damping.	Establish mode shapes, frequencies, displacements, wind energy input, etc. as input for the mathematical model. Both 2 and 8 Chukar bundles. Determine whether bundle tilt is a critical parameter in 8 conductor bundles. Analyze effect of tower stiffness and damping.	6 Months
3A	Monitor single Chukar, 2-OHGW's and multi-bundle conductor.	Evaluate aeolian vibration characteristics.	Simultaneous with Test #3.
4	Transient Testing - Transmission Line System. Rigid spacers, vary spacer spacing and bundle tilt. Natural and staged bundle excitation. Vary tower stiffness and damping if found to be a factor in Test 3.	Verify criteria for positioning of rigid spacers. Determine optimum spacing. Evaluate effect of damping, tower stiffness and bundle tilt. Both 2 and 8 Chukar bundle.	12 Months
4A	Monitor single Chukar and 2 - OHGW's.	Evaluate effects of dampers; spacing and type on aeolian vibrations.	Simultaneous with Test #4.
5	Tests required as a result of preceeding tests and subsequent analysis.	Complete initial phase of test program	3 Months

Figure 42. A portion of the proposed test schedule for the Moro Mechanical Test Facility, 1975.[207]

Distinguishing Features

Distinguishing features of the Moro Mechanical Test Facility include the use of technology at the facility. Included as part of the instrumentation present at the Moro facility was a data link between Moro and Portland using an ultra-high frequency channel and the BPA microwave system (Figure 43).[208] Benefits of these telemetering facilities in Moro included the ability to continuously monitor weather conditions from Portland so that critical testing conditions were not missed.[209] The system was also able to perform remote activation of testing procedures or modify existing procedures, like activating cameras or altering data scan rates.[210] The site also contained an office space in which staff could perform and monitor tests. Another distinguishing feature of the facility was the use of video (Figure 44). Research did not reveal that any other testing facility prior to Moro was planned with video documentation in mind. Video tapes of testing provided insight into severe wind and weather conditions that occurred on site, and the facility was built with this videographic documentation in mind.[211, 212] The site's testing line is another distinguishing feature of the facility. The line was able to perform simultaneous testing and was supported by purpose-built towers with distinct testing platforms. A final distinguishing feature of the Moro Mechanical Test Facility is the reasoning behind its location. The site was specifically chosen due to past mechanical failures in the area.[213] Weather in Moro delivers

[207] BPA, *Supplement to the Environmental Statement, Fiscal Year 1976 Proposed Program.*

[208] BPA. *Moro UHV Test Facility to Portland Data Transmission,* November 25, 1974.

[209] Ibid.

[210] Ibid.

[211] BPA, *Structural – Mechanical Test Program.*

[212] Videos of storms occurring at the facility in 1979 are available online from the BPA library: https://river.bpa.gov/galleries/ba53a777-f692-43ee-bf96-9fee01129591_7c78b296-9503-41a8-9f71-eb848445998f-ExternalUser

[213] BPA, *Moro Test Program Primary Objectives*

heavy ice loading each year and strong winds, and the site was specifically researched to locate the ideal spot for the test line to experience maximum wind exposure.

Figure 43. Staff monitoring the Moro Mechanical Test Facility using a minicomputer in November 1978.[214]

Figure 44. Videographer capturing a test occurring at Moro Mechanical Test Facility on November 29, 1978.[215]

[214] BPA Library, sourced 2025.

[215] BPA-provided scanned slides, slide I0976-12.

Associated Testing Lines

The Moro Mechanical Test Facility used a 1.8-kilometer-long, 1,200 kV test line (Figure 45).[216] The self-supporting towers for the line were designed to allow simultaneous mechanical testing.[217] The configuration of the test line provided two long spans over canyons and three shorter spans over flat terrain.[218] The test line contained specially designed towers that utilized a small elevator, platforms, and other unique hardware. The towers facilitated the handling of special hardware and closer inspection of instrumentation.[219] The facility was adjacent to the John Day-Grizzly No. 2 line and contained the East Conductor Moro Test Line and the Moro 1,100 kV Test Line.

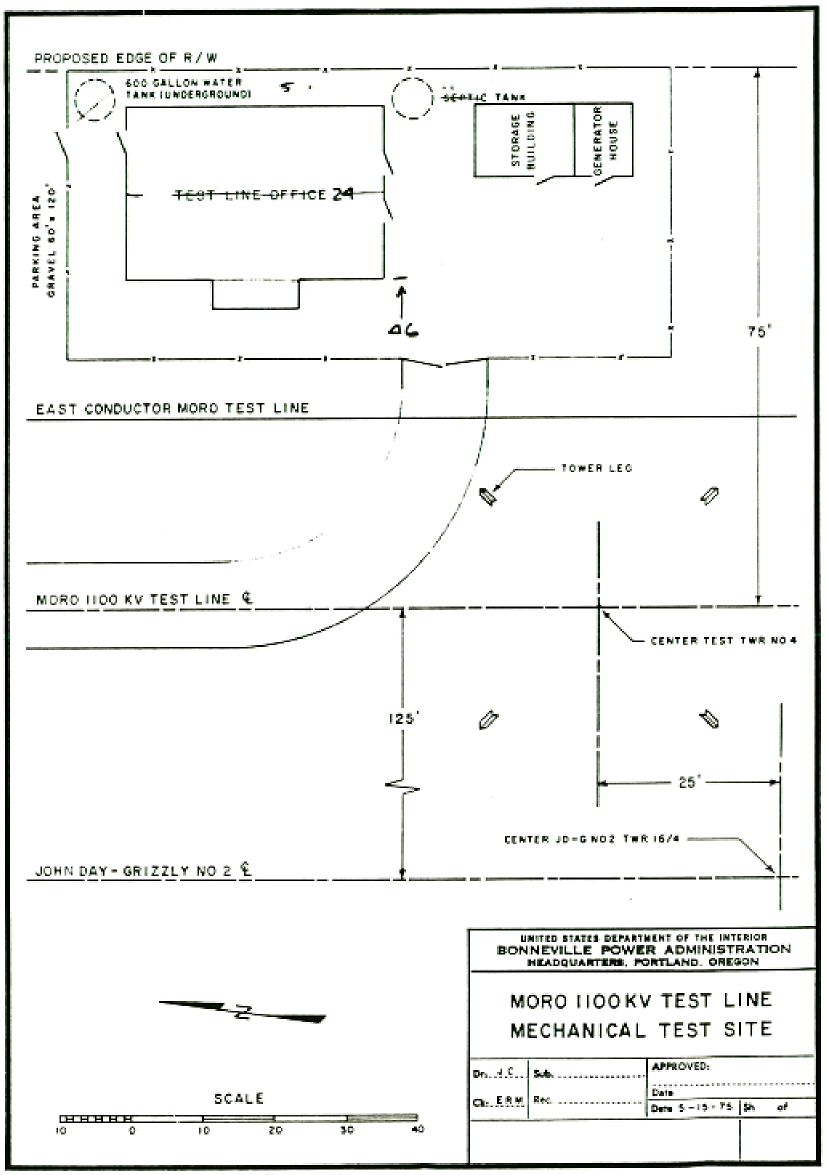

Figure 45. Moro Mechanical Test Facility Site Plan, 1975.[220]

[216] U.S. Department of Energy, *Bonneville Power Administration's Test Facilities.*

[217] Annestrand and Batiste, "Bonneville Power Administration's High Voltage and Mechanical Test Facilities."

[218] BPA, *Moro Test Program Primary Objectives.*

[219] BPA, *Structural – Mechanical Test Program.*

[220] BPA, *Supplement to the Environmental Statement, Fiscal Year 1976 Proposed Program.*

2.4.5 Grizzly Mountain HVDC Research Facility

The Grizzly Mountain HVDC Research Facility was located southeast of Madras, Oregon, next to the DC Intertie and near the BPA Grizzly Substation on the Crooked River National Grassland (Figure 48).[221] The Grizzly Mountain HVDC Research Facility differs from other testing facilities in that no permanent buildings were constructed on site. The site occupied an area of 320 acres and consisted of 2 miles of access roads and a 1-mile road leading to feed pens.[222] A 1986 scholarly publication on the facility details that four cattle pens totaling approximately 240 acres were erected underneath the extant DC transmission line, containing the animals and allowing for movement between different locations beneath the test lines. The article mentions "electrical test stations," but these stations are described as instruments used to measure noise, count ions, and measure electric fields.[223] The Grizzly Mountain HVDC Research Center studied the effects of existing 500 kV DC transmission lines on cattle and crops and was the largest experimental agricultural study ever conducted for any transmission line. After reviewing historic aerial photographs, it appears that the facility was demolished between 1987 and 1994.

Tests Performed

Testing at the site began after BPA completed an Environmental Assessment and obtained a U.S. Forest Service permit in 1984 for an agricultural study in the area.[224] The research study was carried out by scientists from Oregon State University through an intergovernmental agreement between Oregon State University and BPA.[225] The site was selected to study the effects of 500 kV DC transmission lines on cattle and crops, partially sponsored by a group of utility companies interested in finding out more about environmental and electrical effects of HVDC transmission lines.[226] Increasing public and scientific interest in the possible environmental effects of high voltage, increases in operating capacities of the DC Intertie, and lack of previous environmental studies prompted BPA to pursue this study.[227] Utilizing treatment and control groups, the research study was the largest experimental agricultural study ever conducted for any transmission line.[228] The study tested the hypothesis that a DC line had no significant effect on cattle or crops (Figure 46). To conduct the tests, approximately 100 cows and their calves were maintained in four pens under the transmission line, while an additional 100 cows and their calves were kept away from the line (Figure 47).[229] Data were collected on numerous health metrics and behaviors and were processed by computer. Crop studies included planting wheat and alfalfa plants centered within and perpendicular to the DC line right-of-way. Data was collected on the condition and growth of the crops. Data was recorded at 1-minute intervals and stored on site before being transferred to the Ross Complex via microwave technology.[230] Studies at the site ran from 1984 to 1987, with a final project report produced in 1988 on predicting operating characteristics of a DC line. Results of the report concluded that there was "no evidence that a +500kV d-c transmission line caused any effects on cattle or crops that would impact commercial farming or ranching operations."[231] The tests performed at this facility provided BPA with valuable insight into the potential environmental impacts of high voltage transmission and its effects on animals.

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[221] Lee et al., *The Grizzly Mountain HVDC Transmission Research Facility.*

[222] Bonneville Power Administration, *HVDC Biological Environmental Test Site*.

[223] Lee et al., *The Grizzly Mountain HVDC Transmission Research Facility.*

[224] Ibid

[225] Ibid.

[226] Ibid

[227] Ibid

[228] Ibid.

[229] Ibid.

[230] Ibid.

[231] Ibid

Distinguishing Features

Distinguishing features of the Grizzly Mountain HVDC Research Facility include its unique structure layout. The facility contained intentional, wide open space for testing cattle and crops and housed four cattle pens. The openness of the facility, in comparison to other facilities that had more detailed plans and layouts, is a distinguishing feature of the Grizzly Mountain HVDC Research Facility. Similar to other facilities, data collected at the site was sent to the Ross Complex for analysis and collected via an electrical monitor station underneath the test line. A final distinguishing feature of the Grizzly Mountain HVDC Research Facility was its adaptability for various types of tests. The scale and size of the facility allowed for adaptable testing of livestock and crops with limited constraints.

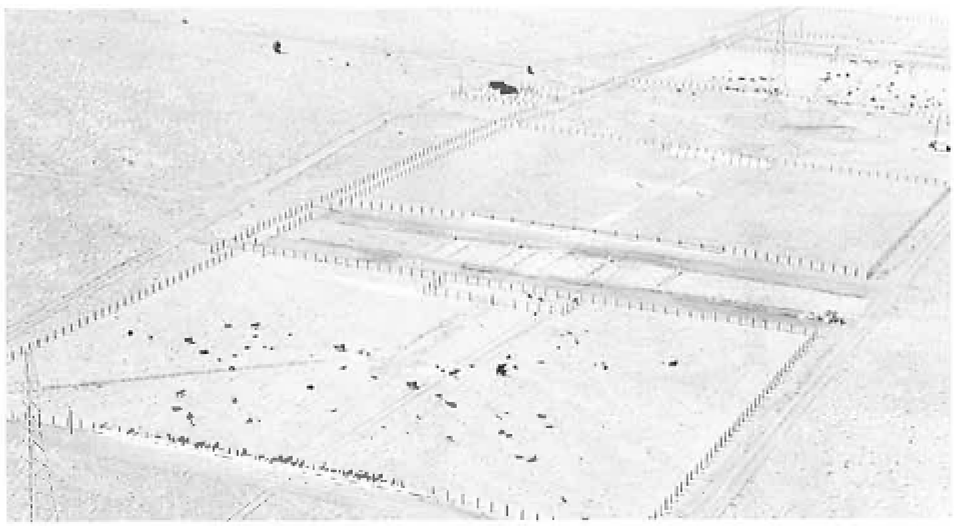

Figure 46. Aerial photograph of the four pens at the Grizzly Mountain HVDC Research Facility, ca. 1984.[232]

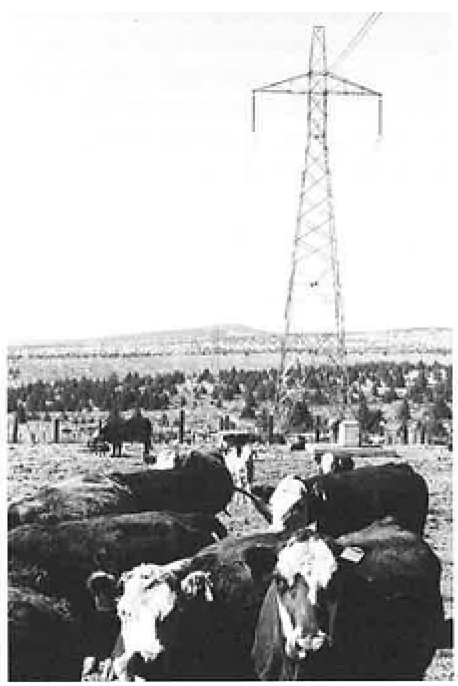

Figure 47. Cattle under study at the Grizzly Mountain HVDC Research Facility, ca. 1984.[233]

[232] Lee et al., *The Grizzly Mountain HVDC Transmission Research Facility.*

[233] Ibid.

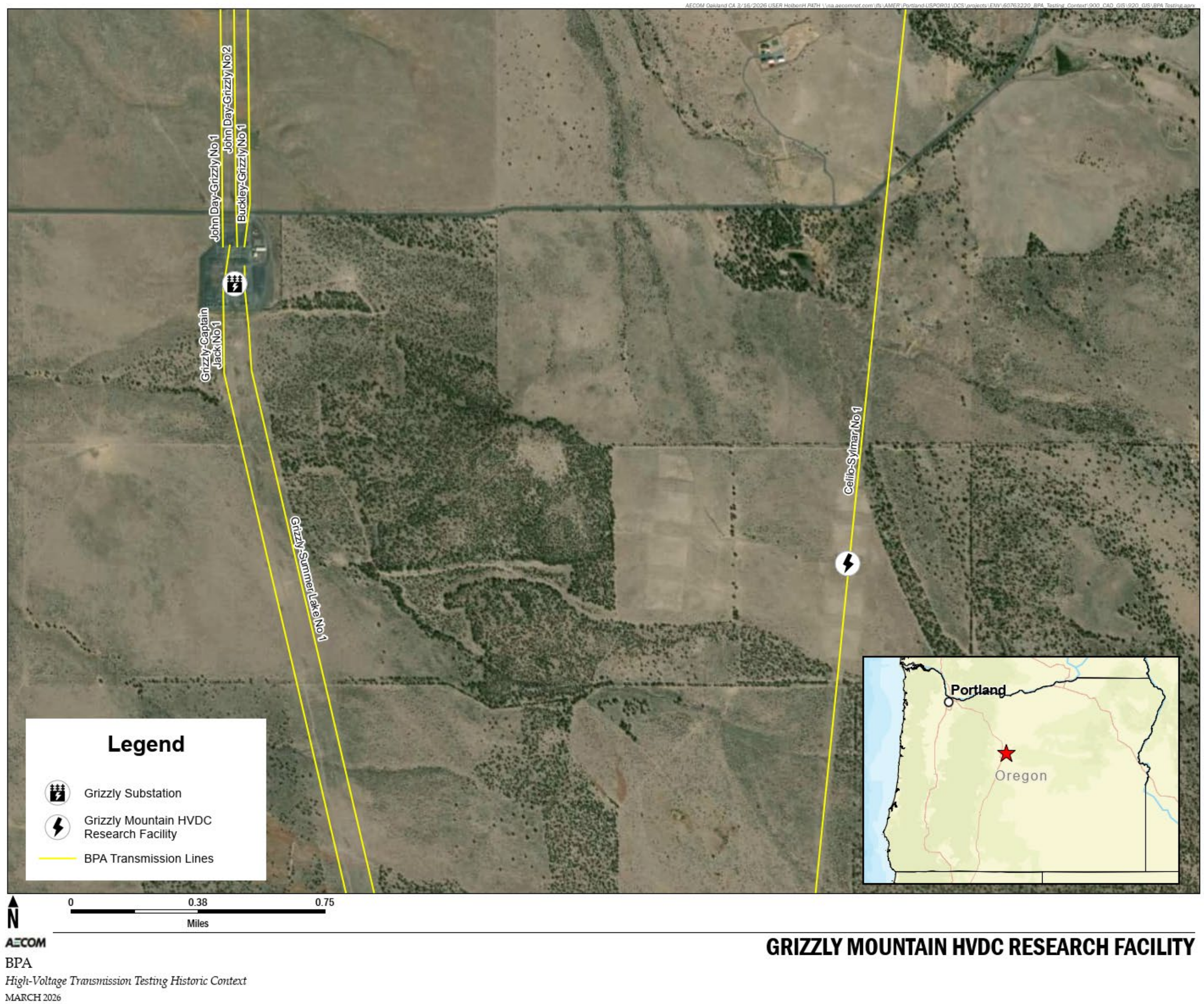

Figure 48. Map of the Grizzly Mountain HVDC Research Facility, Grizzly Substation, and associated transmission line.

2.5 Impact of Testing and Testing Facilities

BPA's historic testing facilities greatly impacted the development of high voltage transmission at BPA and around the world. The technological achievements at these testing facilities propelled BPA to become a world leader in HVDC transmission, and the company pioneered many "firsts" in the field of high voltage. Overall impacts of the testing facilities include reduced consumer costs, increased safety standards, important technological advancements, research contributions, environmental advancements, and greater transmission capacity.

When BPA's first 500 kV lines were built, new mechanical failures occurred. BPA recognized that extensive testing would be required to fix and prevent failures from occurring in the future and subsequently built its own testing facilities at the Ross Complex to identify and solve the mechanical problems occurring.[234] For example, the knowledge gained during a short circuit test program conducted at the Ross Complex Testing Facilities resulted in improved transformer designs and new test standards for the power industry as a whole (Figure 49).[235] The Ross Complex Testing Facilities were the largest such government facility in the country in the 1970s and also held the biggest energy lab on the West Coast.[236] Since the late 1970s, testing at Ross has been completed both for BPA's internal use and for manufacturers, foreign governments, universities, and U.S. government agencies like the U.S. Coast Guard.[237] The testing facilities at the Ross Complex were later used as training facilities for future line workers and to establish preventative maintenance and safety requirements.[238] Because of BPA's foresight and construction of testing facilities, BPA was able to operate safer transmission lines with reduced risk of electrical power system failures. The impact of BPA's historic testing facilities carries through to today. The Ross Complex currently has the only laboratories of its kind on the Pacific Coast and tests almost all of BPA's supplies and materials in the Carey or Mangan Lab.

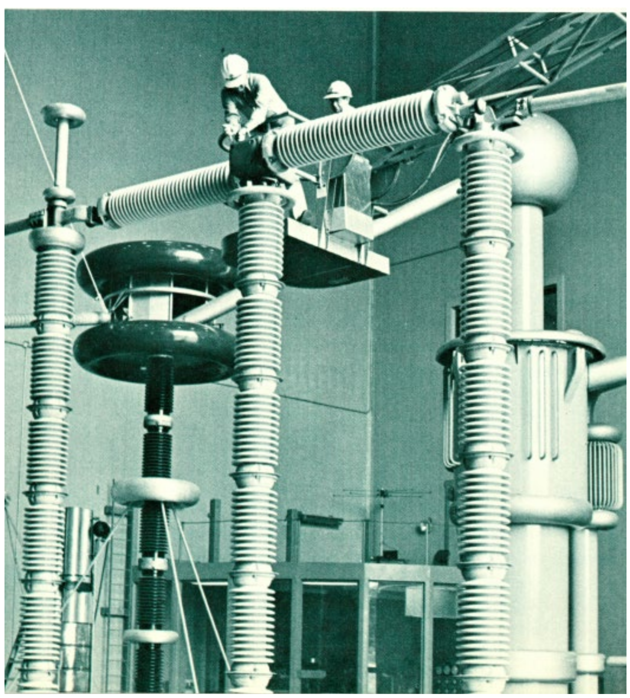

Figure 49. Personnel assembling a 550 kV circuit switcher for testing at the Ross Complex UHV Test Hall ca. 1979.[239]

[234] Annestrand and Batiste, "Bonneville Power Administration's High Voltage and Mechanical Test Facilities."

[235] Ibid.

[236] *The Columbian*, "BPA Engineers Simulate Lightning Bolts"

[237] Ibid.

[238] Annestrand and Batiste, "Bonneville Power Administration's High Voltage and Mechanical Test Facilities."

[239] U.S. Department of Energy, *Bonneville Power Administration's Test Facilities*.

The HVDC Test Center was a prime example of BPA's contributions to the field of HVDC transmission (Figure 50). In the 1960s, BPA recognized a need for transmitting power at a higher voltage in the United States. Because there were no HVDC lines existing in the United States at the time, a Department of the Interior task force provided funding for BPA to study HVDC electricity.[240] The High Voltage Transmission study was scheduled to be a 2-year test program and was an important piece of America's contribution to technology leadership in DC power transmission.[241] Tests conducted at the HVDC Test Center gave BPA the information needed to subsequently build the Intertie, which at the time of construction was the longest of its kind in the world.[242] The Intertie project allowed BPA and Pacific Northwest utilities to sell surplus energy to the Pacific Southwest, generating extra revenue and improving sustainable energy consumption.[243] The Intertie was a monumental engineering achievement that connected the West Coast's main power grids and was the largest transmission project in U.S. history when completed.[244]

Figure 50. UHV testing equipment at the HVDC Test Center, 1963.[245]

At the Lyons Test Facility, BPA made significant improvements to transmission line designs as a result of extensive switching and lightning impulse tests on line insulators and air gaps. BPA's early 230 kV lines were built with 16 insulator units per string.[246] Laboratory tests indicated that the insulators could be reduced to only 12 per string. Further research proved similar results on higher voltage lines, which allowed BPA to reduce transmission line cost by reducing the physical materials needed for each line. The Lyons Test Facility also incorporated testing on environmental aspects like crops and animals (Figure 51). Previous studies on crops and animals did not simulate a transmission line environment during testing; thus, Lyons was the first facility to provide long-term data on transmission line effects. Shifting environmental policies within the United States also shaped testing at BPA. With new requirements like the National

240 Blaser, *Historic American Engineering Record: Bonneville Power Administration Big Eddy Substation, HVDC Center*.

241 BPA, *1963 Annual Report*.

242 BPA, *Extra High Voltage Direct Current Test Center*, 1974.

243 BPA, *1976 Annual Report*.

244 BPA, "Pacific Intertie Map, The Oregon History Project."

245 BPA Archives, E67364, Portland, OR: Bonneville Power Administration of Multnomah County, 1963.

246 U.S. Department of Energy, *Bonneville Power Administration's Test Facilities*.

Environmental Policy Act (NEPA) signed into law in 1970, federal agencies were now required to assess environmental effects of proposed major federal actions. These actions were determined through Environmental Assessment reports and EISs. From 1938 to ca. 1969, the research conducted at BPA testing facilities largely focused on improving mechanical function and determining methods of transmitting high voltage power. Testing facilities constructed after the passage of NEPA in 1970, like the facilities at Lyons and Grizzly Mountain, indicate a newfound interest in research on animals, plants, and the larger environment. These facilities are representative of BPA's response to changing public interest and shifting testing requirements.

Figure 51. BPA scientists testing the impact of transmission lines on wheat and other crops at Lyons Test Facility, ca. 1979.[247]

Regarding environmental testing advancements, the Grizzly Mountain HVDC Research Center was the largest experimental agricultural study ever conducted for any transmission line, studying the effects of 500 kV DC transmission lines on cattle and crops in the right-of-way.

The BPA *Pacific Northwest Transmission System MPD* categorized relevant historic facilities at BPA and provided a framework for the identification and evaluation of facilities. The MPD stated that "testing stations [and facilities] are highly significant within the development history of the BPA Transmission System through their relationship to the implementation of new technologies and technique in transmitting electricity."[248] The development of HVDC transmission resulting from BPA's testing facilities provided opportunities for BPA to transport power further, reaching more consumers. BPA often constructed the first HVDC powerlines in their service areas, improving the lives of individuals, businesses, and industry by providing reliable, affordable power.

Overall, the tests and research and development programs performed at high voltage testing facilities contributed to the BPA goal of designing, building, operating, and maintaining the world's most reliable, safest, most economical, and most environmentally acceptable high voltage power grid at the time and in the future.[249]

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[247] BPA Library historic slides, undated image.

[248] Kramer, *BPA Pacific Northwest Transmission System MPD*. The MPD discusses BPA's testing facilities as "testing stations"; however, this historic context uses the term "testing facilities" to include a wider range of facilities related to high voltage testing.

[249] BPA, *1981 Annual Report.*

2.6 Important People

The following section provides brief biographies of engineers that contributed to BPA's high voltage testing during the period of significance.

2.6.1 Stig A. Annestrand

Stig Alvar Annestrand was a prominent Research Engineer at BPA from 1967 to 1987. Annestrand was born on September 18, 1933, in Husby, Sweden.[250] After receiving a degree in Electrical Engineering from the Royal Institute of Technology in 1958 in Stockholm, Sweden, he worked for the General Swedish Electric Company as the manager of research from 1962 to 1967.[251] Recruited by BPA for his expertise in high voltage electrical systems, Annestrand immigrated to the United States in June 1967 with his wife, Britta, and two children, Peter and Thomas.[252]

Annestrand's first role at BPA was in the High Voltage Unit of the Division of System Engineering, where he wrote technical papers on DC transmission and surge protection.[253] By 1974, Annestrand worked for the Electrical Investigation Section of the Division of Laboratories. In the mid-70s, Annestrand was heavily involved in the design of the UHV Laboratory at the Ross Complex and the Lyons Test Facility (Figure 52).[254] In a memorial to Annestrand, his former colleague Vernon L. Chartier stated that in his new role "Stig's mandate was to greatly improve the quality of work of the laboratories…his persistence enabled him to overcome significant resistance….[and] for the first time BPA's laboratories began producing quality reports and technical papers for publications in journals."[255] Annestrand mandated that engineers write reports on the results of their testing programs, furthering the impact of BPA's testing facilities.

Stig Annestrand, chief of BPA laboratories, stands before the Ross outdoor testing facilities. The silo-like structure in background is capable of building up a charge of 6 million volts to test transmission lines.

Figure 52. Annestrand in front of the Outdoor Test Yard at the Ross Complex.[256]

[250] Ancestry.com, *Naturalization Petition for Stig Alvar Annestrand*, https://www.ancestry.com/search/collections/2530/records/12743?tid=62934372&pid=422367568399&ssrc=pt.

[251] Chartier, Vernon L., "Mr. Stig A. Annestrand Memorial Tribute," *National Academy of Engineering*, https://www.nae.edu/27877/Mr-Stig-A-Annestrand.

[252] Ancestry.com, *Naturalization Petition for Stig Alvar Annestrand*.

[253] Chartier, "Mr. Stig A. Annestrand Memorial Tribute."

[254] Ibid.

[255] Ibid.

[256] "More Power to Us." *The Columbian.*

2.6.2 Ralph S. Gens

Ralph Samuel Gens held many positions at BPA during his tenure, including Chief Engineer in the late 1970s when he was influential in the development of high voltage technology (Figure 53). Born in Berlin on November 25, 1924, Gens was brought to Portland, Oregon, at the age of 14 to escape persecution in Nazi Germany.[257] One of approximately a thousand children transported via kindertransport to the United States between 1934 and 1945, Gens lived with his aunt and uncle in Portland prior to attending college at University of Washington.[258] While attending university, Gens was drafted into the U.S. Army, serving across the Pacific from 1943 to 1946. After concluding his service, Gens earned a degree in Electrical Engineering at Oregon State College where he was mentored by Eugene Starr, a professor and prominent BPA engineer.[259] Encouraged by Starr to pursue a career at BPA, Gens joined the company as an engineering aide in the System Engineering Branch shortly after graduating.[260] Gens led the development of the Intertie, both the 500 kV AC and the 800 kV DC lines to California.[261]

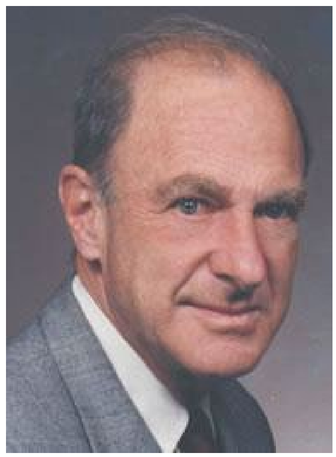

Figure 53. Photograph of Ralph S. Gens.[262]

In 1966, Gens became chief of the Systems Engineering Branch. His work largely focused on high voltage, research and development, planning, and the advancement of high voltage insulation.[263] Throughout the late 1960s and 70s, Gens worked closely with Annestrand and others on the development of high voltage technology. Gen's research on high voltage technology and insulation was renowned around the world. Gens also played a key role in the development of BPA's 500 kV transmission network, which was at the time the largest in the world. Working on BPA's Lyons Test Facility and the HVDC Test Facility, Gens provided unparalleled innovation and contribution in the field of high voltage testing. Gens became the manager of Planning and Research for BPA in 1974 and was appointed Assistant Administrator, Chief Engineer in 1977, which he held until his retirement in 1980.[264] Throughout his career at BPA, Gens authored over 20 technical publications and served on numerous committees, sharing his expertise around the world. Gens passed away on January 3, 2019, at the age of 94 in Kailua-Kona, Hawaii.[265]

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[257] Taylor, Carson W., "Ralph S. Gens, Memorial Tribute"*, National Academies*, https://www.nationalacademies.org/read/26492/chapter/22.

[258] Ibid.

[259] AECOM. *Bonneville Power Administration Transmission Line Historic Context Report.*

[260] Taylor, "Ralph S. Gens, Memorial Tribute."

[261] AECOM. *Bonneville Power Administration Transmission Line Historic Context Report.*

[262] Oregon State University, *Ralph Gens: Engineering Hall of Fame – 1999*, https://engineering.oregonstate.edu/alumni-partners/oregon-stater-awards/searchable-awards-database/ralph-gens-engineering-hall-fame

[263] Taylor, "Ralph S. Gens, Memorial Tribute."

[264] Ibid.

[265] Ibid.

3. Characteristics of BPA's High Voltage Testing Facilities

Each of BPA's testing facilities served a unique testing function and consisted of a set of characteristics that collectively defined the facility. These character-defining features follow the 2023 Ross Complex Testing Facilities Historic Context and include the following:

- Purpose-built buildings, structures, or testing lines
- Utilitarian design
- Testing equipment and testing capabilities

Each of these character-defining features is discussed with examples in the following sections.

3.1 Purpose-Built Building, Structure, or Testing Line

Most BPA testing facilities, including structures, buildings, and yards, were developed and constructed for the purpose of laboratory experimentation or trial installation of electrical transmission equipment.[266] As testing facilities have varied designs, construction materials, and locations, their unifying design feature is the testing purpose for which they were constructed.[267] Common themes found at each testing facility include the following:

- **At least one associated testing line.** Although voltages, length, and quantity vary, testing facilities typically contain a transmission line designated for testing purposes. In the case of the HVDC Test Center, Lyons Test Facility, and Moro Mechanical Test Facility, each facility had two lines.
- **Control house and/or office space.** All facilities except for the Grizzly Mountain HVDC Research Facility contained either a control house, office space, or other type of area for staff to work and perform tests from. Often these spaces served as storage areas for testing equipment and housed data collected during testing.
- **Power source.** All testing facilities had a designated power source to electrify testing lines and equipment. Power sources included reused breakers, as well as rectifiers and transformer with variable voltages. For example, at the HVDC Test Center, the facility was powered by two three-phase solid state bridge rectifiers. The Lyons Test Facility incorporated an existing 230 kV breaker to energize the test facility.

3.2 Utilitarian Design

Most testing facilities were constructed with a utilitarian design, emphasizing its purpose over appearance. Sites were often selected specifically for the type of tests conducted. In order to accommodate the testing equipment and facilitate experimentation, most buildings at testing facilities had minimal fenestration. The lack of windows is apparent and functional, provided a more controlled environment for testing. Garage-style doors allowed large equipment to be moved, and single-leaf metal doors provided access for individuals. Cladding often consisted of simple metal panels, with structural elements exposed on either the interior or exterior of the structure. Hardy materials, including concrete and steel, were used on the floors and walls to withstand heavy testing. Observation areas were also a key feature of the design of the test facilities. Interior and exterior designs featured minimal ornamentation or variation in materials applied, often to facilitate the best environment for conducting tests. All facilities contain an

[266] Kramer, *BPA Pacific Northwest Transmission System MPD*.

[267] Ibid.

outdoor component, with one facility's testing capabilities (like Grizzly Mountain HVDC Research Facility) only existing outdoors.

Another utilitarian component of the testing facilities is that most incorporate a sense of flexibility in their design. For example, the Lyons Test Facility was able to test a variety of crops, animals, and insects under the testing lines, bringing in and transitioning out components once tests were complete. At the Ross Complex, multiple facilities accommodated the movement of big pieces of equipment to and from the building based on testing requirements. The fog test chambers at the Ross Complex and HVDC Test Center could be controlled to meet specific testing needs, and the resistivity of the water could be altered using demineralizing and mixing systems. Other facility-specific examples of utilitarian design include the following:

- **Ross Complex.** The large, purpose-built doors in the Carey Lab leading to the UHV Outdoor Test Yard allowed equipment to be transported between facilities. A built-in faraday cage in the Carey Lab protected workers from dangerous voltages.
- **HVDC Test Center.** Originally contained a nonconductive bubble-shaped structure that was large enough to cover the power supply and control center (Figure 54). The fog chamber was able to produce a variety of types of fog, and the interior elevated control room in the chamber contained fog-proof windows.
- **Lyons Test Facility.** Simplistic facility in comparison to previous facilities. The control house and office space consisted of two non-permanent portable trailers.
- **Moro Mechanical Test Facility.** Contained altered transmission towers to accommodate specific platforms and a small elevator for ease of testing.
- **Grizzly Mountain HVDC Research Facility.** Contained no buildings or structures; this facility had four pens situated under the transmission lines in which researchers rotated cattle.

Although "beautility" design concepts were introduced to BPA's transmission system in the mid-1960s, review of historic reports, blueprints, and planning documents did not reveal that any of these design concepts were directly incorporated into testing facility designs. As discussed in the 2022 BPA Transmission Lines Historic Context, beautility incorporated aesthetics into transmission line design as well as utilitarian factors of function, cost, and safety. From 1965 to 1974, BPA applied a series of "beautility" design concepts to its transmission system. The concepts, recommended by Stanton, Boles, Maguire and Church Architects in their 1966 *Report on Appearance Planning,* followed modern design trends for buildings and landscape design and considered scenery as an important characteristic to preserve. All BPA testing facilities are utilitarian in design and are characterized by a void of decorative features and an emphasis on function and efficiency.[268]

[268] National Park Service, *Architecture: Utilitarian (1860 to the present)*, February 28, 2015, https://www.nps.gov/prsf/learn/historyculture/utilitarian.htm.

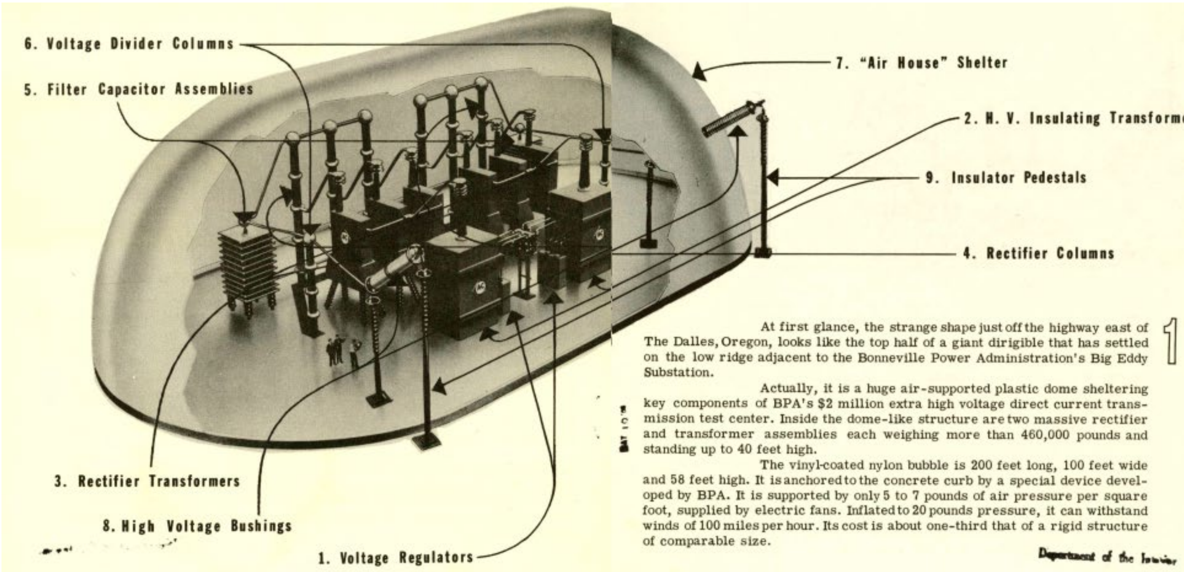

Figure 54. Drawing of the air bubble at the HVDC Test Center.[269]

3.3 Testing Equipment and Capabilities

Each testing facility contained a variety of testing equipment used to perform numerous experiments. The functionality and presence of the historic equipment is a character-defining feature of the testing facilities, as the testing equipment often dictated the design of its facility. The testing capabilities, or functions, of each facility fulfill the purpose of the testing facilities. Testing capabilities are broadly divided into four categories: electrical, mechanical, chemical, and environmental. Shifting environmental policies within the United States also shaped testing at BPA, and environmental testing on plants and animals was more common in the testing facilities built in the 1970s and 1980s (Figure 55). With the passage of NEPA in 1970, testing facilities like those at Lyons and Grizzly Mountain indicate the growing need for greater research on the effect of high voltage on animals, plants, and the larger environment. These facilities are representative of BPA's response to changing public interest and shifting testing requirements.

The types of equipment tested and tests performed at BPA facilities are listed in Table 8 and are sourced from the 1979 BPA and U.S. Department of Energy publication titled *Bonneville Power Administration's Test Facilities.*[270] Facility-specific testing capabilities included the following:

- **Ross Complex.** Whereas at most other testing facilities, the lines were the primary feature, the Ross Complex had the most "indoor" components of any testing facility. The complex performed the most extensive number of tests due to the size of the facility and available resources. Tests performed include testing hardware, conductor requirements, insulation and conductor requirements for UHV lines, and evaluating strength and vibration characteristics under various weather conditions.
- **HVDC Test Center.** Tested corona, radio interference, insulation coordination, and insulator design. During The Dalles Project in the 1970s, testing expanded to include insulation requirements of line and station insulators under varying environmental conditions. Additional testing capabilities included DC hotline maintenance, corona loss, TV interference, and audible noise, as well as the capabilities of insulation to withstand surges.
- **Lyons Test Facility.** Evaluated the impact of high voltage transmission on radio and TV interference and its potential ecological effects to plants and animals, and measured

[269] BPA, *Extra High Voltage Direct Current Test Center*, 1963.

[270] U.S. Department of Energy, *Bonneville Power Administration's Test Facilities*.

ambient and audible noise. The facility was the first to be able to monitor and transmit testing data to/from Portland via new computer technology. The facility transitioned its testing to include a greater emphasis on substation equipment, specifically gas-insulated equipment, which would aid in the development of more cost effective and reliable equipment (Figure 56).

- **Moro Mechanical Test Facility.** Testing was performed to better understand structural and mechanical aspects of UHV transmission design. Testing consisted of monitoring and analyzing performance of conductor bundles and insulators. Key goals of the facility included optimizing the mechanical design of UHV transmission lines, developing and verifying analytical procedures, refining design loads and criteria, and developing construction and maintenance techniques for UHV lines. A unique feature of the facility included its use of video documentation of testing.
- **Grizzly Mountain HVDC Research Facility.** The most specialized facility, research performed included the effects of 500 kV DC transmission lines on cattle and crops.

Figure 55. Bee testing at Lyons Test Facility, late 1970s.[271]

Figure 56. Mechanical testing at Lyons Test Facility, late 1970s.[272]

[271] BPA-provided scanned slides, no date.

[272] BPA-provided scanned slides, slide 281262.

Table 8 Major Types of Tests Conducted at BPA Test Facilities[1]

Equipment To Be Tested	Types of Tests Performed
Transformers and Shunt Reactors	Lightning impulse tests Switch impulse tests Power frequency dielectric tests Induced voltage tests with increased frequency Partial discharge measurements Temperature rise tests Short circuit tests at full voltage Low-voltage impulse diagnostic tests Determination of the operating characteristics (losses, voltage regulations, etc.) Transformer fault gas analyses Vibration analysis Sound level measurements Stress analysis Mechanical and electrical tests on expulsion links
Circuit Breakers	Lightning impulse tests Partial discharge tests Dry and wet power frequency dielectric tests Dry and wet switching impulse tests Vibration analysis Sound level measurements Stress analysis Temperature cycling tests
Fuses	Insulation tests Temperature rise tests Check of the operating features Short-circuit tests for the checking of the breaking capacity Environmental tests
Surge Arresters	Lightning impulse sparkover tests Switching impulse sparkover tests Power frequency sparkover tests Contamination tests High current 60 Hz tests
Disconnecting Switches	Lightning impulse tests Dry and wet switching impulse tests Dry and wet power frequency dielectric tests Partial discharge tests Open gap tests with and without bias voltages Stress analysis High current tests

Equipment To Be Tested	Types of Tests Performed
Insulators	Lightning impulse tests Dry and wet switching impulse tests Dry and wet power frequency tests Partial discharge tests Contamination tests Power arc tests Mechanical–Electrical tests Vibration tests Tensile–Torsional–Environmental tests Fatigue tests Flexural tests Impact tests
Cables	Lightning impulse tests Switching impulse tests Power frequency dielectric tests Partial discharge measurements DC voltage tests Power factor measurement Tension tests Flexure tests Environmental tests
Capacitors	Power frequency dielectric tests Power factor measurements Partial discharge measurements Life tests High current tests on series capacitor assembly Environmental tests
Current Transformers and Busbars	Checking of thermal and electrodynamic behavior under short-circuit conditions Stress analysis Vibration analysis Sound level tests
Hardware and Conductors for Overhead Lines	Temperature rise tests Visual corona and partial discharge measurements Short-circuit stress tests Power arc tests Tension tests Compression tests Flexure tests Vibration tests Hardness tests Impact tests Shear tests Fatigue tests Environmental tests High speed x-ray on armor grip suspension assemblies
Line Construction Equipment	Tension-compression tests Flexure tests Hardness tests Hydraulics tests Magnetic particle inspection

Equipment To Be Tested	Types of Tests Performed
Conduit	Impact tests Flexure tests Compression tests
Structures	Vibration tests Tension tests Flexure tests Magnetic particle inspection
Conductors	Tensile tests Vibration tests Torsion tests Stress analysis Hardness tests Dye-penetrant inspection
Vehicles	Stress analysis Vibration tests Sound level tests
Substation Bus	Temperature rise test Flexure tests Vibration tests Radiography
Materials	Insulating oil testing Industrial water analysis Paint formulation and analysis Domestic water analysis General chemical analysis Adhesive formulation and consultation Wood pole inspection and treatment development Metallographic examination and analysis General physical tests General electrical tests
Instrumentation and Standards	Watt-hour meter tests Relay tests Transducer tests Instrument evaluations Potential transformer tests Current transformer tests Galvanometer testing Battery chargers, inverters and power supply Substation and control center recorders

Notes: BPA = Bonneville Power Administration; DC = direct current; Hz = Hertz

[1] U.S. Department of Energy, *Bonneville Power Administration's Test Facilities*.

4. Identification and Evaluation of Historic Resources Associated with High Voltage Testing

All of BPA's historic testing facilities are located in Oregon and Washington. The Ross Complex in Vancouver, Washington, held the largest number of individual testing facilities and is still used for testing as of 2026. The Ross Complex contains seven individual facilities, which were evaluated for NRHP eligibility in the 2023 *Bonneville Power Administration, Ross Complex Testing Facilities Historic Context*.[273] Collectively, counting Ross as one entity, BPA had a total of five historic testing facilities. The 2012 MPD for BPA's Pacific Northwest Transmission System notes that testing facilities may occur at varied locations, both in association with substations and independently, and include structures developed to test new equipment, especially in connection with the development of the HVDC Intertie or related to new transmission line technologies. The MPD states that testing facilities may include a variety of resources throughout the BPA network, including either buildings or structures, developed and constructed for the purpose of experimentation or trial installation of electrical transmission equipment. In the MPD, testing facilities are highly significant within the development history of the BPA transmission system through their relationship to the implementation of new technologies and techniques in transmitting electricity. The MPD documents the significance of testing facilities and notes a period of significance of 1938 to 1974.[274]

However, this historic context identifies additional property types related to testing facilities and justifies a period of significance of 1938 to 1987, encompassing the development of the Lyons, Moro, and Grizzly Mountain facilities and their subsequent significant tests. Although the Ross Complex continued to perform tests after 1987, research indicates these tests are not exceptionally significant in the larger context of high voltage testing at BPA.

4.1 Minimum Eligibility Requirements

Based on this historic context and identification of the additional property types, the ensuing minimum eligibility requirements are recommended:

- Be designed by BPA for the purposes of testing and/or research
- Be owned and operated by BPA during some portion of the period of significance (1938–1987)
- Be constructed prior to 1987
- Incorporate means of data collection and subsequent evaluation of findings either on site or via transmittal to other BPA facilities

The integrity requirements of testing facilities include the following:

- Location and Setting: Testing facilities were dependent on their location and setting to run tests, collect data, and transmit results. Resources meet integrity for location and setting when they are in their original location and retain key aspects of setting that facilitated conducting tests.
- Design, Materials, and Workmanship: Testing facilities occur in multiple designs and configurations. Resources that maintain essential integrity with their design and construction during the period of significance retain integrity in design/materials and workmanship. Given the temporary nature of testing, ongoing operation or function is not essential to the retention of integrity for testing-related resources.

[273] AECOM, *Bonneville Power Administration, Ross Complex Testing Facilities Historic Context*

[274] Kramer, *BPA Pacific Northwest Transmission System MPD.*

- Feeling: Testing facilities demonstrate integrity of feeling when they effectively convey their original construction and role in the development of the BPA Transmission System and execution of tests.
- Association: Testing facilities that reflect the technological innovations or experimentation associated with the development of the BPA Transmission System retain strong association with its significance.

4.1.1 Property Types

The MPD identifies testing stations as a distinct property type; however, it does not specify the various facilities associated with these sites. This historic context has identified additional the property types present at historic testing facilities, including:

- Office Spaces/Control Rooms
- Storage Facilities
- Power Sources
- Outdoor Testing Areas
- Testing Lines
- Fog Test Chambers
- Visitor Centers

The presence of property types at different facilities varies based on the location, construction date(s), presence of other facilities, and function. For example, the Ross Testing Facilities are located within a larger, established complex and have been developed over time, from 1955 up to 1979. The Ross Complex contains an extensive number of laboratories, an outdoor testing area, a small testing line, and numerous control rooms. In comparison, the Grizzly Mountain HVDC Research Center consisted of an outdoor testing area with four animal pens and testing equipment placed under existing transmission lines.

4.2 Criteria for Evaluating Historic Testing Facilities

The NRHP is the official list of historic properties recognized as significant to the history of the United States at the national, state, or local level. A property is eligible for the NRHP if it meets one of four criteria (listed below) and maintains sufficient historic integrity based on its location, setting, design, materials, workmanship, feeling, and association. In order to be recognized as significant, a property must:

A. be associated with events that have made a significant contribution to the broad patterns of our history;

B. be associated with the life of a person significant in our past;

C. embody the distinctive characteristics of a type, period or method of construction, or represent the work of a master or display high artistic values; or

D. yield, or be likely to yield, information important in prehistory or history.

BPA's historic high voltage testing facilities found to be significant and retaining sufficient historic integrity are eligible for the NRHP under Criteria A and C. Criteria B and D are generally not considered applicable to BPA's historic resources. Significant resources associated with this historic context are eligible at the national and/or state levels and may be individually significant and/or a contributing resource to a historic district.

All of the testing facilities are significant under NRHP Criterion A for their association with BPA's implementation of new technologies and techniques in transmitting electricity.[275] The increase in maximum system voltage over time has necessitated the creation of testing laboratories to identify and solve associated technical problems. These test facilities met a series of objectives essential to BPA's continued function, including verifying component and system design requirements were met, assuring system performance requirements were realistic, determining whether environmental impact of the system was acceptable, and ensuring the system's safety for both BPA and the public.[276] The technological achievements at these testing facilities propelled BPA to become a world leader in HVDC transmission, and the agency pioneered many "firsts" in the field of high voltage. The testing facilities overall reduced consumer costs, increased safety standards, led to important technological advancements, provided insight on potential environmental impacts on animals and plants, and led to greater transmission capacity at BPA, within the United States, and around the world. Thus, the testing facilities are significant under Criterion A in the following areas of significance:

- Engineering and Invention – association with the development of equipment, technology, structures, or machinery to serve human needs. BPA's testing facilities are the first of their kind in the United States and contain machinery specifically built to test BPA materials. The development of these facilities created new technology and inventions that brought faster and more efficient power to BPA customers throughout the western United States, and the technological advancements that were uncovered at the testing facilities were used throughout the world.
- Science – association with the study of natural law and scientific phenomenon. BPA contributed greatly to the knowledge and development of high voltage transmission in the United States. BPA's development of testing facilities furthered scientific discovery and innovation, particularly in relation to DC, high voltage, EHV, and UHV testing.
- Politics/Government – association with federal programs or activities, political issues, or the development or expansion of government impacts. BPA's pivotal role in the development and expansion of public power in the Pacific Northwest and response to changing environmental requirements is significant and led to the establishment of testing facilities to increase expansion in the region.
- Conservation – association with the preservation, maintenance, and management of natural or manmade resources. BPA's testing of high voltage transmission on plants and animals contributed to the knowledge of safe practices and operations. BPA's testing facilities built after the 1970 passage of NEPA often provided the first-of-its-kind data on the environmental effects of high voltage on the environment.

Although multiple BPA engineers contributed to BPA's high voltage testing throughout the period of significance, no one individual is individually significant within a specific historic context. Key BPA engineers that contributed to BPA's high voltage testing during the period of significance include Stig A. Annestrand and Ralph S. Gens. Although these individuals contributed to the development of testing facilities at BPA, the facilities are not eligible under Criterion B.

Regarding Criterion C, the testing facilities may be associated with the development and technology and may be eligible under Criterion C. The MPD states that testing facilities eligible under Criterion C must be "[e]xemplar of a particular significant technology" and retain a "HIGH level of integrity to relate that technology."[277] For example, the technology associated with the development of the Intertie was exemplified in the HVDC Testing Facility at the Big Eddy

[275] Kramer, *BPA Pacific Northwest Transmission System MPD*.

[276] Annestrand and Batiste, "Bonneville Power Administration's High Voltage and Mechanical Test Facilities."

[277] Kramer, *BPA Pacific Northwest Transmission System MPD*.

Substation. Similar equipment existed at the Lyons Test Facility and Moro Mechanical Testing Facility; however, the presence of this technology today is unknown.

Criterion D is not applicable because the resources have not yielded, nor are they likely to yield, information important in history.

4.2.1 NRHP Criteria Considerations

Only NRHP Criteria Consideration G could be applicable to BPA's testing facilities and may be applicable when a testing facility has achieved significance within the past 50 years and is of exceptional importance.[278] Only the Grizzly Mountain HVDC Research Facility (1984) has achieved significance since 1976. However, this facility appears to have been demolished between 1987 and 1994. As of 2026, the Ross Complex is still utilized for testing. However, the modern tests performed at Ross do not meet the threshold to be considered exceptional. Thus, Criteria Consideration G does not apply.

4.3 Significant Historic Testing Facilities and Lines

Using the framework detailed above, the historic testing facilities listed in Table 9 have been identified as possessing individual significance associated with BPA's historic context. BPA determined the HVDC Test Center eligible for listing in the NRHP under Criteria A and C in 2013. Archaeological Investigations Northwest, Inc., completed a HAER report to mitigate the demolition of the HVDC Test Center in 2016.[279] The testing facilities located at the Ross Complex were evaluated by AECOM in 2023 as part of an updated determination of eligibility (DOE) report on the complex. These resources were recommended as significant at the national and/or state levels. The Lyons Test Facility, Moro Mechanical Test Facility, and Grizzly Mountain HVDC Research Facility have not been evaluated for listing in the NRHP.

Table 9 Significant Historic Testing Facilities

Testing Facility	Construction Date(s)	NRHP Criteria	Notes
Ross Complex Testing Facilities Historic District	1953–1972	A	Significant for its association with BPA's implementation of new technologies and techniques in transmitting electricity. **Surveyed and determined eligible for the NRHP under Criterion A in 2023.**
HVDC Test Center at Big Eddy	1963; 1972	Not Extant	Significant for studies on HVDC transmission and its role in the development of the Intertie. Determined eligible for the NRHP in 2013. **Demolished in 2017.**
Lyons Test Facility	1976; 1979	Not Extant	Significant for studies on UHV transmission and environmental research on the effects of UHV on plants, insects, and animals. Significant under Criterion C for specialized testing equipment. **Demolished between 1982 and 1992.**
Moro Mechanical Test Facility	1976	Not Extant	Significant for studies on UHV transmission and environmental research on ice and wind impacts to transmission lines. Significant under Criterion C for specialized testing equipment. **Potentially demolished between 1987 and 1994, condition/integrity unknown.**
Grizzly Mountain HVDC Research Facility	1984	Not Extant	Significant for environmental research on the effects of high voltage. **Demolished between 1987 and 1994.**

Notes: HVDC = high voltage direct current; NRHP = National Register of Historic Places; UHV = ultra high voltage

[278] National Park Service, *National Register Bulletin 15: How to Apply the National Register Criteria for Evaluation,* Washington D.C.: U.S. Government Printing Office, 2005. BPA's historic high voltage testing facilities do not include any religious properties (Criteria Consideration A), relocated properties (Criteria Consideration B), birthplaces or graves (Criteria Consideration C), cemeteries (Criteria Consideration D), reconstructed properties (Criteria Consideration E) or commemorative properties (Criteria Consideration F).

[279] Blaser, *Historic American Engineering Record: Bonneville Power Administration Big Eddy Substation, HVDC Test Center.*

5. Recommendations for Future Work

Recommendations for future work on BPA's historic high voltage testing facilities include DOEs for unevaluated facilities, inventories of historic testing equipment and exhibition displays, oral histories of BPA testing facility employees, and updating the 2012 MPD.

5.1 Determinations of Eligibility for Unevaluated Facilities

Several historic testing facilities have not been surveyed or evaluated for listing on the NRHP. The Lyons, Moro, and Grizzly Mountain facilities have not been as thoroughly documented as the Ross Complex and HVDC Test Center. Although a review of historic aerial images indicates that most (if not all) of these facilities are no longer extant, surveying each facility to assess current conditions and integrity and providing a formal DOE would assist in future planning efforts. This historic context, in combination with future DOEs, could be used by BPA to generate NRHP nominations for historic testing facilities.

5.2 Inventory of Historic Equipment

The extant testing facilities may contain historic test equipment dating to the period of significance. A previous 2023 survey of the Ross Complex testing facilities, as well as the 2016 HAER documentation of the HVDC Test Center, indicated that both facilities contained historic-period equipment. An inventory of equipment that was historically housed at the Lyons Test Facility (Figure 57) and Moro Mechanical Test Facility could yield more information on the types of tests performed in these facilities and could be utilized to compare how testing was similar or different between facilities.

Further research on and documentation of the Visitor Center at the Lyons Test Facility would prove useful in better understanding the importance of the center and its impact on visitors. Similar to the components of the HVDC Test Center that were salvaged by BPA Historians and Librarians in 2016/2017, there may be remnants of past interactive exhibits, displays, or other media that could be useful in future BPA displays. Although the Lyons Test Facility and Visitors Center appears to have been demolished, an exhibit on the history of this site utilizing historic equipment could create an engaging display or interactive StoryMap.

5.3 Oral History

The 2023 survey of the Ross Complex testing facilities revealed that several BPA employees had recently retired from working in the testing facilities, and that several more were still with BPA.[280] As noted in previously conducted interviews, these employees contain a wealth of knowledge about the testing facilities and associated equipment. Oral histories are recommended to document their experience with these facilities, the tests performed, and knowledge of the technology used. Research identified several written publications regarding these facilities; however, interviews with individuals associated with these facilities appear limited. Interviews with individuals associated with the Lyons, Moro, and Grizzly Mountain facilities should be prioritized, as they have less-thorough documentation than the Ross Complex and HVDC Test Center. Although most of the testing facilities operated in the 1960s–1980s, some BPA employees may recall the decommissioning of these facilities or remember information shared by previous colleagues.

5.4 Multiple Property Documentation Revisions

The 2012 MPD lists that one of the minimum eligibility requirements of testing facilities is that they must have been constructed prior to 1975. This date range does not include three of BPA's

[280] AECOM, *Bonneville Power Administration, Ross Complex Testing Facilities Historic Context*

historic testing facilities: Lyons, Moro, and Grizzly Mountain. To better include all of BPA's historic testing facilities, it is recommended that content from this historic context be incorporated into any potential future revisions of the MPD, and the date range for eligible facilities be increased from 1975 to 1987. Research revealed that the testing conducted at the Grizzly Mountain HVDC Research Facility from 1984 to 1987 was the last significant testing performed at a BPA testing facility that informed HVDC decision making. The Grizzly Mountain HVDC Research Facility was the last facility built for specifically testing high voltage, marking the end of the construction of testing facilities at BPA. Extending this period of significance to 1987 encapsulates the significance of the identified testing facilities; however, this historic context does not justify the expansion of the period of significance for non-testing facilities.

Figure 57. Worker performing tests on a line at Lyons Test Facility, October 4, 1982.[281]

[281] BPA-provided scanned slides, slide P390B-18.

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