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Cultural Resources Technical Report No. 106
Division of Earth and Ecosystem Sciences
Desert Research Institute
Las Vegas, Nevada

2011

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Prepared for

U.S. Department of Energy
National Nuclear Security Administration
Nevada Site Office, Las Vegas, Nevada
and
U.S. Department of Defense
Defense Threat Reduction Agency
Nevada Test Site Office, Mercury, Nevada

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ABSTRACT

This report presents a historical evaluation of the U12n Tunnel on the Nevada National Security Site (NNSS) in southern Nevada. The work was conducted by the Desert Research Institute at the request of the U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office and the U.S. Department of Defense, Defense Threat Reduction Agency (DTRA). The U12n Tunnel was one of a series of tunnels used for underground nuclear weapons effects tests in Rainier and Aqueduct Mesas. A total of 22 nuclear tests were conducted in the U12n Tunnel from 1967 to 1992. These tests include Midi Mist, Hudson Seal, Diana Mist, Misty North, Husky Ace, Ming Blade, Hybla Fair, Mighty Epic, Diablo Hawk, Miners Iron, Huron Landing, Diamond Ace, Mini Jade, Tomme/Midnight Zephyr, Misty Rain, Mill Yard, Diamond Beech, Middle Note, Misty Echo, Mineral Quarry, Randsburg, and Hunters Trophy. DTRA sponsored all tests except Tomme and Randsburg which were sponsored by the Lawrence Livermore National Laboratory. Midnight Zephyr, sponsored by DTRA, was an add on experiment to the Tomme test. Eleven high explosive tests were also conducted in the tunnel and included a Stemming Plan Test, the Pre-Mill Yard test, the two seismic Non-Proliferation Experiment tests, and seven Dipole Hail tests.

The U12n Tunnel complex is composed of the portal and mesa areas, encompassing a total area of approximately 600 acres (240 hectares). Major modifications to the landscape have resulted from four principal activities. These are road construction and maintenance, mining activities related to development of the tunnel complex, site preparation for activities related to testing, and construction of retention ponds. A total of 202 cultural features were recorded for the portal and mesa areas. At the portal area, features relate to the mining, construction, testing, and general everyday operational support activities within the tunnel. These include concrete foundations for buildings, ventilation equipment, air compressors, communications equipment, mining equipment, rail lines, retention ponds to impound tunnel effluent, and storage containers. Features on the mesa above the tunnel generally relate to tunnel ventilation and cooling, borehole drilling, and data recording facilities. Feature types include concrete foundations, instrument cable holes, drill holes, equipment pads, ventilation shafts, and ventilation equipment.

The U12n Tunnel complex is eligible to the National Register of Historic Places under criteria a and c, consideration g of 36 CFR Part 60.4 as a historic landscape. Scientific research conducted at the tunnel has made significant contributions to the broad patterns of our history, particularly in regard to the Cold War era that was characterized by competing social, economic, and political ideologies between the former Soviet Union and the United States. The tunnel also possesses distinctive construction and engineering methods for conducting underground nuclear tests. The Desert Research Institute recommends that the U12n Tunnel area be left in place in its current condition and that the U12n Tunnel historic landscape be included in the NNSS monitoring program and monitored for disturbances or alterations on a regular basis.

ACKNOWLEDGMENTS

This research was conducted under the direction of Linda Cohn, NNSA/NSO Cultural Resources Manager for the U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office (NNSA/NSO) and Lori Plummer, Acting Team Leader, NNSA/NSO Environmental Protection Team; and Jeff Fraher from the U.S. Department of Defense, Defense Threat Reduction Agency (DTRA). Colleen M. Beck, Desert Research Institute, was project director and the cultural resources field work was conducted under the supervision of Robert C. Jones and assisted by Barbara Holz, Desert Research Institute. Thomas F. Bullard, Desert Research Institute, conducted the geomorphological study.

The Desert Research Institute extends special thanks to Laurence Ashbaugh and Wayne Griffin. Both gentlemen, as former members of the DTRA Nevada Operations Office, shared their extensive knowledge of the events and history surrounding the DTRA Underground Nuclear Weapons Effects Test program and contributed much to the report. Martha DeMarre helped in providing historic documents and photographs on file at the Nuclear Testing Archive, Las Vegas. Loretta Bush at the NNSA/NSO Technical Library, North Las Vegas helped in obtaining key scientific reports for the various nuclear tests conducted in the U12n Tunnel. Troy Leonard provided engineering drawings on file at the Archives and Records Center, Mercury, Nevada. Maxine Trost provided photographs on file at the Archives and Records Center, Lawrence Livermore National Laboratory, California. Janice Langley was instrumental in providing access to the historic photographs on file at the Remote Sensing Laboratory, Las Vegas. Connie Salus facilitated our access to the documents on file at the Defense Threat Reduction Information Analysis Center (DTRIAC), Kirtland Air Force Base, New Mexico. Virginia Sedillo provided access to the photographs of the U12n Tunnel operations on file at DTRIAC.

Special thanks are also due to a number of unique persons willing to share their knowledge and past experiences at the tunnels in recorded video and audio interviews. We would like to thank Bill Flangas, a former Mine Superintendent, Project Manager, Department Manager, and Operations and Maintenance Division Manager for Reynolds Electrical and Engineering Company, Inc., and Vice President of Edgerton, Germerhausen, and Grier, Inc., for his time and effort in providing information and giving an interview about the U12n Tunnel. Byron Ristvet, DTRA, a Containment Scientist, provided an exceptional interview on the history of U12n Tunnel. Laurence Ashbaugh, a former DTRA Test Group Engineer, Chief of Engineering, and Manager of the DTRA Nevada Operations Office, and Wayne Griffin, a former DTRA Test Group Engineer and an Assistant Tunnel Superintendent for Reynolds Electrical and Engineering Company, Inc., at U12n Tunnel, discussed the operations and purpose of the tunnel. In an audio interview, Margaret Townsend, geologist with National Security Technologies, provided an understanding into the geology of U12n Tunnel. Keith Kolb, videographer for National Security Technologies, provided his skills and experience to make the video interviews possible.

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INTRODUCTION

The U.S. Department of Energy (DOE), National Nuclear Security Administration Nevada Site Office (NNSA/NSO) requested the Desert Research Institute conduct a historical evaluation of the U12n Tunnel in Area 12 of the Nevada National Security Site (NNSS), Nye County, Nevada (Figure 1). The intent of this historical evaluation is in reference to Section 110 of the National Historic Preservation Act of 1966, as amended, and involves the identification and evaluation of historic properties.

The U12n Tunnel was in operation from 1962 to 1998 and used by the U.S. Department of Defense, Defense Threat Reduction Agency (DTRA) for 20 nuclear weapons effects tests and nine high explosive tests and by Lawrence Livermore National Laboratory (LLNL) for two nuclear weapons tests and two high explosive tests. A total of 22 nuclear tests and 11 high explosive tests were carried out at the tunnel. The U12n Tunnel complex, consisting of portal and mesa areas, encompasses 600.8 acres (243.1 hectares) on the side and top of Rainier Mesa in the northern part of the NNSS. Modifications to the landscape have resulted from development of the tunnel complex and a total of 202 cultural features associated with this activity have been recorded. The U12n Tunnel complex is eligible to the National Register of Historic Places as a historic landscape under criteria a and c, consideration g of 36 CFR Part 60.4. It is eligible under criterion a because of its historic significance at the NNSS and its role in national defense during the Cold War between the United States and the former Soviet Union. It is eligible under criterion c because of specialized engineering techniques and achievements developed to carry out nuclear tests underground.

Because of the nature and significance of the property, the U12n Tunnel complex is recommended to be maintained in situ as a historic landscape. A historic landscape is one associated with a historic event or series of events, where the landscape has been planned, altered because of a desired function, and has a discernable pattern. The U12n Tunnel complex is also recommended to be included in the NNSS cultural resources monitoring program to be monitored on a regular basis.

The following sections of this report are the research design and methods for this historic evaluation; historic context for nuclear testing at the NNSS, with an emphasis on underground testing; environmental setting of the U12n Tunnel that discusses the location, geology, topography, and natural resources; description of the U12n Tunnel that presents summaries of the nuclear tests conducted in the tunnel, the geomorphology, and descriptions of the cultural features; and, overall summary, with National Register eligibility and management recommendations. Appendix A provides a more detailed description of the geology for Rainier Mesa and Appendix B lists the contractors and government agencies that participated in the U12n Tunnel tests.

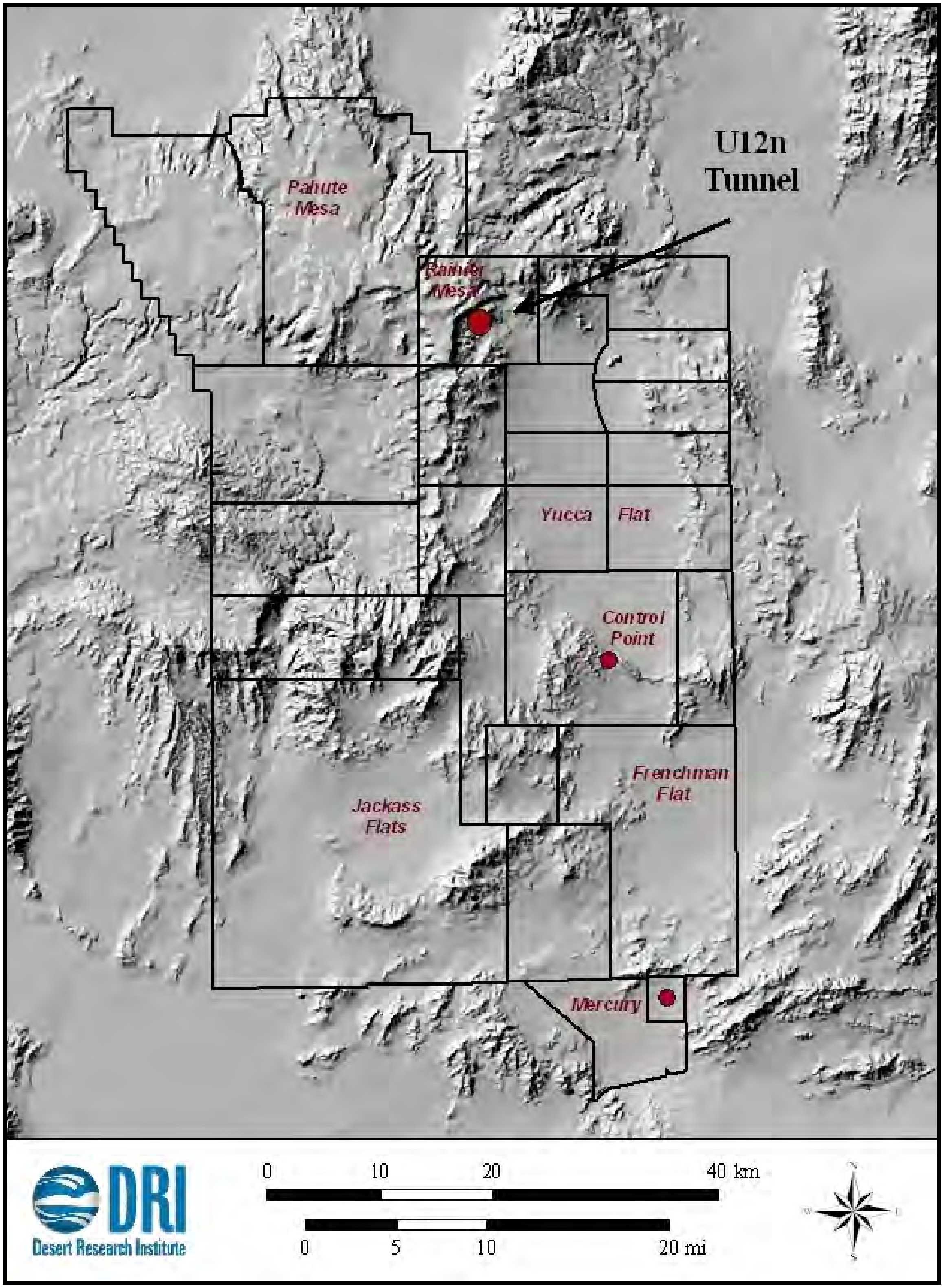


Figure 1. Location of the U12n Tunnel on the Nevada Test Site.

RESEARCH DESIGN AND METHODS

The U12n Tunnel historical evaluation is the fourth study of a nuclear testing tunnel at the NNSS. The other three are the U12b Tunnel (Jones et al. 2006), the U12e Tunnel (Drollinger et al. 2007), and the U12t Tunnel (Drollinger et al. 2009). Historic themes for these studies are nuclear testing and national defense. Other studies of cultural resources on the NNSS with similar historic themes are the Area 2 Equipment Support Yard (Johnson 1994), the Japanese Village (Johnson and Edwards 1996), Camp Desert Rock (Edwards 1997), the Apple-2 Historic District in Yucca Flat (Johnson and Edwards 2000), the Frenchman Flat Historic District (Johnson et al. 2000), the Yucca Lake Historic District (Jones et al. 2005), underground nuclear test locations in Frenchman Flat (Jones and Drollinger 2001), bunkers used in atmospheric nuclear tests (Edwards and Johnson 1995; Johnson 2002; Jones 2003, 2004), benches for viewing atmospheric nuclear tests (Jones 2005), buildings in the Area 6 control point area (Drollinger et al. 2003), the Super Kukla facility (Drollinger et al. 2000; Drollinger and Goldenberg 2004), and the Pluto Control Facility Historic District (Drollinger et al. 2005).

Cultural resources determined eligible to the National Register of Historic Places from the above studies include structures in the Frenchman Flat and Yucca Lake Historic Districts, houses and other structures in the Apple-2 Historic District, the Japanese Village, the atmospheric testing bunkers, the viewing benches, buildings in the control point, the Super Kukla facility, the Pluto Control facility, and the U12b, U12e, and U12t Tunnels. Sedan Crater, a Plowshare nuclear experiment conducted in 1962 on the NNSS, is listed on the National Register of Historic Places. All of these historic properties date to the Cold War era and are representative of the various nuclear testing activities carried out at the NNSS during this period.

The research design for this historical evaluation of the U12n Tunnel complex consisted of background research, interviews, and field documentation. A major focus for this study was to obtain documents to describe the historic context of the U12n Tunnel in order to evaluate its historic significance and exceptional importance for eligibility to the National Register of Historic Places. Historic information for this evaluation is based on available unclassified records and interviews. These include documents and photographs from the NNSA/NSO Nuclear Testing Archive, Las Vegas; the NNSA/NSO Technical Library, North Las Vegas; the NNSA/NSO Remote Sensing Laboratory, Las Vegas; the Archives and Records Center, Mercury, Nevada; the Archives at Lawrence Livermore National Laboratory, Livermore, California; and the Defense Threat Reduction Information Analysis Center (DTRIAC), Kirtland Air Force Base, New Mexico. In addition, the Desert Research Institute in Las Vegas maintains records of the cultural resources inventories, historic evaluations, mitigations, and archaeological site information for the NNSS. Interviews were conducted with key personnel who worked at U12n Tunnel. All photographs and drawings in this report have been approved for public release.

A second major focus of this study was the physical setting and description of the U12n Tunnel complex and consisted of on-site visits, photographs, mapping and measurements of extant features, and mapping of the geology and geomorphology. Components of the U12n Tunnel complex are shown in Figure 2. These include the portal area with 52.6 acres (21.3 hectares) and the mesa area with 548.2 acres (221.8 hectares). Total surface area for the tunnel complex is 600.8 acres (243.1 hectares). Fieldwork for the U12n Tunnel complex consisted of 20 intermittent days from July to

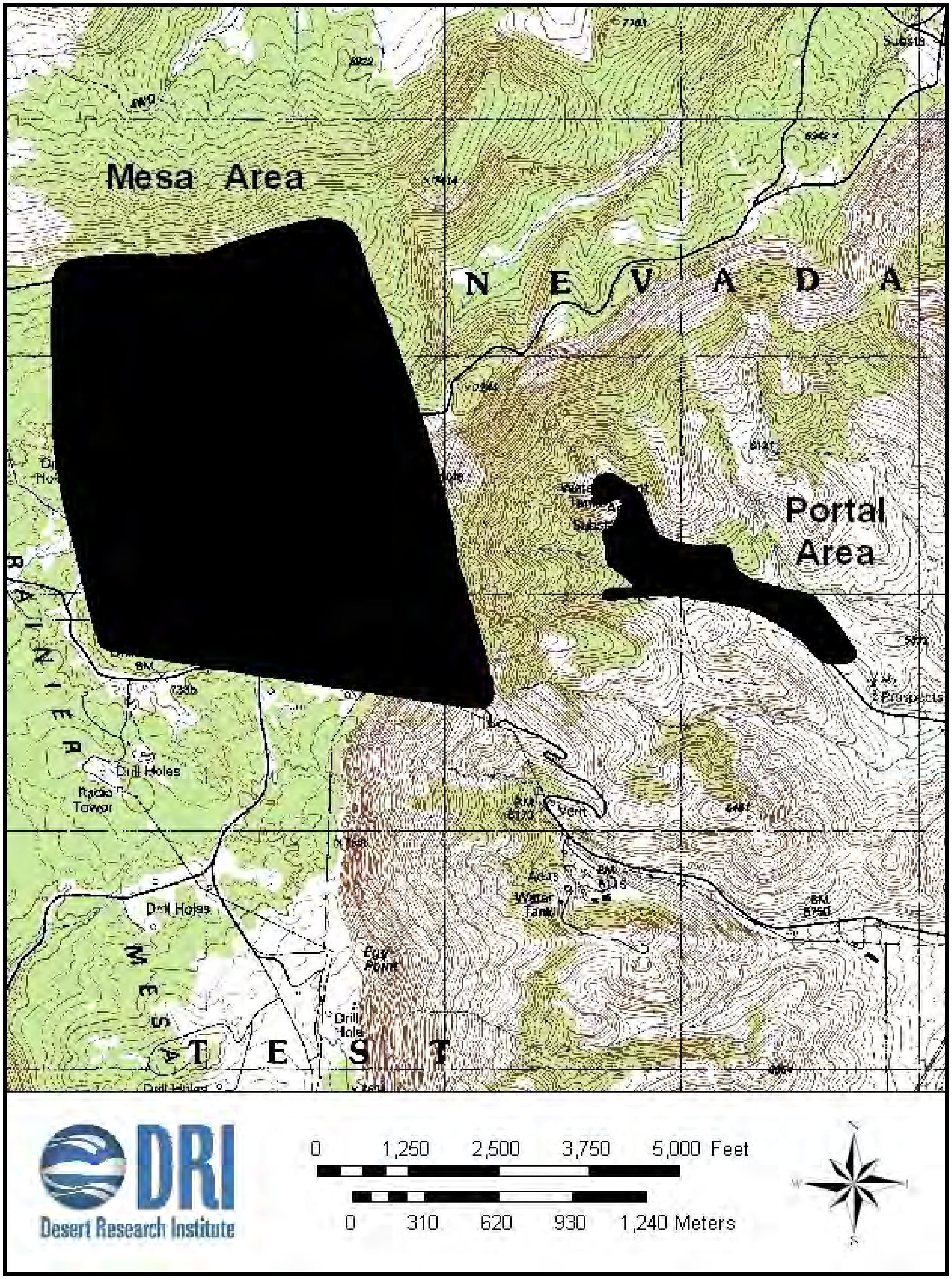


Figure 2. Mesa and portal areas for the U12n Tunnel (USGS Rainier Mesa 7.5 min 1986).

November 2008 and March 2009. The fieldwork was restricted to the exterior settings of the portal and mesa areas. Boundaries of the U12n Tunnel historic landscape and the geomorphology study area were based on these field recordings and from available documents. This work was conducted by archaeologists Robert Jones and Barbara Holz, Desert Research Institute, Las Vegas and geomorphologist Thomas F. Bullard, Desert Research Institute, Reno. A total of 202 cultural features, 83 at the portal area and 119 at the mesa area, were recorded. Overall dimensions and digital, color, and black-and-white photographs were taken of each feature. The negatives of the photographs and electronic copies of the digital photographs are on file at the NNSA/NSO curation facility, Frank H. Rogers Building, Desert Research Institute, Las Vegas.

The purpose of the geomorphology study was to document the changes in the landscape as a result of site preparation and tunneling activities. This study, conducted in November 2008, was accomplished by making a reconnaissance-level map of the surficial and bedrock geology at the site. During field visits, the extent of waste rock or muck from mining operations, fill emplacements, cut slopes, material side-cast during road construction activities, and building pad preparations on Rainier Mesa were mapped to the degree that time and access permitted. No surface disturbing activities (e.g., digging) or detailed field descriptions of bedrock or soils were undertaken.

The general geologic framework of the area was based on published literature, geological survey reports of rock units encountered during tunnel construction, and the distribution of muck and change in surface characteristics. During the nuclear weapons testing period in the U12n Tunnel, geological studies were carried out by the United States Geological Survey (USGS) and Fenix and Scisson, Inc., to address the geology and structure, mineralogy and chemistry of rock units, and to thoroughly characterize geophysical and physical properties of the tunnel rocks. Surface and subsurface geologic mapping was performed along with a number of geophysical investigations both in situ (for example spontaneous potential logs and sonic logs) as well as inspection and testing of borehole cores for mineralogy, chemistry, and geophysical properties, and vertical and lateral porosity and permeability. Geophysical surveys carried out in the U12n Tunnel complex were some of the most extensive in the tunnel complexes of Rainier Mesa (Carroll and Kibler, 1983).

HISTORIC CONTEXT

The historic context for the U12n Tunnel is both local and national because of its role in the United States nuclear weapons testing program at the NNSS during the Cold War with the former Soviet Union. A result of this confrontation was an ever-escalating arms race for nuclear weapon superiority (Anders 1978:4; Loeber 2002:80; Ogle 1985:20). This led to numerous nuclear detonations worldwide in the atmosphere, outer space, underwater, and underground.

U.S. Department of Energy

Shortly after World War II, the Atomic Energy Commission (AEC), now the U.S. Department of Energy (DOE), was established when President Harry Truman signed the Atomic Energy Act of 1946. The purpose of the act was to address government control of fissionable material, nuclear experiments for military applications, and regulations pertaining to the release of scientific and other related data. The function of the AEC was to maintain civilian government control of the research, development, and production of atomic weapons for the military (Anders 1978:2). Nuclear weapons research was conducted at the Los Alamos Scientific Laboratory (LASL), now the Los Alamos National Laboratory (LANL), New Mexico, established in 1943 as part of the Manhattan Engineer District. Development and production of the weapons took place at Sandia Laboratory, now the Sandia National Laboratories, New Mexico, established in 1948; the Y-12 Plant in Oak Ridge, Tennessee; at Hanford, Washington; and the Rock Island Arsenal in Illinois (Anders 1978:3; Brady et al.1989:18-19; Stapp 1997). Following the first nuclear detonation by the former Soviet Union in 1949 (Anders 1978:4; Ogle 1985:20), increased efforts for research and production were implemented in the United States. A second nuclear weapons research laboratory was established in 1952 at Livermore, California (Brady et al.1989:18). The Livermore laboratory was initially designated as the University of California Radiation Laboratory, a branch of the Berkeley Radiation Laboratory, and then in 1958 it became the Lawrence Radiation Laboratory. In 1971, it separated from the Berkeley laboratory to become a national laboratory, and in 1982, it became the Lawrence Livermore National Laboratory (LLNL) (DOE 1997:203). Other facilities added to the nuclear weapons industry in the 1950s included manufacturing plants at Rocky Flats near Golden, Colorado; the Kansas City Plant in Missouri; the Burlington Army Ordnance Plant in Iowa; the Pinellas Plant in Largo, Florida; Mound Laboratory in Miamsburg, Ohio; and the Pantex Plant near Amarillo, Texas (Anders 1978:4; DOE 1997:27).

The United States and the former Soviet Union ceased nuclear testing in 1958 by self-imposed moratoriums at the urging of internal and external forces (Ogle 1985:30-31), but by 1961 both superpowers were once again conducting nuclear tests. Except for a few surface and near-surface tests, most of the tests were placed underground, and after ratification of the Limited Test Ban Treaty by the United States, the former Soviet Union, and Great Britain in 1963, all nuclear tests were underground (Friesen 1995:6). According to the treaty, no tests could be conducted in the atmosphere, outer space, or underwater. Furthermore, certain safeguards for the United States were established in order for the U.S. Senate to ratify the treaty (DTRA 2002:246). These safeguards were an intensive underground testing program, maintenance of the weapons laboratories, the ability to resume atmospheric testing on short notice, and improvements in verifying compliance to the treaty. In 1974, the United States and the former Soviet Union agreed to the Threshold Test Ban Treaty and, in 1976, to the Peaceful Nuclear Explosions Treaty in order to restrict nuclear test explosions to a defined test site and to yields no greater than 150 kilotons. A second self-imposed moratorium on nuclear testing by the United States was established in 1992, and in 1996, the United States signed the Comprehensive Test Ban Treaty banning all nuclear tests. This latter treaty, however, has yet to be ratified by the U.S. Senate.

U.S. Department of Defense

The U.S. Department of Defense (DoD), with the establishment of the Armed Forces Special Weapons Project (AFSWP) in 1947, had a continuing role post-World War II in the testing of nuclear weapons at the Pacific Proving Grounds and later at the NNSS (DTRA 2002). This group evolved over the years through reorganization and mission change into the Defense Atomic Support Agency (DASA) from 1959 to 1971, the Defense Nuclear Agency (DNA) from 1971 to 1996, the Defense Special Weapons Agency (DSWA) from 1996 to 1998, and currently as DTRA, established in 1998. General L.R. Groves, who was instrumental in developing the first nuclear weapon during the Manhattan Project and in keeping the military active in the nuclear weapons industry after the war, was appointed chief of AFSWP in early 1947 (DTRA 2002:35). The primary mission was to train military personnel in the assembly, storage, and firing of the atomic weapon, tasks previously conducted primarily by civilian scientists.

By 1949, when AFSWP was set up and operating, it was assigned the tasks of studying the effects of nuclear weapons on targets underwater, underground, and in the atmosphere and for radiological warfare (DTRA 2002:71-72). More tasks soon followed as the agency and the nuclear weapons industry as a whole became more adept. For example, the agency began to provide specialized training and technical support, coordinated storage and oversight of the ever-expanding nuclear weapons stockpile, and became more involved in the planning and operation of the weapons tests (DTRA 2002:80, 104). Most importantly, for the first time the defense agency participated in the development of the nuclear weapons and associated systems. DASA became the new name for the organization in 1959, and with the change, the added responsibility for the supervision of weapons effects tests for all the different military branches (DTRA 2002:149). The agency by this time also served as an integral information source in Cold War strategy for the United States.

Significant changes occurred in the agency during the 1960s. The number and diversity of nuclear weapons, including the associated delivery and defense systems increased dramatically in response to the high state of nuclear readiness of the Cold War policy (DTRA 2002:173). DASA had to modify the weapons effects tests and management of the weapons stockpile accordingly. It also meant changes or upgrades in scientific and technical staff within the organization to increase research and development. At the same time, as the role and prominence of the agency changed, control of the agency was placed directly under the civilian Secretary of Defense rather than the joint chiefs of the military services. In addition, because of the current situations and readiness for immediate response in case of attack, custody of the nuclear weapons stockpile was formally transferred from the AEC to the DoD (DTRA 2002:178). It was agreed that the AEC would be responsible for weapons development, quality assurance of the weapons stockpile, effects tests on warhead components, and management of the NNSS; while DoD through DASA would provide testing facilities, certain hardware for diagnostics and data recording, field support, and funding (Brady et al. 1989:9; DTRA 2002:180). Both agencies would still be able to conduct nuclear tests, with devices supplied by the Livermore or Los Alamos national laboratories through the AEC, and both would do research in detecting nuclear tests by other nations.

A major difference in research objectives also occurred between the AEC and DASA (DTRA 2002:189). DASA began to emphasize research on the actual use and effects of the nuclear weapon by the military. This emphasis contrasted with the research interests and desires of the weapon developers for the AEC, whose main focus was on developing the weapon and not how it was going to be used. Because of limits imposed on testing in 1963, three methods of nuclear weapons effects tests were implemented by the defense agency (DTRA 2002:191). The first was improvements in underground testing techniques, particularly for containment; the second was the use of high explosives rather than nuclear explosives for some of the effects tests; and the third was the use of simulators, such as reactors, in some of the effects tests. Large scale simulators, once constructed and operating, could do a series of tests in one day compared to a single nuclear test in a tunnel or shaft that could take up to two years to conduct (DTRA 2002:239). High explosive testing could also be prepared faster and easier than a nuclear test and with less safety and security concerns. These types of tests and simulations, however, could not replicate all the experiments and effects that could be conducted with a nuclear explosion, so nuclear testing was still considered necessary. It was found that nearly all the military systems, when fully assembled and all components interacting together, initially failed during an actual nuclear weapons effects test, (Ristvet et al. 2007). Nuclear testing was also considered necessary for testing the reliability of the weapons stockpile (DTRA 2002:250).

Several important changes were made in the 1970s. One was the reorganization of the AEC due to conflicts of interest in regulating itself. It was divided in 1974 into the Energy Research and Development Administration (ERDA) and the Nuclear Regulatory Commission to solve the problem (Buck 1983:8; DTRA 2002:216). Soon thereafter, in 1977, ERDA was incorporated into a cabinet level organization as DOE. A second change was the reorganization and reduced responsibilities of the DASA, including a new name, the DNA (DTRA 2002:216). The DNA’s primary mission now consisted of nuclear weapons management, nuclear weapons testing, and nuclear weapons effects research. Reduction in personnel at the agency was also implemented and reflected the military branches increasing supervision of the nation’s nuclear weapons, particularly by the U.S. Air Force. In Albuquerque, New Mexico, the Kirtland Air Force Base, the Sandia Base, and the Manzano Base came under the control of the Air Force; Johnston Atoll remained under the management of the Air Force, with a lesser role by the DNA; and training in nuclear weapons became the responsibility of each of the military branches. Nuclear weapons training would return to the DNA in the early 1990s, however.

In the late 1970s and early 1980s, DNA had an important role in the buildup of the military and national defense of the United States (DTRA 2002:259). The central theme of this role was survivability from a nuclear weapons attack, particularly the improvement and hardening of the various military weapons systems against such an attack. Efforts were also made to improve and harden communication systems, airplanes, airplane components, missiles, missile components, and underground bunkers. These efforts often used high explosive tests in order to simulate open air reactions or blast effects to the materials and structures as in an actual attack. Earlier weapons effects data from atmospheric nuclear tests at the NNSS were also used to bolster these efforts.

The late 1980s and early 1990s heralded the end of the Cold War and an assortment of treaties calling for the reduction of strategic and tactical weapons (DTRA 2002:282, 294). In 1992, the Hunters Trophy test conducted in the U12n Tunnel was the last nuclear weapons effects test at the NNSS (DTRA 2002:296). Since then, the NNSS has served as a testing ground for non-nuclear munitions against hardened installations. Also, because of changing world conditions and the emergence of weapons of mass destruction and terrorism, the mission of the DNA was re-evaluated and a reorganization was sought that reflected these conditions and the perceived needs of the military. Consequently, the DNA was replaced by the DSWA in 1996 with a new mission focusing on threat reduction, arms control, and support for counter proliferation activities (DTRA 2002:314). DSWA still performed the previous tasks, including the management of the military nuclear weapons stockpile. Tantamount to this was the vast amount of information the agency possessed from its inception about nuclear weapons (DTRA 2002:318-319). Programs, such as the Data Archival and Retrieval Enhancement Program, were initiated to assemble data about the technical history of atmospheric and underground nuclear weapons effects testing. These programs enabled the information already gathered over the years to be stored for future use and provide to new defense projects the research material about nuclear weapons effects without having to repeat the tests.

DTRA was created in 1998, incorporating DSWA, the On-Site Inspection Agency, the Defense Technology Security Administration, and some staff from DoD (DTRA 2002:322). While it still retained its nuclear stewardship responsibilities, this newest agency would concentrate on perceived defense threats. Its mission statement is to reduce threats to the United States and its allies from nuclear, biological, chemical, conventional, and special weapons (DTRA 2002:323). These tasks, though somewhat altered due to evolving technologies and management roles, still conform to the mission when the agency first started and it still maintains a key presence in the testing programs at the NNSS today.

Nevada National Security Site

During the late 1940s, a search was conducted to establish a test site in the continental United States, remote from the populace and near the research laboratories. The main reasons for this were security, shorter travel times, and economic costs in the transportation of people and equipment (Lay 1950; Ogle 1985:44; Tlachac 1991). At the time, testing was conducted at the Proving Grounds in the Pacific Ocean and was expensive in both cost and time. Security at the Pacific locale became a major concern due to the situation developing in Korea (DTRA 2002:77). Four places in the United States were seriously considered for a continental testing ground: Camp Lejeune in North Carolina, Dugway Proving Ground in Utah, White Sands Proving Ground in New Mexico, and the Las Vegas Bombing and Gunnery Range in southern Nevada (Lay 1950). The ideal location, in addition to the attributes described above, was to have favorable and predictable weather and terrain conditions to be able to test year round, be under federal control, and have an infrastructure already in place (Lay 1950; Tlachac 1991).

The bombing and gunnery range in southern Nevada was the place chosen that best met the conditions for the continental test site. The first nuclear weapon test, Able of Operation Ranger, was carried out in Frenchman Flat on January 27, 1951 (Ogle 1985:43-44; Titus 1986:58). Construction of the facilities for the Nevada Proving Grounds, as it was originally designated, began soon afterwards. After a series of name changes, it became the Nevada Test Site on the last day of 1954 and remained so until August 2010 when the name was changed to Nevada National Security Site. The first land withdrawal by the AEC establishing the official nuclear weapons testing ground in the continental United States was February 12, 1952 under Public Land Order 805. Additional land parcels were obtained under public orders and memorandum of agreements. Today the NNSS encompasses an area of approximately 1,360 square miles (3,522 sq km), and spans approximately 55 miles (89 km) north-south and 30 miles (50 km) east-west.

A total of 928 atmospheric and underground nuclear tests have been conducted at the NNSS, with 120 performed in the 1950s and 808 after 1961 (DOE/NV 2000; Friesen 1995:6, 10). Atmospheric tests number 100, and most were conducted on Frenchman Flat or Yucca Flat during the 1950s. Three atmospheric nuclear tests were conducted in the upper Fortymile Canyon area. Most of the underground nuclear tests were either in vertical shafts on Pahute Mesa and Yucca and Frenchman Flats or in horizontal tunnels mined into the sides of Aqueduct and Rainier Mesas. Some underground tests were on Buckboard Mesa, Oak Butte, and Dome and Shoshone Mountains.

Atmospheric Nuclear Testing

In the 1950s, the nuclear devices were initially dropped from airplanes for the atmospheric nuclear tests on the NNSS, but due to efforts for greater monitoring and a general lack of control on air drops, the devices were placed near the ground, on top of towers, and eventually elevated by balloons to the desired height. Also at this time in the Pacific arena, high altitude tests of large yield were being performed, mostly by balloon, a few on rockets into outer space, and some on barges and underwater (Ogle 1985:49-50). Main objectives of the testing were for monitoring, measuring, perfecting techniques, and technological improvements of the nuclear weapons (Ogle 1985:84-85). Other objectives included physical effects (DTRA 2002:106). Some of the earliest experiments determined the physical effects on naval ships, while later experiments were physical effects on airplanes, tanks, jeeps, automobiles, clothing, docks, and different types of houses, underground structures, and radio and radar transmissions. At the NNSS, various structure and building designs were included for civil defense, such as underground shelters, domed subterranean structures, concrete and brick buildings, residential houses, a metal bridge, and a bank vault. In some cases, U.S. Army personnel participated in the tests for preparation of nuclear warfare. Camp Desert Rock, located at the south edge of the NNSS, was created to house military and other personnel involved in the nuclear tests as participants or as observers (DTRA 2002:80, 85; Edwards 1997).

Underground Nuclear Testing

The concept of the underground test, versus atmospheric, was not acted upon until the late 1950s when containment of the nuclear explosions became a major issue (Carothers 1995:16, 20; Johnson et al. 1959:2; Malik et al 1981:12; Byron Ristvet, personal communication 2006). Radioactive fallout was a safety and health concern for both the workers doing the tests and for the public at large. Following the signing of the Limited Test Band Treaty in 1963, all nuclear tests were designed to be contained underground except for four Plowshare cratering experiments (Schoengold et al. 1996:2). Initially, this posed a new engineering challenge and learning experience and not all tests were able to be contained right away. After a number of underground nuclear tests had been completed, it was determined that radioactive material from nuclear tests could be satisfactorily contained with proper depths of burial, stemming of the drill hole or tunnel, blocking seeps around cables and pipes, and understanding the surrounding geology for possible cracks or other weaknesses (Malik et al 1981:12-15).

Most of the underground nuclear tests at the NNSS have been for either weapons development or for weapons effects (DOE/NV 2000). A few tests had other purposes, such as safety experiments, industrial engineering for the Plowshare program, and seismic monitoring. Weapons development tests evaluated the performance of the nuclear device itself and were usually placed in vertical shafts; whereas, weapons effects tests evaluated the effects on critical components of missiles and warheads, and sometimes entire systems, and were usually conducted in horizontal tunnels deep underground (Brady et al. 1989:2; Wolff 1984). Generally, two to four years went into the planning, preparation, construction, and post test analyses of a single underground nuclear weapons effects test.

At DTRA in the early 1960s, a shift toward weapons effects rather than the interests of the weapon developers guided the research (DTRA 2002:189). The effectiveness of the weapons systems during a nuclear attack was a primary concern. To further advance this research and because the treaty required testing to be conducted underground, new methods of testing had to be devised. A range of underground testing options was explored from line-of-sight pipe systems assembled within vertical shafts and horizontal tunnels to cavities and underground structure experiments mined or constructed within a tunnel complex or at the bottom of a vertical shaft. The underground nuclear weapons effects tests conducted by DTRA used each or a combination of these options. The primary objectives of a DTRA underground nuclear weapons effects test were to construct a facility in which to install, expose, and protect the experiments; record data obtained from the experiments; contain the nuclear detonation and its byproducts underground; and recover the experiments and equipment after a test.

As underground testing techniques improved, horizontal tunnels increasingly were preferred over vertical shafts by DTRA because of the flexibility they provided (DTRA 2002:193-194). For example, rooms could be readily mined to appropriate dimensions to house various sized equipment, including entire systems rather than just parts of systems, and secondary drifts could be added or drifts from a previous test could be used to place additional experiments and equipment. In contrast, the number and size of experiments were more limited in vertical shafts. Moreover, when line-of-sight pipes were constructed in vertical shafts, experiments and signal conditioning equipment positioned over the shaft had to be quickly pulled off the test locale to keep them from falling into the subsidence crater that often developed shortly after the test.

Recovering equipment and experiments from the tunnels was standard practice and undertaken with great caution because the nuclear explosion potentially created hazardous physical conditions and the possibility of high radiation levels (LRL 1961). Hazardous conditions included damage from the shock wave, which could result in a total or partial collapse of the test drift or the main tunnel; upheaval of the floor or movement along fault lines; damage to the utility infrastructure, such as ventilation; and the presence of trapped toxic and explosive gases.

Rainier Mesa

DTRA and the national research laboratories began studies in the mid 1950s on the development of underground complexes to meet their testing needs. These studies, which included high explosive testing and geology, indicated that the Rainier Mesa area would be a good location for underground nuclear testing. High explosive tests conducted in the U12a Tunnel supported the concept and Rainier Mesa was subsequently selected for this purpose. LLNL started work in Rainier Mesa by developing the U12b, U12c, U12d, U12e, and U12f tunnel complexes in the mid to late 1950s. LLNL also started the U12n Tunnel in 1962. The first underground nuclear test in a tunnel, code named Saturn, was a safety experiment that took place at the U12c Tunnel in August 1957 (DOE/NV 2000:8). The Saturn test had zero yield. The Rainier nuclear weapons-related test with a yield of 1.7 kilotons was conducted in the U12b Tunnel a month later and was the first contained underground nuclear detonation in the world (Carothers 1995:31; DOE/NV 2000:10).

Geology of Rainier Mesa, an erosional volcanic remnant, basically consists of 2,000 to 3,000 ft (610 to 914 m) of volcanic ash-fall tuff resting on earlier granitic and sedimentary rock (LaComb et al. 1996:11). Stratigraphically, it is capped at the surface by welded or rhyolitic ash-flow tuff, 150 to 300 ft (46 to 91 m) thick, more dense and stronger than the underlying tuff. Below the caprock is an unsaturated section of friable and vitric bedded tuff 600 to 800 ft (183 to 244 m) thick and below that is a thin section of welded tuff, followed by a thick section of zeolitized and water-saturated bedded tuff lying on older granitic and sedimentary rocks (LaComb et al. 1996:11). This lower bedded zeolitized tuff section is between 650 and 1,150 ft (198 and 351 m) thick and is where most of the tunnel complexes were mined. It is divided into Tunnel Beds 1 to 4, with Tunnel Bed 1 being the lowest. A more detailed description of these beds is provided in Appendix A.

The degree of water or air-void content of the geologic formations was found to affect the speed of the shock wave traveling through the rock and that certain locations for the working point, also known as ground zero or zero point, were better suited than others for the best transmission of the shock wave. Geologic samples by way of exploratory drill holes were taken of the rock formations before mining of the tunnel drifts in order to place the nuclear device in the most optimum location. Horizontal exploratory core holes drilled from within the tunnel were typically 3.25 inches (8.26 cm) in diameter and from 1,000 ft (305 m) to 2,500 ft (762 m) in length. Cores from these holes were tested for such things as bulk density, moisture content, grain density, porosity, compressive strength, triaxial compression, ultrasonic shear and compressive wave velocity (Horton et al. 1987:12). This testing was usually performed for DTRA by Holmes and Narver in the materials testing lab at the NNSS, TerraTek Corporation in Salt Lake City, Utah, and the U.S. Army Corps of Engineers, Waterways Experiment Station in Vicksburg, Mississippi. These data were required to map and understand the surrounding geology of a planned test in order to design and construct the test bed facility and protect the experiments and the environment both inside and outside the tunnel complex.

Experiment Protection

Because the 1963 Limited Nuclear Test Ban Treaty required nuclear tests to be conducted underground, new methods of testing had to be devised. A steel pipe, hundreds of feet long attached to a steel box (A-box) containing the nuclear device, was soon discovered to be a solution (Figures 3-5). This configuration, called a line-of-sight pipe, was placed in a horizontal or vertical position depending on where the test was located, in a tunnel or shaft, and served to enclose and protect experiments from the surrounding geologic media. It was also possible to create a vacuum inside the line-of-site pipe to simulate a high altitude atmospheric or exoatmospheric environment.

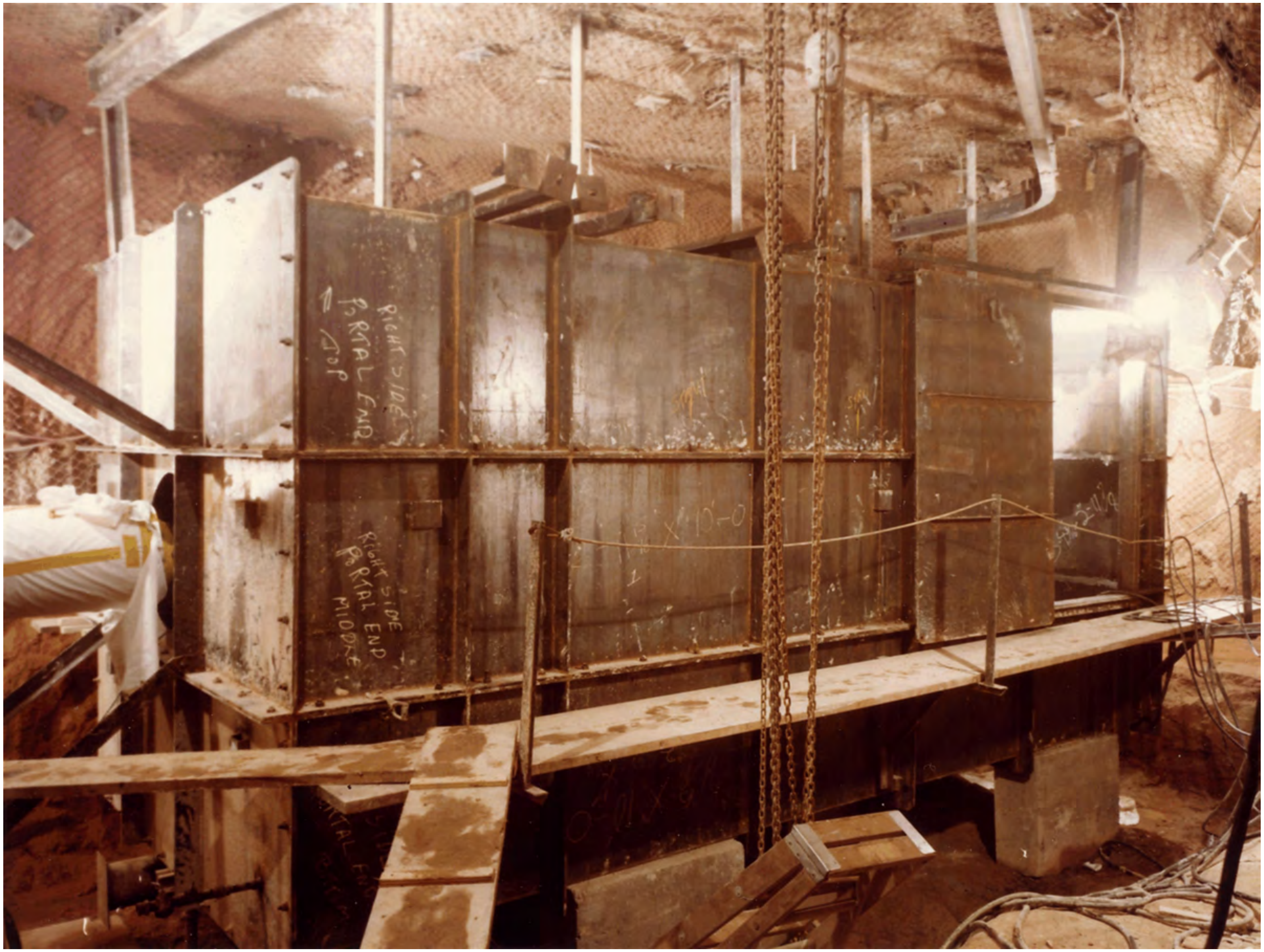


Figure 3. Construction of the A-box in the zero room for the Huron Landing nuclear test, 1981 (photograph CAA-027-2, copy on file at NNSA/NSO Curation Facility, Las Vegas, Nevada).

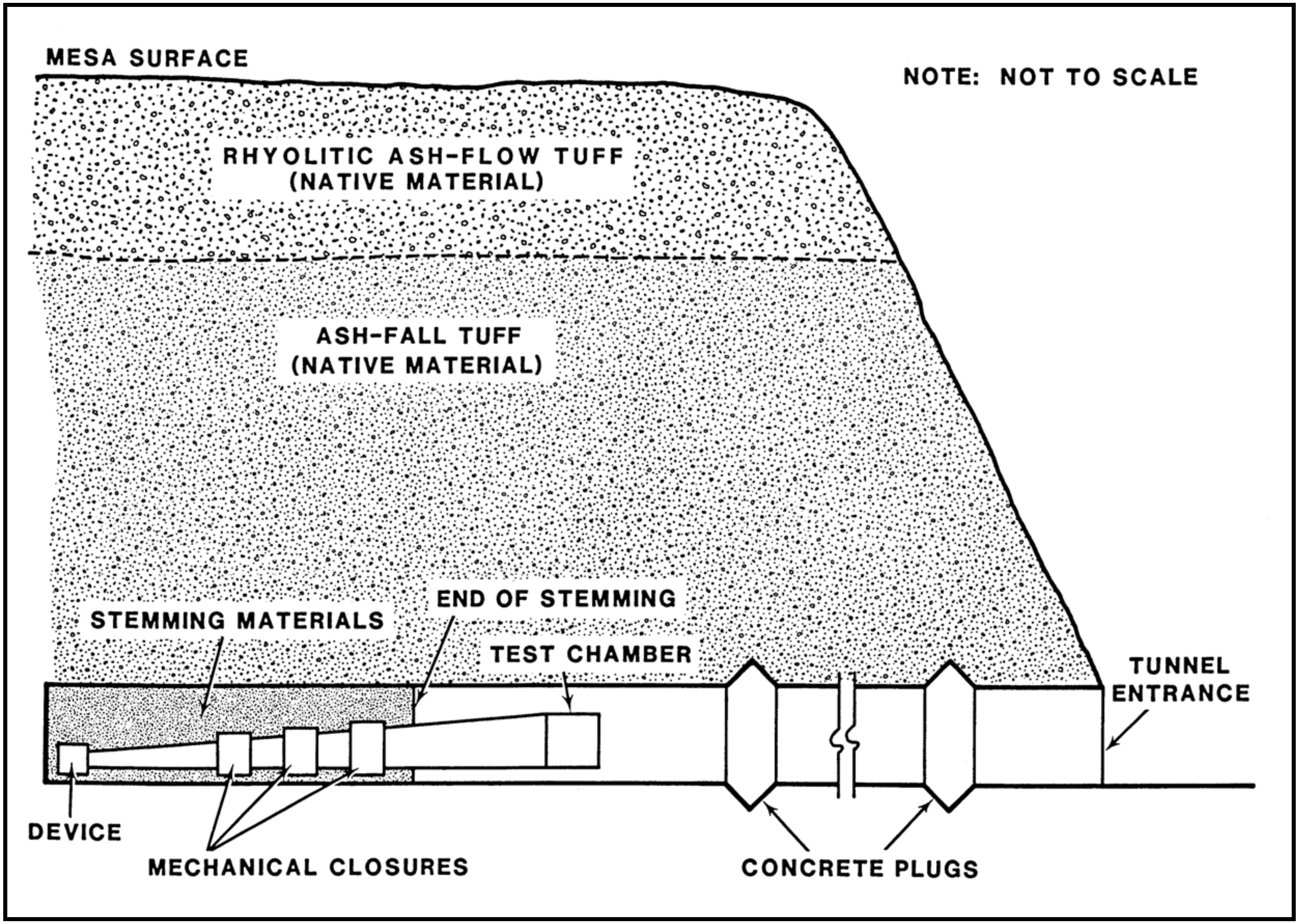


Figure 4. Schematic of an idealized horizontal line-of-site pipe configuration for tunnels (Horton et al. 1987).

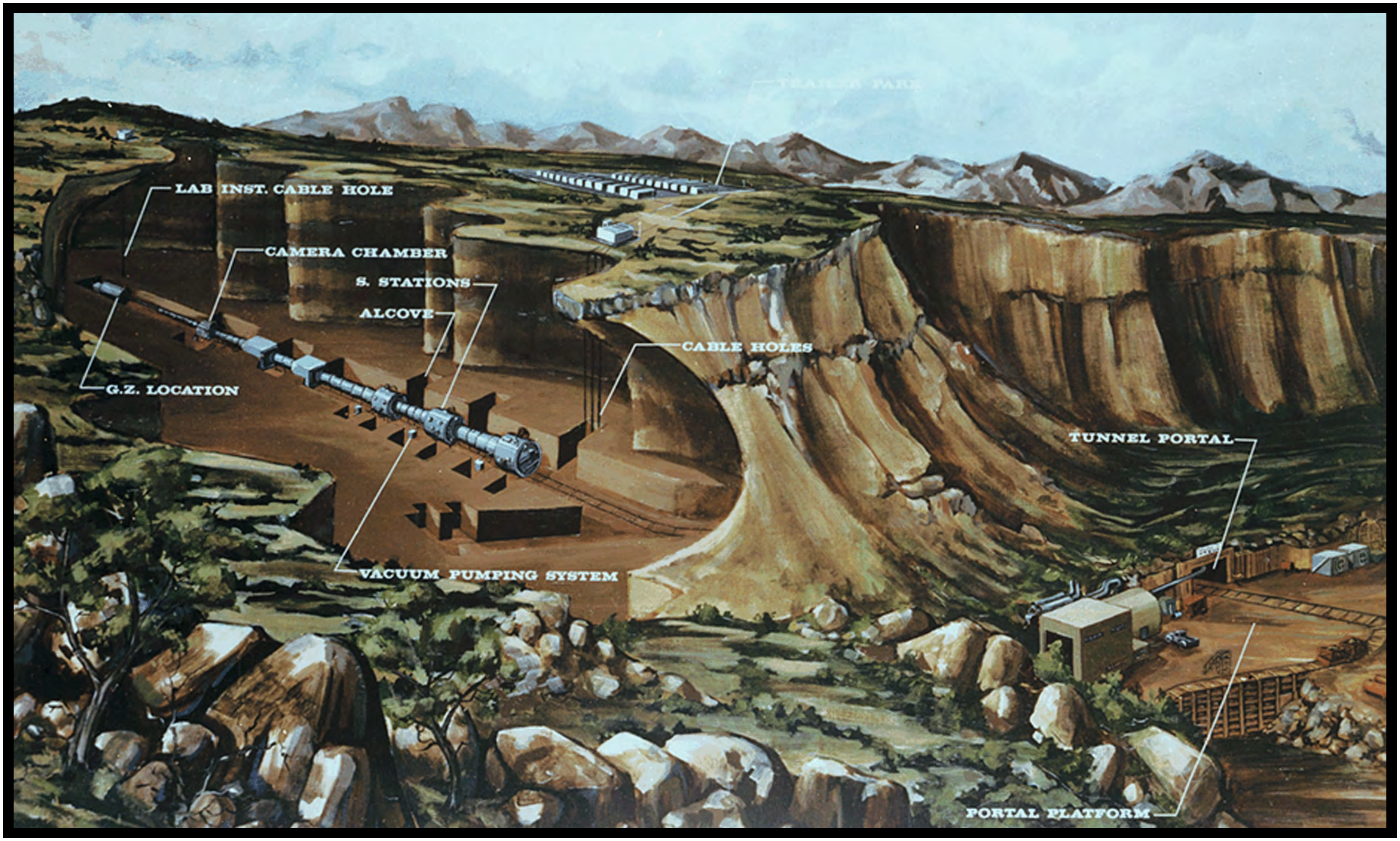


Figure 5. Typical layout of an underground nuclear weapons effects test (photograph NF-2054, on file at Remote Sensing Laboratory, Las Vegas, Nevada).

The horizontal line-of-sight pipe used in tunnels was tapered to support an expanding cone of radiation which emanated from the nuclear explosion (Figures 6-7). The horizontal line-of-sight pipes were as small as 4 inches (10 cm) in diameter at the end nearest the nuclear device and from 10 ft (3 m) to 27 ft (8 m) in diameter at the portal end; lengths varied from 100 ft (30.5 m) to 1,900 ft (580 m). Samples or experiments were placed in test chambers located at the portal end of the pipe (Figure 8), and were exposed to the radiation effects of the nuclear detonation as they passed through the pipe. The pipe was constantly checked with lasers for proper alignment during construction (Figure 9). Following pipe installation and alignment, an extensive vacuum check was conducted to determine if any leaks were in the pipe system or if there were any foreign materials in the pipe that would out gas, thereby lowering the ability to obtain the desired vacuum. Leaks were repaired and stemming of the annulus between the pipe exterior and the tunnel wall was started following a successful vacuum check. This stemming was done early to allow the heat of hydration generated by the curing grout to decrease to a level that would not distort the laser beam during installation and critical alignment of the experiments.

Experiments were mounted on special non-metallic bulkheads in test chambers. Experiments were also placed in an assortment of stub pipes at the end of the pipe. The stub pipes functioned to reduce the fluence level traveling down the horizontal line-of-sight pipe as required for some experiments, support increased vacuum requirements for some experiments, or create a specific environment for experiments where isolation from the test chamber was required.

As a final check, just prior to installing the device in the A-box at the working point, an x-ray source was used to verify alignment of each experiment in relationship to other experiments and to the eventual nuclear exposure. The temporary x-ray source was placed at the working point and the exposure face (working point side) of each experiment was covered with photographic film. Following exposure to the x-rays, the film was developed and carefully reviewed to verify that all experiments would be fully exposed to the nuclear source and that no experiment would shadow another.

Another challenge for underground nuclear weapons effects tests was preservation of the samples or equipment being tested (DTRA 2002:193). The objective of the test was to produce radiation from the nuclear explosion, allow it to travel through the line-of-sight pipe at the speed of light, and irradiate the experiments. The problem was that debris and gases from the explosion, and also traveling down the line-of-sight pipe but at a lesser velocity than the radiation, could strike and potentially destroy the experiments. The solution was to install a series of fast-closing gates or closures that effectively closed the pipe after the radiation had passed, thereby, preventing the debris from damaging or destroying the experiments. The first of these gates was the fast acting closure located closest to the working point, about 200 ft (61 m) away (Figure 10). The fast acting closure had a 30 inch (76 cm) diameter line-of-sight opening, surrounded by a copper sleeve that was surrounded by an aluminum sleeve. The sleeves were encircled with 500 pounds of high explosive data sheet and the explosive was surrounded by lead. The high explosive drove the copper and aluminum sleeves into the line-of-sight opening, creating a plug, and closing the line-of-sight pipe within one millisecond after detonation of the nuclear device. The gas seal auxiliary closure was the next in line (Figure 11), about 400 ft (122 m) from the working point. The line-of-sight opening in the gas seal auxiliary closure was about 60 inches (152 cm). The closure had two 1 ft (30 cm) thick high-strength aluminum alloy doors that slid across the line-of-sight opening from opposite sides,

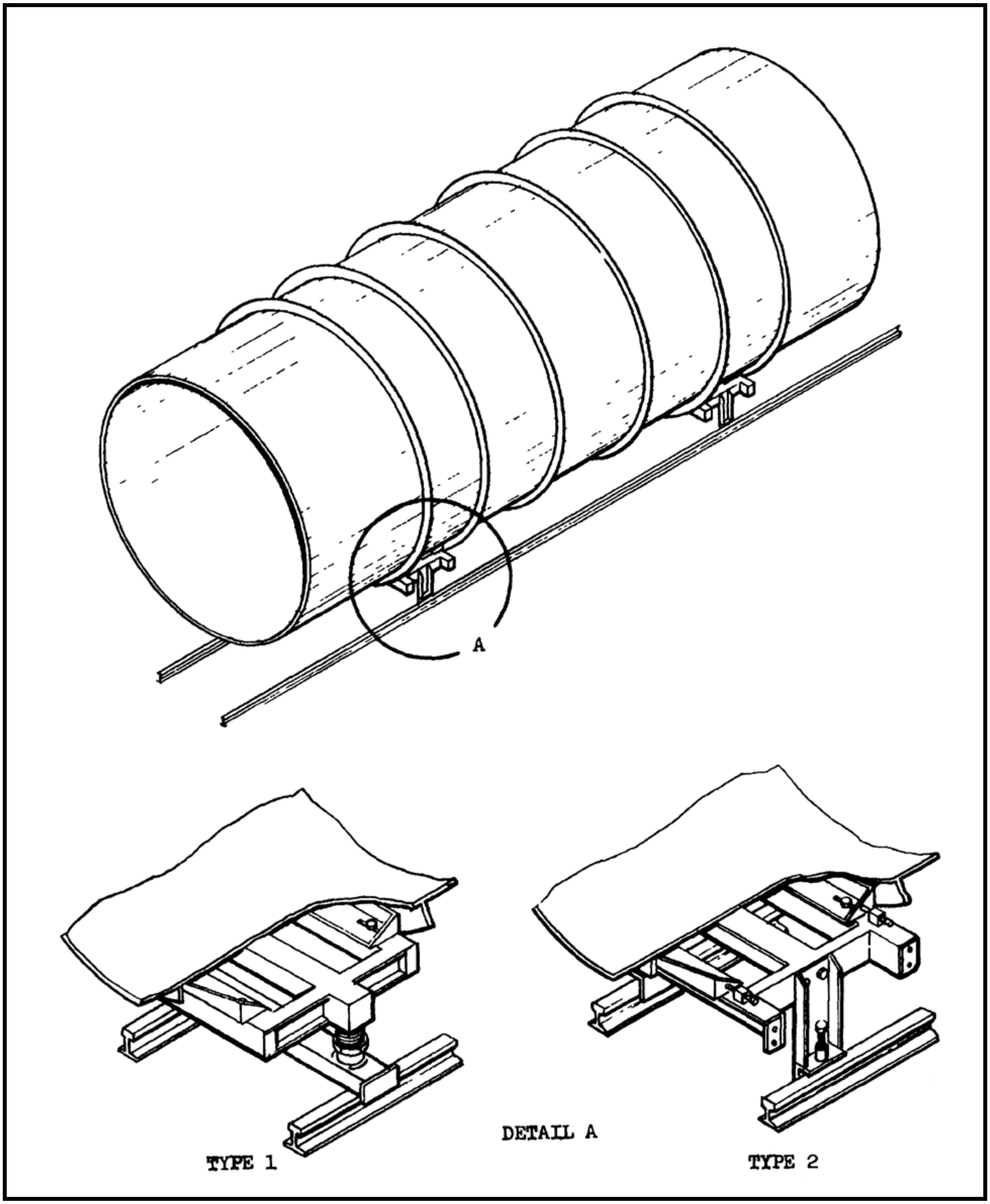


Figure 6. Sketch of a conical line-of-sight pipe section and supports (Carpenter 1971). Note the use of the tunnel rail system for attaching and aligning the pipe supports.

Figure 7. Installation of a line-of-site pipe section near the working point for the Huron Landing nuclear test, 1981 (photograph CAA-027-4, copy on file at NNSA/NSO Curation Facility, Las Vegas, Nevada).

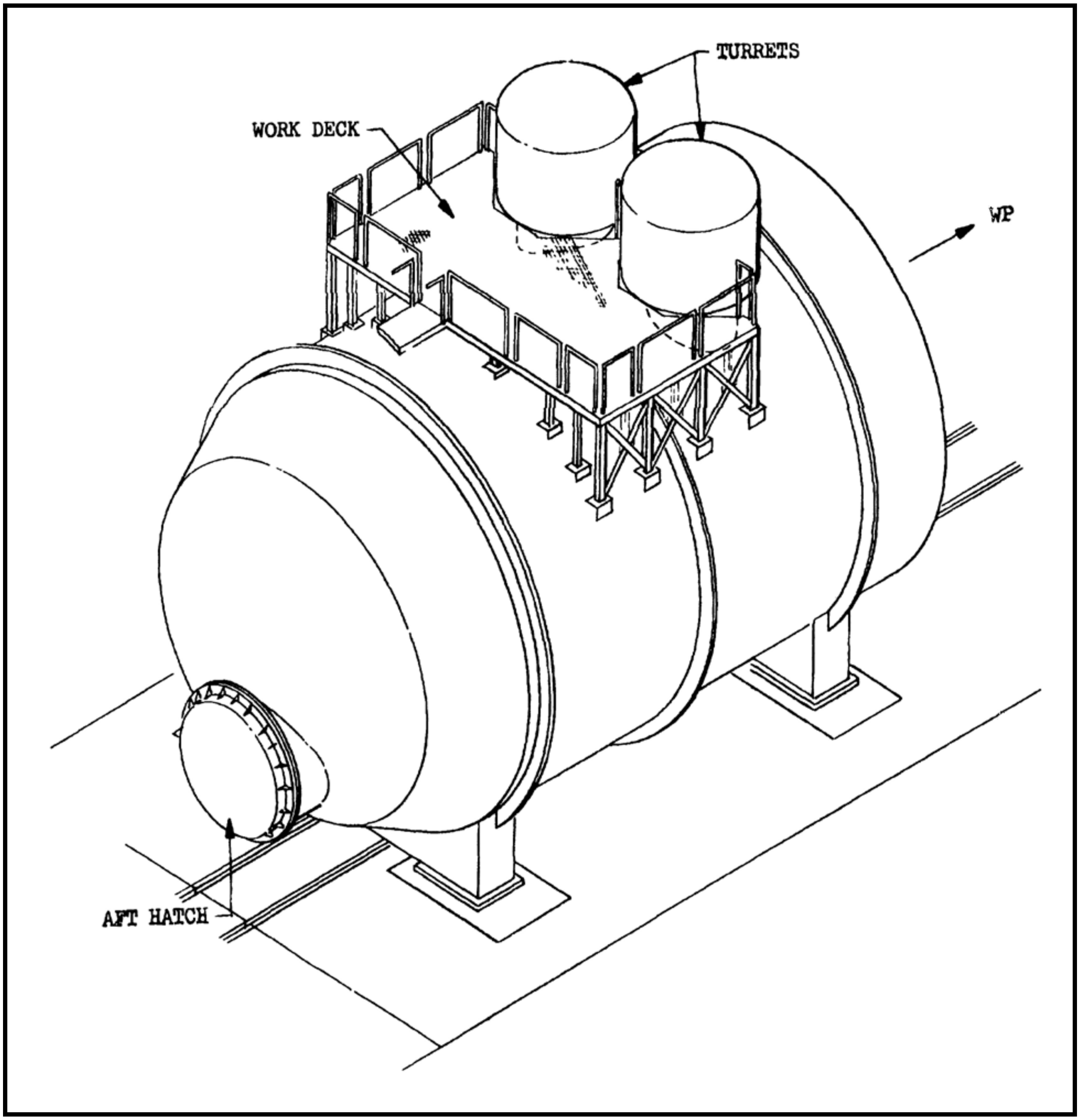


Figure 8. Sketch of a test chamber (Carpenter 1971).

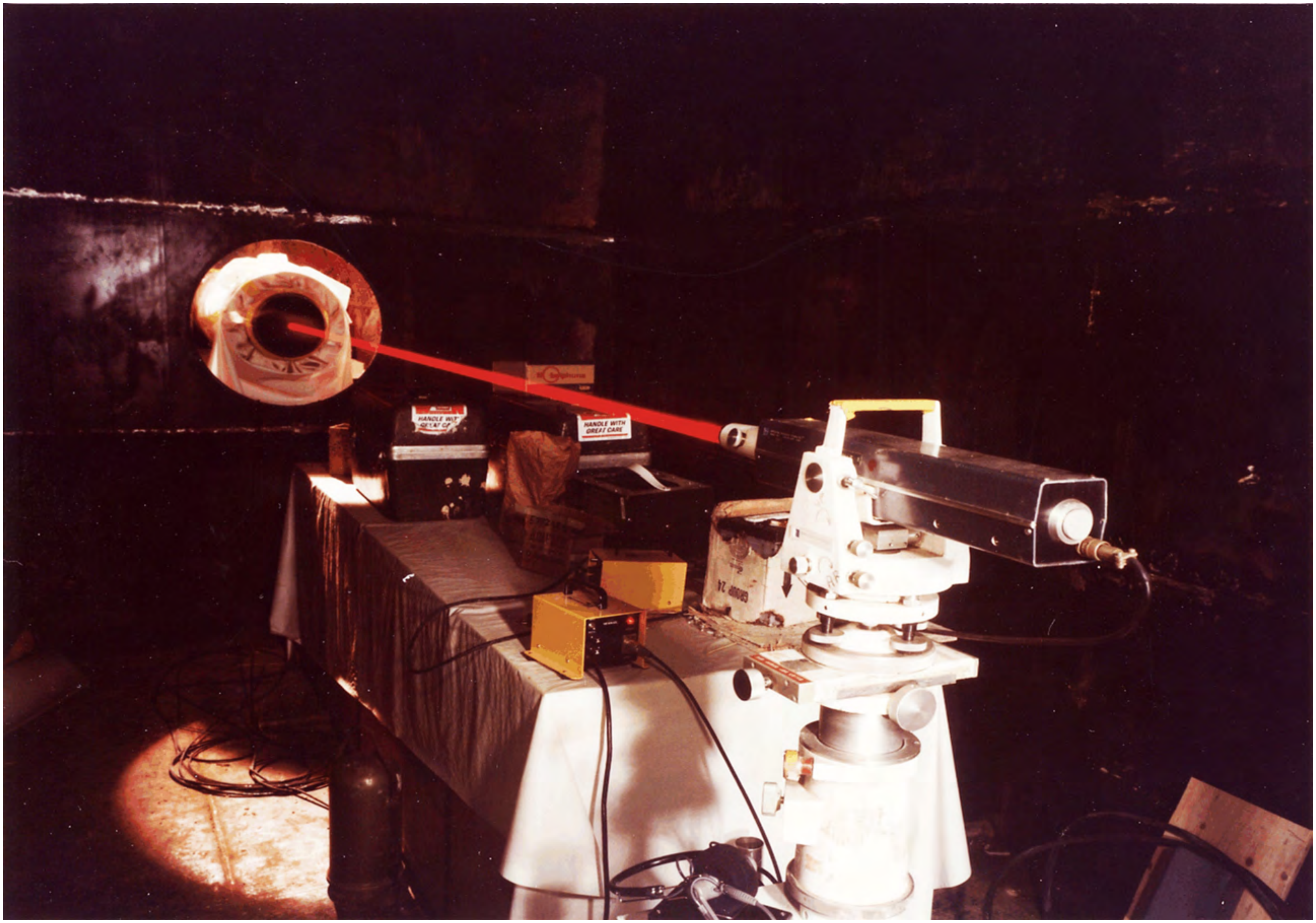


Figure 9. Aligning laser inside the A-box for the Huron Landing nuclear test, 1981 (photograph CAA-027-3, copy on file at NNSA/NSO Curation Facility, Las Vegas, Nevada).

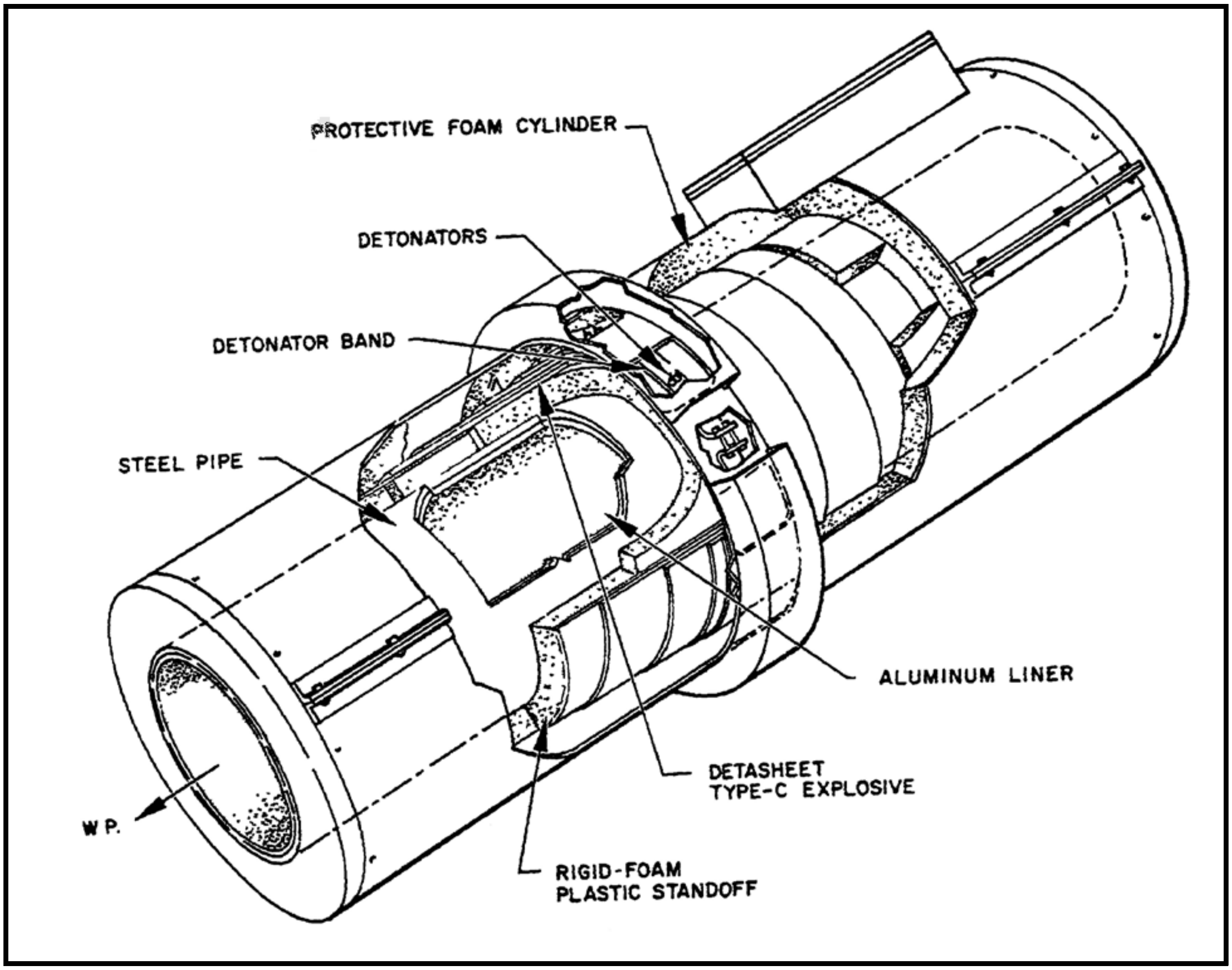


Figure 10. Sketch of a high explosive machine or fast acting closure (Buys and Williamson 1972).

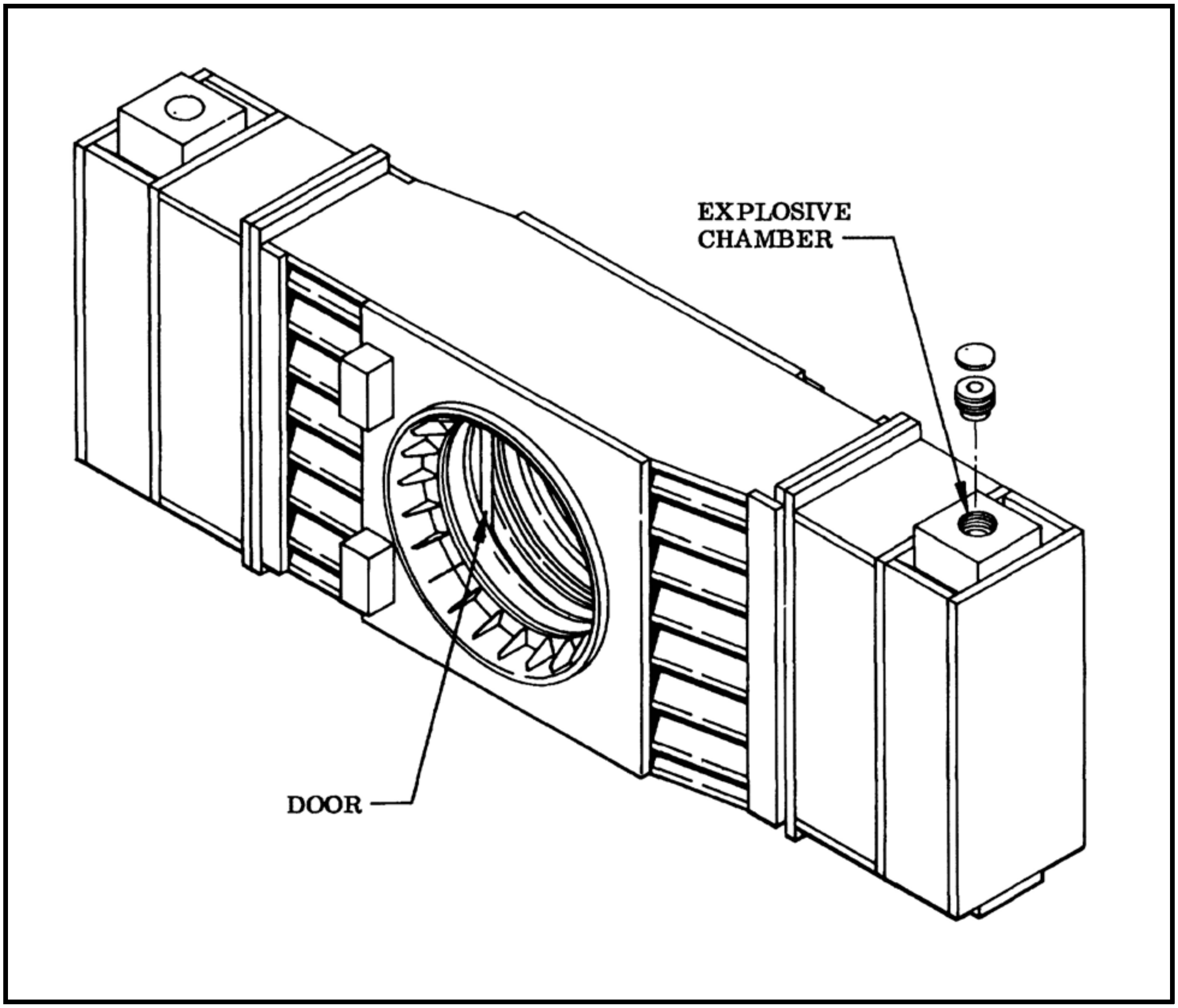


Figure 11. Sketch of the DNA gas seal auxiliary closure (Buys and Williamson 1972).

sealing it within 30 milliseconds. Its function was to stop debris and provide a tight closure so gases would not escape. The tunnel-and-pipe-seal was the third and final closure in the series (Figure 12). The tunnel-and-pipe-seal, positioned about 500 ft (152 m) from the working point and weighing approximately 45 tons, included a massive steel round door, hinged at the roof, and held open in a horizontal position by an explosive bolt. The bolt released the five ton door at exactly the same time device detonation occurred, allowing the door to free fall, close, and seal the pipe in about 750 milliseconds. The purpose of the tunnel-and-pipe-seal was to prevent radioactive gases and any debris that might get past the first two closures from damaging experiments in the test chambers. The tunnel-and-pipe-seal was designed to withstand 1,000 degrees Fahrenheit and 1,000 psi gas pressure for a period of two hours. A decoupler was located in the line-of-sight pipe about 600 ft (183 m) from the working point, just outside the end of stemming. The decoupler was specifically designed with flexible segments to mitigate the effects of the shockwave traveling down the line-of-sight pipe and avoid damage to experiments in the test chambers. For some tests, a muffler was installed in the line-of-sight pipe near the device (Figures 13-14). This was an expanded section of pipe that created turbulence and stagnation, thereby reducing the flow of energy down the pipe.

The horizontal line-of-sight pipe, device canister (A-box), test chambers, test chamber experiment bulkheads, and vacuum systems were manufactured at the Lockheed Shipbuilding and Construction Company in Seattle, Washington. If the shipyard facilities were not available, the pipe system fabrication was subcontracted to either American Pipe and Construction Company of Portland, Oregon or Welk Brothers, Inc., of Spokane, Washington. The horizontal line-of-sight pipe system was trucked to the NNSS in sections by Widing Transportation, Inc., of Portland, Oregon. Prior to shipment, the test chambers and bulkheads were taken to the Lockheed shipyard facilities in Seattle and assembled with mock experiments (wood templates) to verify the critical fit and proper alignment. When the pipe sections arrived at the NNSS, they were transported underground on the tunnel train system for final assembly. Lockheed Missiles and Space Company provided technical guidance during the installation. Other features of the pipe system were designed by Sandia National Laboratories. Sandia National Laboratories designed, procured, and shipped the fast acting closures.

Data Recording

Initially, data were gathered from the underground tests by sensors and cables stretching from the experiments mounted in the test chambers and other underground instrumentation to recorders in trailers positioned outside the portal (DTRA 2002:196). Cables also extended from the nuclear device to the portal. The ability to drill large diameter holes had been developed by the time DTRA began testing at the tunnel complexes and trailer parks for instrument trailers on top of the mesa became feasible. It was more economical to drill the holes vertically into the tunnel complex from the top of the mesa and install a permanent cable plant in the tunnels. This was a shorter path than to the portal and cut the costs in cable lengths. The shorter cable lengths also provided a better and faster signal to the recording instruments (Ristvet et al. 2007). All cables installed in the drill holes were gas blocked at the bottom where they entered the tunnel and at the top where they exited the hole on the mesa. The entire cable hole was grouted for containment purposes. The underground cable runs consisted of jumper cables from the experiments in the test chambers to a gas block connector in the wall of the line-of-sight pipe, and then to a signal-conditioning equipment alcove located within a few hundred feet of each test chamber. The conditioned signals were then routed via cables to the underground splice alcove at the bottom of the cable hole where each cable was

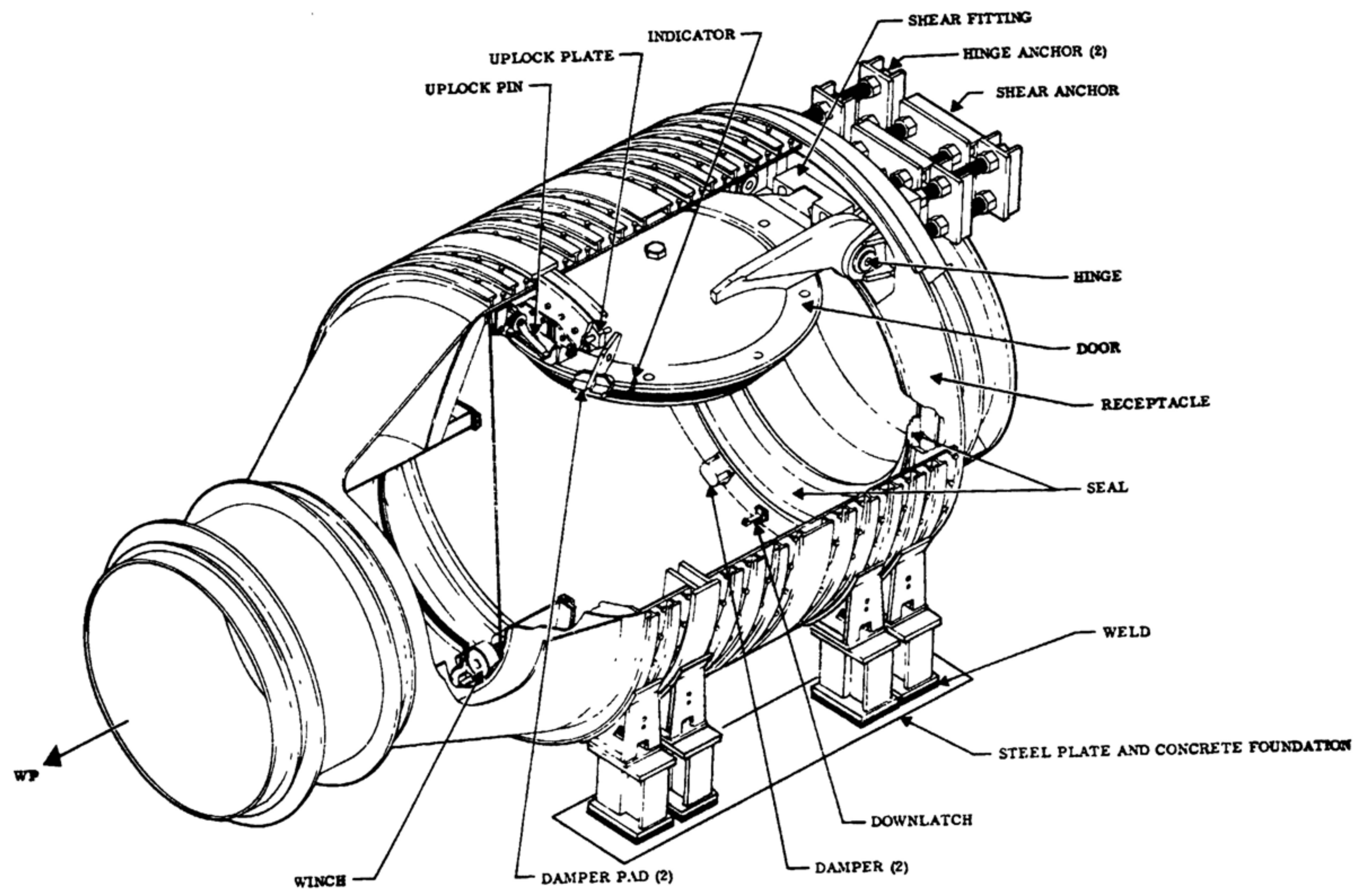


Figure 12. Sketch of a tunnel-and-pipe-seal closure (Carpenter 1971).

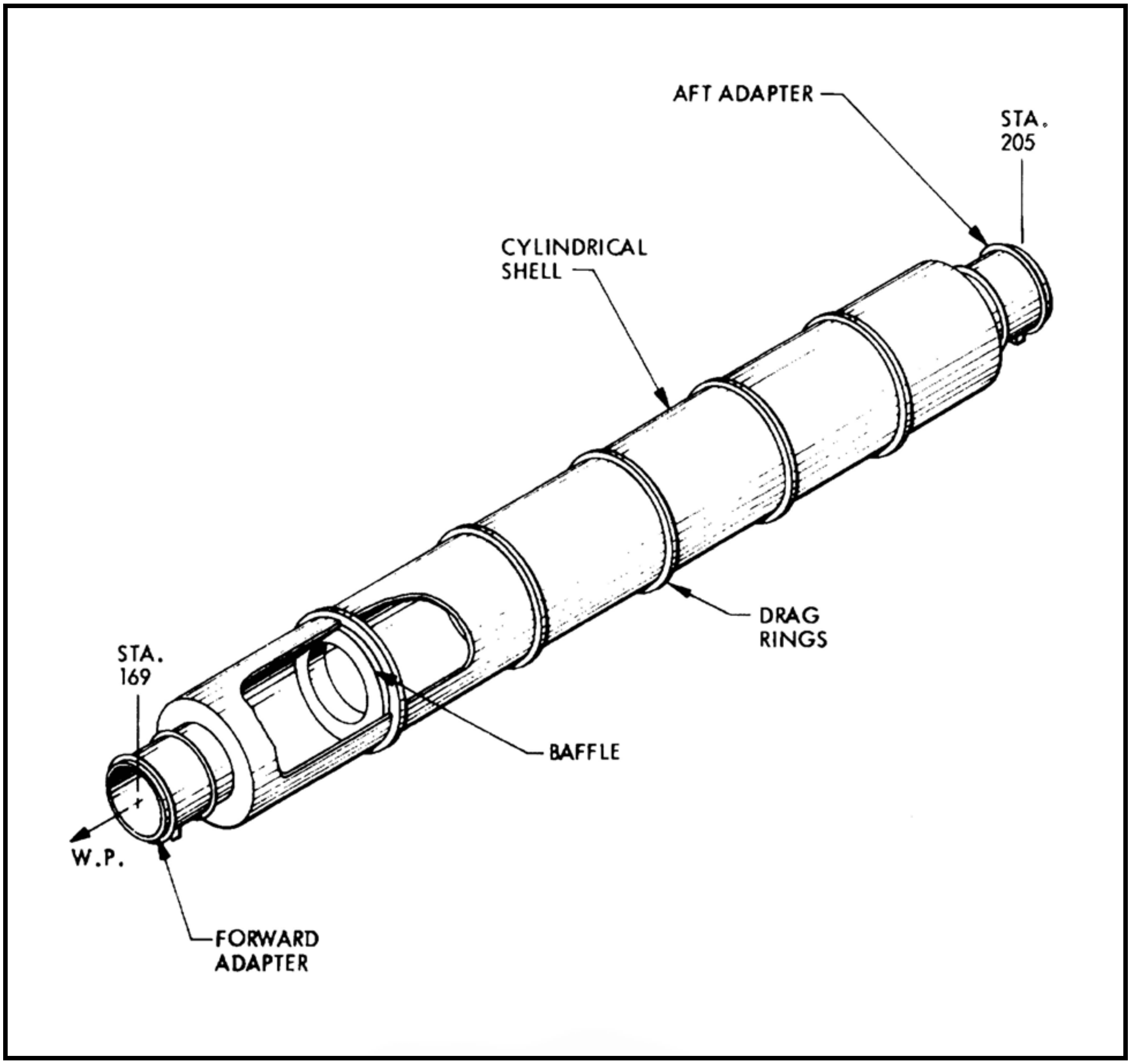


Figure 13. Sketch of a muffler for a line-of-sight pipe (Wilson 1976:32).

Figure 14. Line-of-sight pipe and muffler sections for the Huron Landing nuclear test, 1981 (photograph CAA-019-5, copy on file at NNSA/NSO Curation Facility, Las Vegas Nevada).

attached to a gas block connector. On the mesa one end of another jumper cable was attached to a gas block at the top of the cable hole and the other end was connected to an instrumentation trailer where the signal was recorded.

Following installation of temporary signal generators in the test chambers, configuration of the instrumentation equipment in the alcoves and on the mesa, and set up of the control room in the DTRA data recording station at the main control point in Area 6, the test equipment was ready for signal dry runs. Signal dry runs were necessary to work out any flaws in the instrumentation recording systems. The temporary signal generators were each activated by a timing and firing signal initiated at the Area 6 control point. The temporary signals were then sent through the entire instrumentation system to the final recording station. The DTRA scientific director was in charge the signal dry runs. The control room was operated for DTRA by EG&G, Inc., Las Vegas. Signal dry runs were conducted until every experiment and associated recording device operated flawlessly. This process could take up to two months. The final signal dry run was referred to as the mandatory full participation dry run. Upon conducting a successful mandatory full participation dry run, the test bed was ready for installation of the nuclear device. After the nuclear device was installed, the final containment stemming operation took place.

Eventually, the original mix of cables became outdated when faster signals were required and not enough coaxial cables were available in the existing cable holes to the mesa. To satisfy the requirement, a new recording system was developed, the Recorder and Oscilloscope Sealed Environmental System (ROSES). The ROSES was a portable climate-controlled mini-version of an instrumentation trailer and used underground to house electronic equipment for recording data from the experiments (see Figure 15). As such, the system reduced downhole cables, the number of tunnel cable runs and gas blocking, and the use of the mesa trailer park. An experiment using a single ROSES unit was conducted during the Husky Ace test in 1973 in the U12n Tunnel (Sites and Wetzel 1975). Later, the ROSES was first employed in 1975 on the Dining Car test in the U12e Tunnel in order to validate the system during an actual test. The ROSES was designed by electrical engineer Robert L. Shirkey of the DTRA Nevada Operations Office, who was also responsible for their procurement and monitoring during their initial use. The ROSES units, holding up to six racks of electronic recording equipment, could be placed underground and closer to the test chambers than was possible with the instrumentation trailers on the surface. This allowed for faster recording of high-speed data generated from the later tests. The ROSES units were shock-mounted in a manner similar as the instrumentation trailers; that is, with crushable foam pads and anchored to the back and invert of the drift to keep them from tipping over. A 250 ton combination underground and surface chilled water system cooled the ROSES units.

The ROSES was successfully used on all tests from Dining Car in the U12e Tunnel through Midas Myth/Milagro in the U12t Tunnel. During the Midas Myth/Milagro test, the tunnel walls and roof collapsed and destroyed most of the ROSES units. Fortunately, during the interval that the ROSES units were being used, a recording system that utilized fiber optic cables was being developed. The loss of the ROSES units and final development of the fiber optic recording system coincided enough that the newer system was soon implemented. Configuration of the new fiber optic system began with data from the experiments to underground recording alcoves being transmitted primarily on fiber optic cables. In 1983, the Midnight Zephyr test in the U12n Tunnel was the first to be fully recorded using the fiber optic system (DTRA 2002:388). Instrumentation racks, assembled in groups

Figure 15. View of the ROSES drift for the Huron Landing nuclear test, 1982 (photograph CAA-100-29, copy on file at NNSA/NSO Curation Facility, Las Vegas Nevada).

of four to ten and mounted on wheels, were transported underground by train, offloaded at the entrance to recording alcoves, and rolled into position. The racks were shock mounted and tied off to the back and floor of the tunnel for stability during ground shock. The recording alcoves created a pressurized and sealed environment with a concrete alcove protection plug placed in the entrance to protect the recording equipment and data. An alcove protection plug, with a 36 inch (91 cm) to 48 inch (122 cm) diameter crawl tube through it for personnel access to the alcove, was built after the recording equipment was installed. The crawl tube was closed during tunnel button-up and the alcove was pressurized to five pounds per square inch prior to the test to prevent any post test residual radiation from getting into the alcove.

The data were recorded in the instrumentation alcoves and transmitted to a secondary data recording station at the portal, called a portal recording station. The portal recording station transmitted the data a distance of 20 miles (32 km) over fiber optic links to a third recording station at the Area 6 control point. There, the data were printed out soon after the test so technical personnel and test group staff could quickly evaluate the data quality and quantity. Prior to employing this new fiber optic system, along with the underground recording capability, data had to be manually retrieved from recording equipment at the portal, on the mesa, or from the ROSES underground. This type of data recovery could take days and even weeks, and sometimes the instruments recording the data were destroyed or contaminated.

Containment

Containment of tunnel tests was developed and continually refined as a result of lessons learned during postshot analyses of expended tests and the in-depth technical calculations that resulted in the design of what is described as the three nested vessel system. The first of these, Vessel I, is the horizontal and vertical region surrounding the working point and extending out for a distance of about 600 ft (183 m) to the ends of stemming in both the bypass and line-of-site drifts. It was designed to withstand the effects of ground shock and contain the cavity temperature, pressure, and radiation. Immediately following insertion of the device in the A-box, the zero room was filled with sandbags to eliminate as many voids as possible and to aid in keeping the room dry (Figure 16). Stemming in each drift consisted of similar types of cement grout, with stemming of the line-of-site drift normally completed two to three months prior to final button-up of the bypass drift. Three types of grout were used: rock-matching grout, super lean grout, and high strength grout. Rock-matching grout, designed to match the shock velocity and other characteristics of the surrounding natural rock, was used in the first zone of stemming extending outward from the zero room. The purpose of rock-matching grout was to allow the nuclear cavity to grow uniformly as much as possible. The next stemming section was called super lean grout. Super lean grout was designed to have the consistency and behave like toothpaste. It would easily flow when compressed by the shock wave, filling any natural or shock induced fractures in the rock. In the early development of super lean grout, sections with different colors were placed in the line-of-site drift. Reentry drifts, which were mined post test to evaluate the containment design, would encounter the different colors of super lean grout, thereby enabling the containment scientist to determine how far it traveled. Continuing beyond the super lean grout region was a mixture called high strength grout. High strength grout was used for the last several hundred feet, or to the end of stemming, and was designed to act like a high strength plug or anchor. Finally, all mechanical and electrical penetrations that exited the end of stemming were protected with redundant 1,000 psi and 1,000 degree Fahrenheit rated valves and cable connectors.

Figure 16. View of sand bags in the Huron Landing zero room, 1982 (photograph CAA-114-17, copy on file at NNSA/NSO Curation Facility, Las Vegas, Nevada).

Vessel II in the nested vessel containment system included Vessel I and extended out to the overburden plug (Figures 17-18). The objective of Vessel II was to provide a larger tunnel volume to dissipate energy in case of a containment failure in Vessel I. The overburden plug was designed to contain any radioactive gases that could potentially seep from the line-of-site pipe or from the end of stemming. The overburden plug was located within the tunnel complex so that the depth of rock over the plug would have an overburden pressure equal to or greater than 1,000 psi. All electrical and mechanical features that extended through the overburden plug had gas block connectors or containment valves on both sides of the plug with a design rating of 1,000 psi and 1,000 degrees Fahrenheit for a minimum of one hour. The containment valves at the overburden plug could be opened or closed underground, from the portal, or from the Area 6 control point.

Vessel III in the nested vessel containment system included Vessels I and II and extended out to the gas seal plug usually located in the tunnel's main access drift. Its primary purpose was to ensure that no radiation escaped to the atmosphere if the first two containment vessels failed. The gas seal plug, a concrete mass approximately 15 ft (4.6 m) thick, was located within the tunnel complex so that the depth of rock over the plug would have an overburden pressure equal to or greater than 500 psi. The gas seal plug was placed far enough away from the overburden plug to provide a tunnel volume large enough to reduce the design to 500 psi and 500 degrees Fahrenheit for one hour. The same cable connectors and mechanical valves as used on the overburden plug were used on the gas seal plug, but only on the portal side of the plug.

The gas seal plug was a later addition to the containment scheme. Originally a steel door, known as the gas seal door and located closer to the portal, was used in conjunction with the overburden plug. The gas seal door was designed for 75 psi for one hour. The gas seal door was closed and pressure checked for leaks just after completion of the stemming operations and prior to test zero time. After several uses, however, it was discovered just prior to a test that ground shock from the previous test had distorted the concrete and steel door frame and the gas seal door would no longer hold pressure. This created an urgent need for a new plug that had to be built before the current test could be conducted. A new concrete plug was hastily constructed between the gas seal door and the overburden plug so as not to delay the test any longer than necessary. As a result, this plug was called the "hasty plug." The name lasted until the gas seal plug concept was developed and a permanent, reuseable gas seal plug was constructed. Even though the old gas seal door would not hold pressure, it was still closed on button-up as a redundant plug to stop any debris that may have traveled that far.

Button-Up Activities

Tunnel button-up activities normally involved at least one representative from every agency associated with the test. Button-up normally started the day before the test, known as D-1, and extended straight through until completed, just prior to test time. The button-up team consisted of a team chief and his deputy, both of whom were DTRA personnel from the Nevada Operations Office; members of the test group directors staff, including the test construction engineer and the cable coordinator; the architectural and engineering project engineer and his deputy; the construction contractors staff, including the project manager and the mining, mechanical, and electrical superintendents; and the DOE project engineer for mining. The function of the button-up team was to verify that all experiment requirements, both mechanical and electrical, were in test configuration;

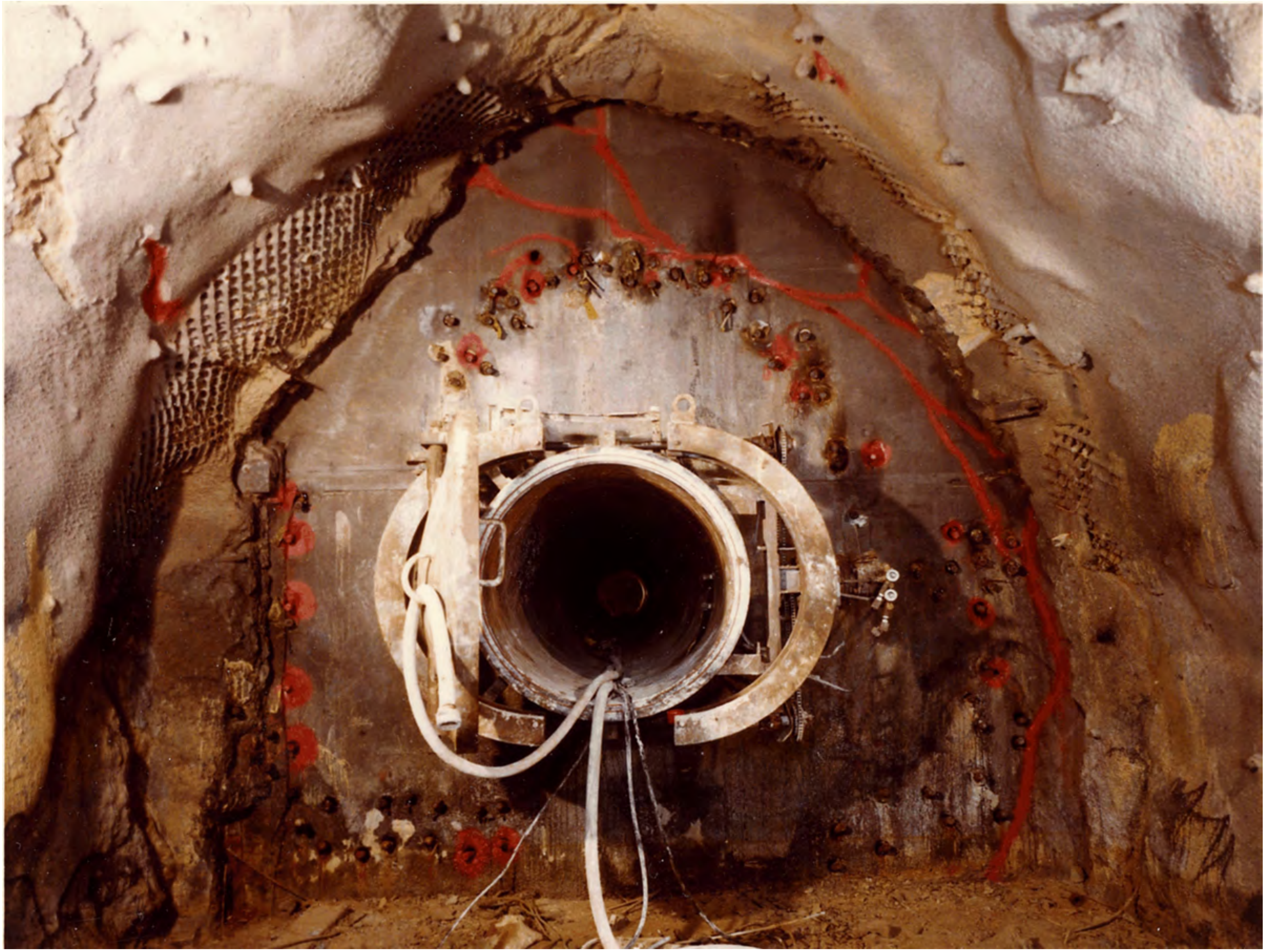


Figure 17. Overburden plug in the U12n.03 drift for the Huron Landing nuclear test (photograph CAA-001-1, copy on file at NNSA/NSO Curation Facility, Las Vegas, Nevada).

Figure 18. View toward portal of the trainway and overburden plug being constructed in the U12n.08 drift, 1982 (photograph CAA-092-14, copy on file at NNSA/NSO Curation Facility, Las Vegas, Nevada).

all features, structural, mechanical, and electrical, were in test configuration; and that the entire tunnel complex was configured to support post test activities.

Prior to button-up, a DTRA staff engineer and the cable coordinator developed detailed mechanical and electrical systems check lists to show how the facility would be configured at test time. The Button-up check lists generally filled a thick notebook binder and covered all features within the entire tunnel complex. Button-up of items and areas of the tunnel not directly related to the current test were completed on D-1. Test related activities, such as recording alcoves, were buttoned-up as the experimenters completed their activities and were ready to depart the tunnel. All other button-up activities, starting at the end of stemming in both the line-of-sight pipe drift and the bypass drift, through the containment plugs and out to and including the portal, were started as soon as the laboratory device engineers completed their work and turned the complex over to the button-up team. Construction crafts completed last minute tasks, such as closing gates, late time sandbag shielding, and removing blocks from under recording equipment racks so they were resting on the shock mounting material. At this time, the button-up team, the laboratory device arming team, and the Wackenhut Services, Inc., security force were the only people in the tunnel.

Following the arming of the device, the button-up team started working its way out the tunnel, checking every item on its respective check lists. As the button-up progressed, the security force secured areas within the tunnel. At the overburden plug, the gas seal plug, and the gas seal door all mechanical features were closed per containment requirements (i.e., tunnel ventilation ducts, water lines, and compressed air lines). As each was closed, the status of the button-up was reported to personnel in the monitoring room at the control point. The monitoring room personnel monitored all systems and tracked the progress of the button-up team so, if necessary, a problem could be repaired before continuing. When the button-up team reached the portal, the electrical team component completed their checklists by placing the portal electrical systems in shot and reentry configuration. The mechanical team component verified that the retention ponds downslope were empty. When the button-up was completed, the team chief notified the DOE test controller's office that the team was on its way to the control point. The Wackenhut Services security force escorted the team. After a final all-is-ok meeting, the DOE test controller gave the laboratory device engineer the okay to start the final countdown.

Detonation

When the firing signal is sent to the nuclear device for a typical DTRA underground nuclear weapons effects tunnel test there is a sequence of significant events that happen upon detonation (DOE/NNSA 2004:126-127; U.S. Congress 1989:32). These events begin within a few nanoseconds of the detonation and include the prompt release of radiation down the line-of-sight pipe to expose the experiments; the mechanical closures (e.g., fast acting closure and tunnel-and-pipe-seal) are triggered; and a shockwave, essential for closing the line-of-sight pipe and containing the extremely high temperatures and pressures created in the nuclear cavity, begins to expand radially from the device.

The energy of the shockwave eventually overcomes the line-of-sight pipe, the surrounding super lean grout, thereby collapsing and closing the tunnel and the line-of-sight pipe before it reaches the mechanical closures. The collapsing and closing of approximately the first 200 ft (61 m) of the tunnel and line-of-site pipe supports the containment concept for Vessel I. The shockwave, depending on the size of the test, can be monitored many thousands of miles away from the detonation point as seismic waves.

At the same moment the experiments are being exposed to radiation generated during the detonation and ground shock is beginning to close the line-of-sight pipe, a cavity surrounding the working point is forming. The thermal energy reaches several million degrees Kelvin and instantly vaporizes the device canister, the sand bag fill, and the surrounding rock. As the cavity expands outward it reaches its maximum size when the pressure is equal to the overburden pressure of the surrounding rock. The final diameter of the cavity is therefore dependent upon both the yield and the depth of burial of the device. The expanding shockwave crushes and fractures the rock until it becomes so weak that it no longer has an affect on the rock. At the cavity, thermal energy melts the surrounding rock and it condenses in the bottom of the cavity. The growth of the cavity stops when the stress field in the surrounding rock is greater than the pressure in the cavity. Within minutes and up to days following detonation the cavity pressure decreases to the point that it no longer supports the overlying rock and the roof collapses into the cavity void. This further weakens the rock above the cavity where additional rock collapse occurs. This process continues until the rubble-filled chimney stops growing. The height of the rubble-filled chimney for a tunnel nuclear weapons effects test may extend to the underside of the overlying cap rock on the mesa.

Reentry and Recovery

After detonation of the nuclear device, the DOE test controller and his staff monitor the data from the remote area monitoring system units inside the tunnel and outside at the portal and on the mesa. These units detected and measured gamma radiation. The weather at the NNSS, as well as in the surrounding areas, continued to be monitored. When all conditions were correct, the DOE test controller gave permission to prepare for manned reentry to the portal area and to trailer parks on the mesa. The reentry teams assembled at the construction trailer located at the control point. Following a briefing to the teams on current status of the areas, the DOE test controller gave permission to proceed to the portal first. The portal reentry team, upon arrival at the portal, quickly assessed the condition of the area. If all appeared safe and the readings from the remote area monitoring system units were normal, the team started to reestablish the portal power. Experiment recovery teams for both the mesa and portal trailer parks would depart the control point area while portal power was being reestablished. Power to the trailers on the mesa would also be reestablished and data recovery would start soon after.

Tunnel reentry and experiment recovery operations required more precise industrial hygiene monitoring than most other operations within the tunnels. This was due to the potentially hazardous environment that industrial hygiene and radiation-safety personnel, construction crafts, and scientist could encounter during reentry and recovery operations. Prior to sending reentry and recovery personnel underground, the remote area monitoring system was used to determine if radiation, toxic gasses, or explosive mixtures were present and, if so, at what concentration. The health physicist then used that information to determine what level of personnel protective equipment was required to protect members of the reentry and recovery teams.

Tunnels were routinely ventilated by way of controlled releases after each test so workers could work in them without unnecessary exposure to toxic, explosive, or radioactive gases. During a controlled release the air was discharged in measured amounts, which would then be diluted by the atmosphere to trace amounts so as not to endanger anyone's health. Depending on the conditions within the tunnel and the weather for the next few days, tunnel ventilation could be reestablished between the portal and the gas seal door. The portal reentry teams would then depart the portal area. Security would remain on the access road to both the portal and the mesa until work crews arrived the next morning. The following morning the reentry control staff would meet at the control point to assess the current status of the remote area monitoring system units in the tunnel and the weather report for the day.

During the time the reentry control staff were being briefed, the tunnel reentry teams would be getting prepared to go underground. Anti-contamination suits and self contained breathing apparatus were worn for the initial reentry into the tunnel (Figure 19). Three reentry teams would suit up, two for reentry and one for rescue, if required. If tunnel conditions up to the gas seal door were acceptable and permission was received from the test controller, a work team would go to the gas seal door, open it, and reestablish the rail line through it so the reentry teams could ride a train to the gas seal plug. The work team would establish a communication line so the reentry teams could maintain constant communication with the reentry control staff at the portal. Ventilation was also reestablished through the gas seal door to the portal side of the gas seal plug.

As soon as the teams were suited up and ready and the gas seal door had been opened, the staff health physicist briefed them on the current status of the tunnel based on latest readings from the remote area monitoring system. When the briefing was completed, and with the DOE test controller's permission, the primary reentry team would enter the tunnel and proceed to the gas seal plug using the man train. No electrical power was established until the initial reentry and tunnel condition assessment was completed so, except for their headlamps, the reentry team worked in total darkness. At the gas seal plug, the team checked for radiation and any gases that may be present on the working point side of the plug and reported the data to the reentry control staff at the portal. With approval of the DOE test controller, the team then opened the ventilation line containment doors and reconnected the ventilation ducts so air could be circulated to the portal side of the overburden plug. The crawl tube door in the gas seal plug was then opened and the team proceeded to the overburden plug using the man train that was purposely left on the working point side of the gas seal plug by the button-up team. At the overburden plug, the procedure was repeated. The reentry team then proceeded to the line-of-sight pipe drift and the test chamber area. There they assessed tunnel conditions, took radiation and gas measurements, and checked for fallen rock, bad ground, or any other debris that could hamper experiment recovery. If all was okay outside the line-of-sight pipe and test chamber, the team remotely sampled for radiation and gases inside the pipe. If levels inside the pipe were acceptable, the team opened the test chamber doors far enough to get a quick look inside at the experiments. The reentry team then returned to the portal where they were checked for any contamination, removed the anti-contamination clothing, and showered and dressed. If conditions were acceptable the experimenters would then enter the tunnel to begin recovering their experiments and data.

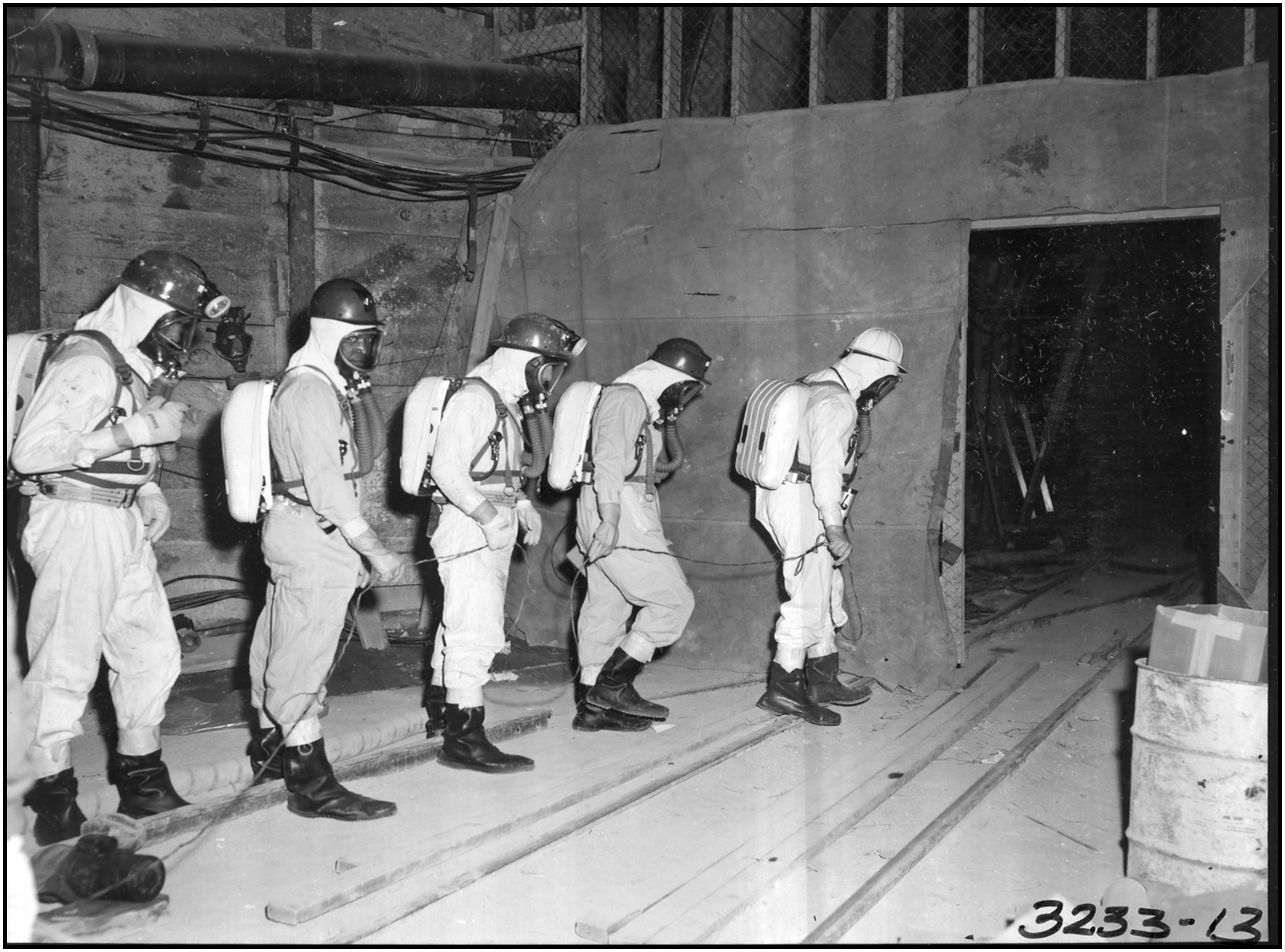


Figure 19. Reentry team, 1970 (photograph 3233-13, on file at the Nuclear Testing Archive, Las Vegas).

Responsibilities

The manager of the Department of Energy, Nevada Operations Office administered all activities at the NNSS, including real estate and facilities, support services, and the planning and execution of nuclear tests. The manager delegated authority to execute a nuclear test to a DOE test controller, who assumed responsibility for the safe conduct of the test. The test controller had authority to delay, postpone, or proceed with a nuclear test. The test controller assumed complete operational control of the NNSS during the test execution period which started the day before the test, D-1, through to completion of the initial reentry following the test. The NNSS returned to normal operations only when the test controller determined it was safe for employees and the environment.

Test group directors, appointed by DTRA or the national laboratories (i.e., LLNL or LANL), directed the fielding and technical aspects of experiments and tests and were also responsible for compliance with applicable environmental laws and regulations. The LLNL or LANL test group director, depending on which laboratory supplied the nuclear device, assumed responsibility for radiological safety from the time the device was delivered to the tunnel until it was detonated. After detonation, the DOE test controller assumed responsibility for radiological safety until it was determined that no uncontrolled venting had occurred. The tunnel was then transferred back to the DTRA test group director for post test reentry and recovery operations.

The Reynolds Electrical and Engineering Company, Inc., Environmental Sciences Department, performed all radiological safety services for the tests and was accountable to each of the test group directors before and after the tests (Mullen and Eubank 1977). Agencies or experimenters with experiments on a test were responsible for design, preparation, installation, post test removal, and analyzing and reporting experiment data. James Metcalf, health physicist, Sandia National Laboratory, provided health physics support to the DTRA nuclear weapons effects test program from 1969 until the last test in 1992. He worked closely with Reynolds Electrical and Engineering Company, Inc., personnel to design and develop a remote area monitoring system. Reynolds Electrical and Engineering Company, Inc., was responsible for installing and maintaining the remote area monitoring system. They also ensured that calibrated radiation monitoring instruments and an adequate supply of personal protective equipment, i.e., self-contained breathing apparatus and anti-contamination clothing, were available. Metcalf provided real-time post test radiation data and analysis to the DOE test controller and DTRA management. Upon receiving approval from the DOE test controller, Metcalf briefed every tunnel reentry and recovery team on the type of environment they could expect to encounter. Metcalf was the lead communicator with the reentry teams and responsible for recording all communications. He was also responsible for knowing exactly where the reentry team was underground and the physical condition of each team member at all times; for knowing what conditions they had encountered, for advising the test group staff; and for maintaining a detailed hand written log of activities. A second log was maintained by the Reynolds Electrical and Engineering Company, Inc., lead health physicist; thereby, providing DTRA and DOE with complete and redundant documentation of the reentry and recovery operations for each test.

Fenix & Scisson, Inc., designed and engineered the tunnels and drill holes; Reynolds Electric and Engineering Company, Inc., constructed the tunnels; and Lockheed Missile and Space Corporation developed the test beds, specifically, the line-of-site pipes used to house and protect experiments, and the vacuum systems to reduce the internal pressure in the line-of-sight pipe to represent deep outer space. Holmes and Narver, Inc., and later Raytheon Services, Nevada, provided architectural and engineering services for the NNSS. They provided civil, structural, electrical, and mechanical design support for the NNSS including development of the tunnels. LLNL and LANL provided the nuclear devices, while Sandia National Laboratory was responsible for arming and firing the LLNL devices. LANL conducted their own device arming and firing. EG&G, Inc., supplied instrumentation for the national laboratories, while Bendix Corporation, and later Honeywell, Inc., supplied instrumentation for DTRA experiment recording. The U.S. Geological Survey, and later Fenix & Scisson, Inc., provided detailed mapping of the geology (Ristvet et al. 2007; Townsend 2007). The U.S. Army Corps of Engineers, Waterways Experiment Station was responsible for designing and developing concrete and grout mixes and for quality control during the blending and batching process in preparation for stemming placement. Reynolds Electrical and Engineering Company, Inc., performed all mining and construction and was responsible for operating and maintaining the tunnel complexes.

ENVIRONMENTAL SETTING OF U12N TUNNEL

The NNSS is approximately 65 miles (105 km) northwest of Las Vegas by way of U.S. Highway 95 and lies within the southern portion of the Great Basin, characterized by high mountain ranges interspersed by valleys and bolsons (Dohrenwend 1987). Climate is generally of limited precipitation, low humidity, and extreme daily temperature ranges. The lower elevations of the NNSS have dry, hot summers and mild winters, while the higher elevations have increased precipitation and lower temperatures. Most of the precipitation is in the form of snow and winter rainstorms, with an occasional storm during the fall and spring. Rainstorms do occur in the summer, but are rare. Permanent natural water sources for the NNSS are springs and seeps, and in the nearby area of the tunnel complexes are Rainier Spring, White Rock Spring, and Captain Jack Spring.

The U12n Tunnel is reached from Mercury, located toward the southeast corner of the NNSS (see Figure 1), by initially traveling north on the Mercury Highway for about 21 miles (34 km), over Checkpoint Pass, through Frenchman Flat, over Yucca Pass, and into Yucca Flat to the Tippipah Highway intersection. Turning west onto the Tippipah Highway, which curves back to the north and parallels the west side of Yucca Flat, proceed another 19 miles (30 km) to where the Tippipah Highway merges with the Rainier Mesa Road just southeast of the Area 12 Camp (Figure 20). From the merge point, traverse past the Area 12 Camp in a westerly direction for another 1 mile (1.6 km) to a right turn to the west onto the U12n Tunnel road. After turning right, continue for 1.5 miles (2.4 km) to the U12n Tunnel portal area. All roads from Mercury are paved with asphalt.

The U12n Tunnel portal area is on the east sloping flanks of the lower slopes of Rainier Mesa (Figure 21). Aqueduct Mesa abuts and is north of Rainier Mesa and is several hundred feet lower in elevation. Both mesas comprise a relatively flat highland between Pahute Mesa to the west and Yucca Flat to the east (Howard 1985:8). The U12n Tunnel portal is at an elevation of 6,024 ft (1,836 m). The highest elevation above the tunnel on top of Rainier Mesa is 7,485 ft (2,281 m). Topography on the east slope of Rainier Mesa is rugged, and stream valleys are narrow and steep. Stream systems on Rainier Mesa include the headwaters of The Aqueduct and numerous ephemeral tributaries. The Aqueduct is a major tributary to Tongue Wash and drains about 5,000 acres (2,070 hectares) of Rainier and Aqueduct Mesa. Mesa top activities associated with U12n Tunnel were situated in the headwaters of The Aqueduct, in an area of approximately 835 acres (335 hectares). At the base of Rainier Mesa, the U12n Tunnel portal, consisting of about 150 acres (60 hectares), is situated in a small Tongue Wash tributary valley that drains a portion of the east flank of Rainier Mesa. The principal access road leading to the U12n Tunnel complex is situated in the center of the lower part of this valley. The top of Rainier Mesa is presently accessed from the southwest side of the mesa near the drainage divide between Tongue Wash and Stockade Wash.

Located at the lower boundary of the Great Basin Desert, vegetation around the U12n Tunnel area is classified as a singleleaf pinyon tree (*Pinus monophylla*) and black sagebrush (*Artemisia nova*) woodland (Ostler et al. 2000). This woodland typically occurs on slopes, mesas, plateaus, and ridges of dry mountain ranges of the Great Basin region and eastern foothills of the Sierra Nevada (Brown 1994; NatureServe 2003). It is found exclusively in the northern part and at the higher elevations of the NNSS, particularly on the mesas. Black sagebrush dominates the association, representing over 50 percent of the plants. Other common plants include the Utah juniper tree (*Juniperus*

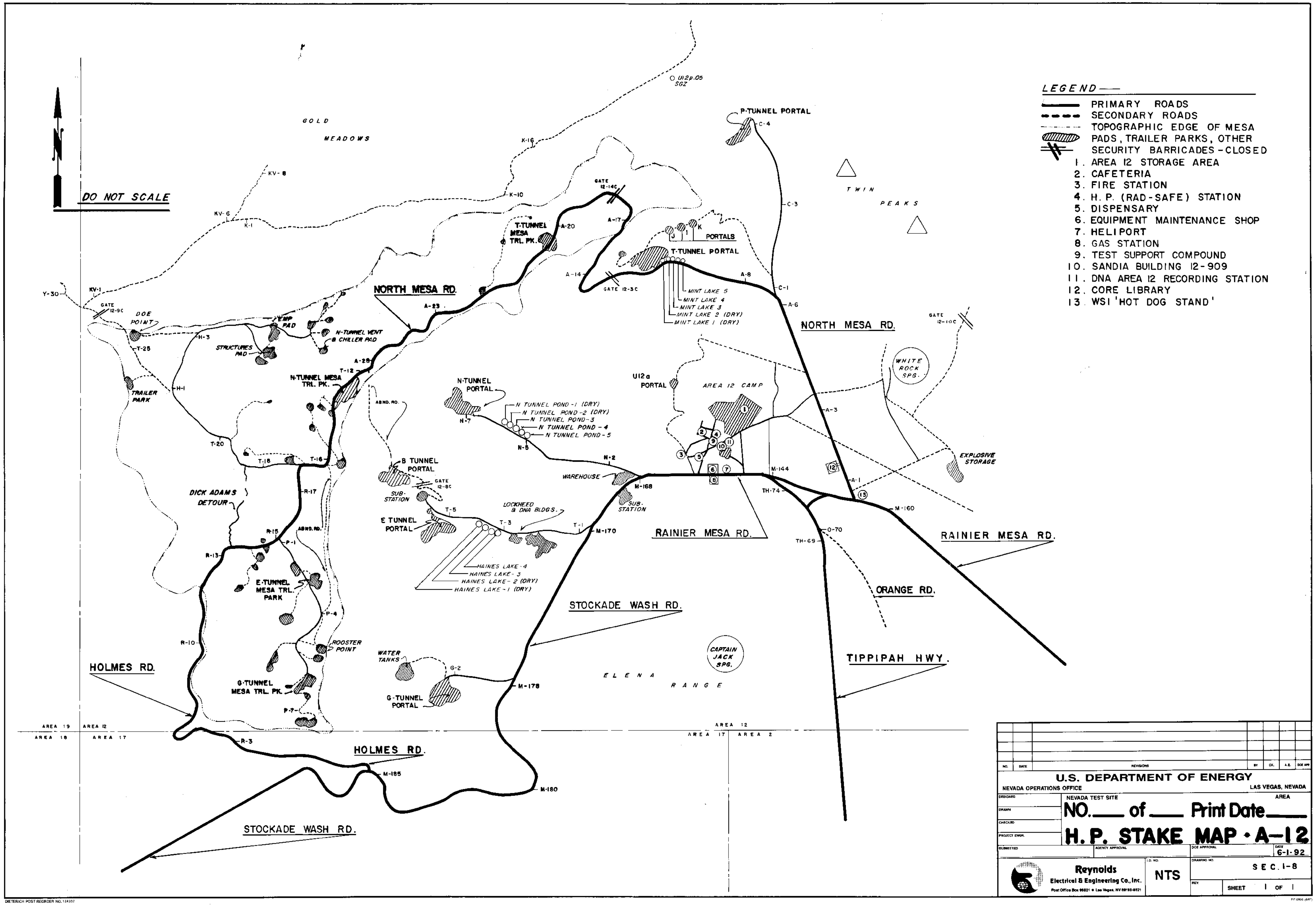


Figure 20. Map of Area 12 tunnel complexes and roads, 1992 (drawing SEC. 1-8, on file at the Archives and Records Center, Mercury).

Figure 21. View northward of the U12n Tunnel area, 1990 (photograph NF-11266, on file at Remote Sensing Laboratory).

osteosperma), green rabbitbrush (*Chrysothamnus viscidiflorus*), and big sagebrush (*Artemisia tridentata*).

Nearly 80 percent of the fauna on the NNSS consists of insects, and of these, most are ants, termites, and beetles (Castetter and Hill 1979; Greger 1994; Medica 1990; O'Farrell and Emery 1976). The more noticeable fauna near the U12n Tunnel are coyote (*Canis latrans*), badger (*Taxidea taxus*), kit fox (*Vulpes macrotis*), mule deer (*Odocoileus hemionus*), raven (*Corvus corax*), red-tailed hawk (*Buteo jamaicensis*), chukar (*Alectoris chukar*), quail (*Callipepla gambelii*), jay (*Aphelocoma coerulescens*), golden eagle (*Aquila chrysaetos*), mice (*Perognathus parvus*), kangaroo rats (*Dipodomys microps*, *Dipodomys ordii*), squirrels (*Ammospermophilus leucurus*, *Spermophilus townsendii*, *Spermophilus variegatus*), jackrabbits (*Lepus californicus*), cottontails (*Sylvilagus audubonii*, *Sylvilagus nuttallii*), lizards (*Sceloporus graciousus, Sceloporus occidentalis*, *Eumeces skiltonianus*), and snakes (*Chionactis occipitalis*, *Pituophis melanoleucus*, *Crotalus mitchellii*, *Crotalus lutosus*, *Crotalus stephensi*). Other animals known to occur in the region are mountain lion (*Felis concolor*), pronghorn antelope (*Antilocapra americana*), and the occasional bighorn sheep (*Ovis canadensis*).

Soils of the NNSS are similar to those of surrounding areas and include Aridisols and Entisols (Peterson 1988; Taylor 1986; Wesling et al. 1992; Whitney et al. 1986). The degree of soils development reflects their age, and the soils types and textures reflect their origin. Entisols generally form on steep mountain slopes and in stream valleys along active washes. Aridisols commonly are older and form on more stable alluvial fans and stream terraces. In the U12n Tunnel complex area, older hillslope soils formed on colluvium derived from Tertiary rocks have well developed B horizons that contain accumulations of calcium carbonate present on the undersides of stones, although there are only a few exposures where road and construction activities cut through colluvial mantles. Elsewhere, hillslope soils are thin and weakly developed, minimally developed on tailings slopes, and weak to undeveloped along the major wash along the base of the tailings pile. Exposures of well-developed soils were not observed on the mesa top.

Geology of the Rainier Mesa area is described as consisting of 2,000 to 3,000 ft (610 to 914 m) of layered calc-alkaline Tertiary ash flow, peralkaline ash fall of the Indian Trail Formation, reworked ash fall, and tuffaceous sandstone units (USGS 1978; LaComb et al. 1996). These units were deposited on an irregular surface of Mesozoic granite at the northern edge of the mesas and Paleozoic sedimentary rocks comprised of carbonate and clastic rocks under the central and southern parts of the mesa. The top of Rainier Mesa is capped by a thick, competent, welded ash-flow.

Rock units encountered within the U12n Tunnel complex consist of Tertiary bedded non-welded high silica vitric tuffs formed from ash-fall tuff and densely welded tuffs of similar high-silica, rhyolitic composition of the Belted Range Tuffs (Frizzell and Shulters 1990), principally within Tunnel Bed 4, subunits G-K of the Indian Trail Formation (see Appendix A). The degree of welding affects the density and competency of the tuffs as well as influencing fracture patterns and fracture frequency as well as porosity and permeability. Paleozoic rocks consisting of Devonian, Silurian, and Ordovician dolomite and limestone, which are possibly correlative to Devil's Gate Limestone and Nevada Formation (rock unit Ddc of Sargent and Orkild 1973) and quartzite of the Cambrian and Precambrian Wood Canyon Formation and Stirling Quartzite underlie the Tertiary section well below the level of the U12n Tunnel complex. These Paleozoic and Precambrian rocks are not exposed at the surface in the U12n Tunnel Portal Area but exposures of the Devonian dolomite and limestone are present as prominent hills southwest of the decanting ponds below the U12n Tunnel tailings.

Tertiary rock units are represented by Oligocene to Pliocene volcanic and volcaniclastic rocks that include ash-fall tuff, tuffaceous sandstone, welded tuffs of the Belted Range Tuff, which consists of the Grouse Canyon Formation (Frizzell and Shulters 1990) and the Indian Trail Formation, Grouse Canyon member (Gibbons et al. 1963), and ash-fall tuffs coeval with the Timber Mountain Tuff and related lavas (Frizzell and Shulters 1990; Sargent and Orkild 1973) and with the Survey Butte member of the Piapi Canyon Formation (Dickey and Emerick 1962; Gibbons et al. 1963). These two ash-fall units were initially mapped as units or members of the Oak Spring Formation (Hansen and Lemke 1957) and over the years, variations on this theme have emerged (see Appendix A). At the surface and in the U12n Tunnel, bedrock exposures indicate geologic structure consists primarily of northeast striking beds with northwest dip angles of generally less than 10 degrees, north northwest trending high-angle faults, prominent fracture zones and northwest trending synclines (Gibbons et al. 1963; Lee 1972; Sargent and Orkild 1973; Baldwin et al. 1994).

DESCRIPTION OF U12n TUNNEL AND TESTS

The U12n Tunnel complex consists of the U12n main and U12n extension drifts and portals (Figures 22-30), interior drifts U12n.01 to U12n.25 used for nuclear and high explosive tests (Figure 31), a substantial muck pile fronting the portals (see Figures 27-28), five retention ponds downslope of the muck pile (Figures 32-33), and instrumentation trailer parks and drill holes on top of Rainier Mesa (Figures 34-36). Numerous structures and equipment were built on or near the edge of the muck pile to support the tunnel project, including rail lines and switches, a camel back and a rotary dump to empty the trains of muck cars hauling waste rock and debris out of the tunnel, electrical substations, compressors, ventilation fans, water storage tanks, office buildings, recording stations, a microwave tower, workshops, storage buildings, and a grout blending and pumping station. Data recording equipment in instrumentation trailers were placed on top of Rainier Mesa and were connected by way of vertical cable holes from the trailer parks to the tunnel interior. Also on the mesa were ventilation equipment, ventilation shafts from the tunnel interior, and drill holes and pads.

LLNL began construction of the tunnel in 1962, shortly after the testing moratorium ended between the United States and the former Soviet Union. LLNL abandoned the tunnel soon thereafter when the laboratory began to focus its testing program on the new, large diameter, vertical shafts in Yucca Flat and elsewhere rather than the tunnels (Ashbaugh and Griffin 2009; Flangas 2009; Ristvet 2009). The U12n Tunnel was reopened by DTRA in December 1965 and numerous drifts were mined to support the tests conducted from June 1967 to September 1992 when, as directed by a Presidential decision document, the nuclear testing program entered a moratorium. The tunnel by this time, however, had nearly reached its limit in depth to where it would soon become to costly to conduct tests in it (Ristvet 2009). The underground portion of the U12n Tunnel on the working point side of the gas seal plugs was mothballed in early 1994 to mitigate environmental concerns. The tunnel was later used until 1998 by DTRA and Sandia National Laboratories to conduct high explosive tests on the portal side of the plugs in the U12n extension drift.

A total of 15.63 miles (24.14 km) were mined for the U12n Tunnel. The first drifts were mined in a drill-and-blast technique. The first step of this technique consisted of drilling a series of horizontal holes about 10 ft (3 m) in length into the rock face. The number of horizontal holes depended on the size of the drift and ranged from an average of 35 holes for the smaller drifts to 45 holes for the larger ones (Flangas 2009). The correct amount of explosive for each hole was based on the skill and experience of the miners, and was usually one stick of dynamite per drilled foot. After detonation, the resulting rock rubble was mucked out to the portal by way of muck cars and rails and deposited at the end of the muck pile. The rail lines were extended further inward and the process repeated. This method was also used on post test reentry mining. The later drifts in the tunnels were mined with Alpine miners (Flangas and Harvey 2007; Townsend 2007). The Alpine miner with a rotary head on a boom was capable of mining with greater precision and better control (Figures 37-38). No explosive was involved and the end product was a more uniform and smoother drift. The machine had a flat pan in front that pushed into the rubble pile, created by the cutting head, as the machine advanced. Two articulating arms mounted on the pan gathered the muck onto a conveyor which moved it through the machine to the rear where it dumped into a train of mine cars to haul the muck out to the portal dump.

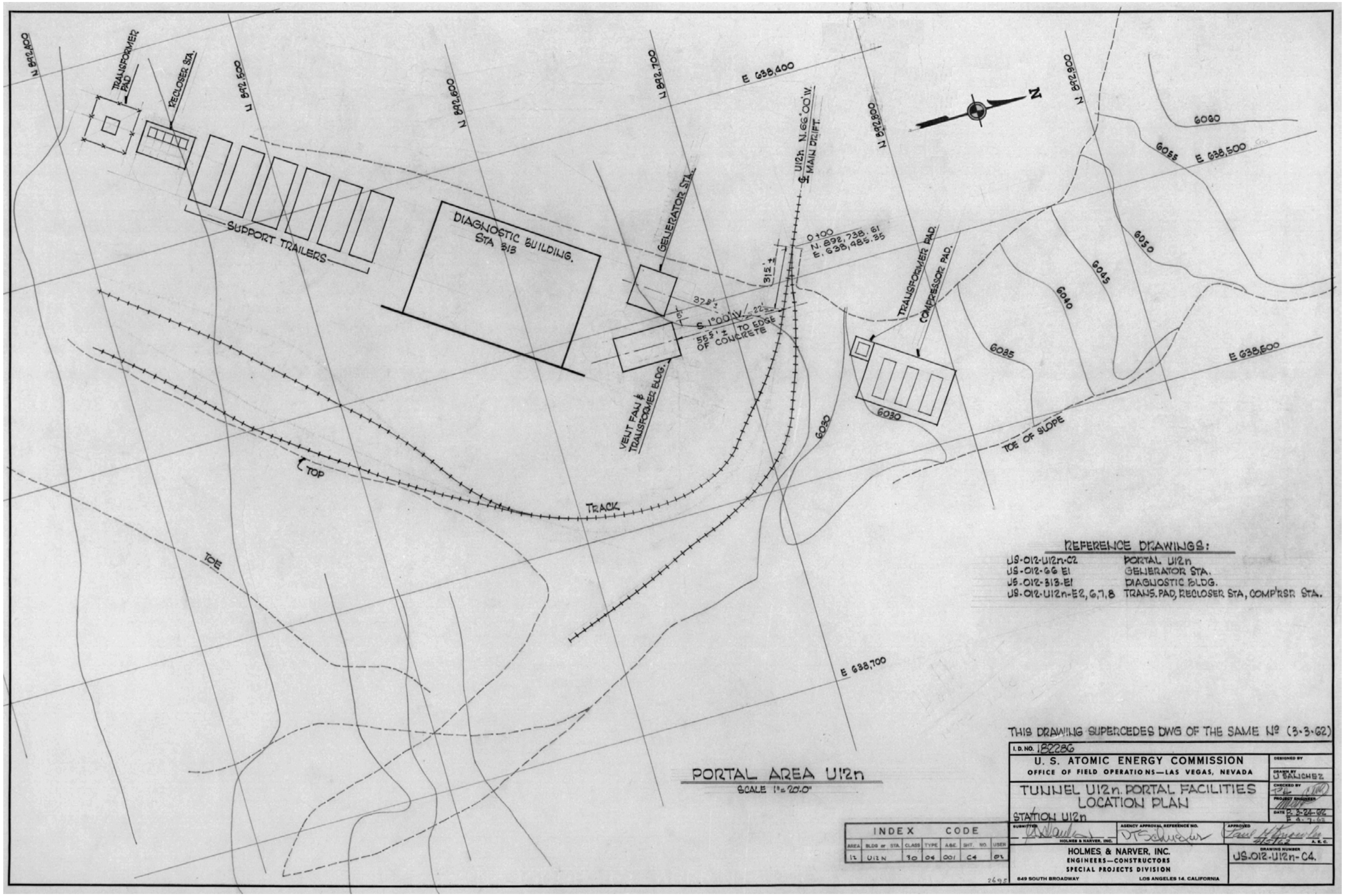


Figure 22. Plan of the U12n Tunnel portal area, 1962 (drawing JS-012-U12n-C4, on file at the Archives and Records Center, Mercury, Nevada).

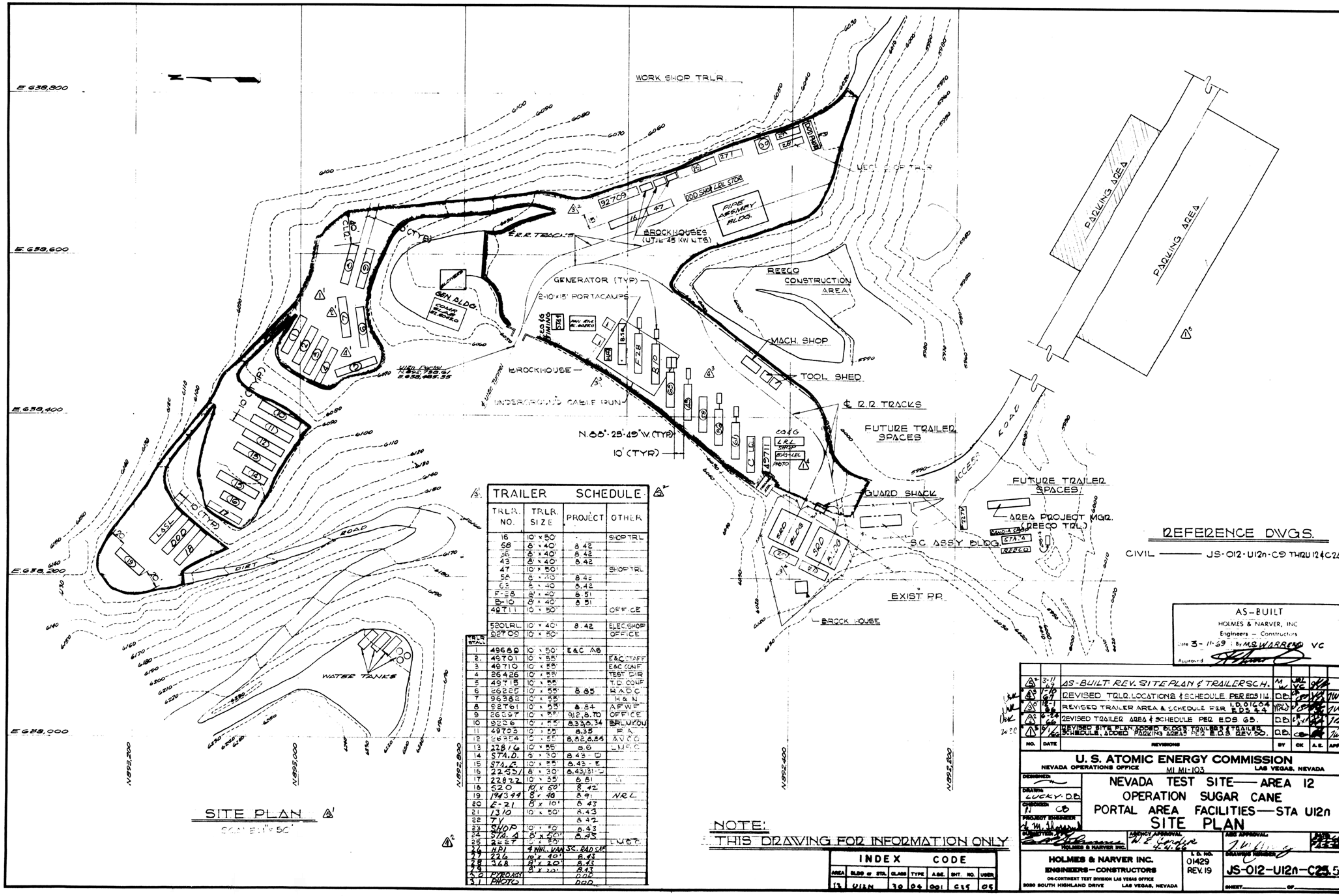


Figure 23. Plan of the U12n Tunnel portal area, 1966 (drawing JS-012-U12n-C25.5, on file at Archives and Records Center, Mercury, Nevada).

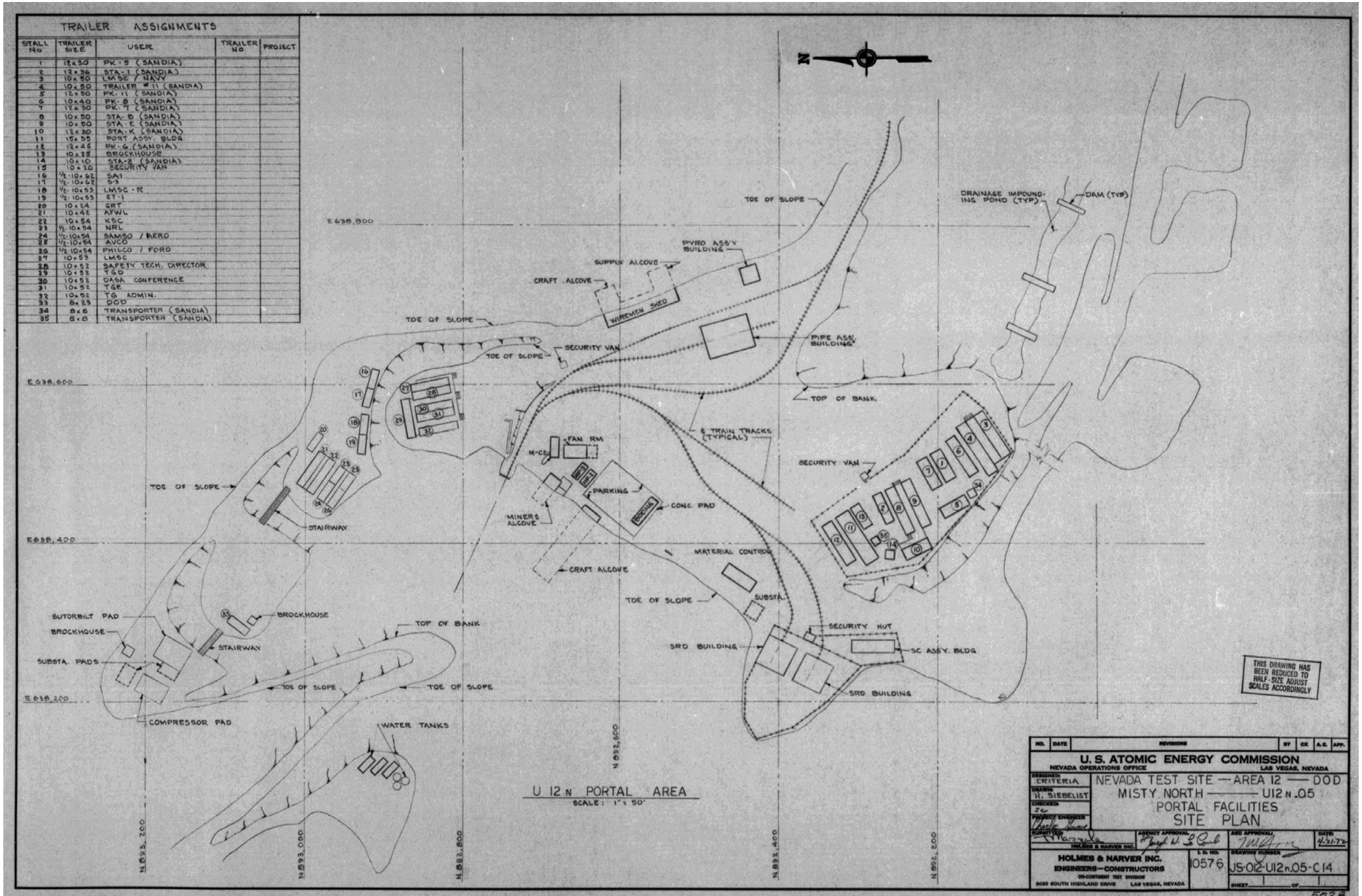


Figure 24. Plan of the U12n Tunnel portal area, 1972 (drawing JS-012-U12n.05-C14, on file at Archives and Records Center, Mercury, Nevada).

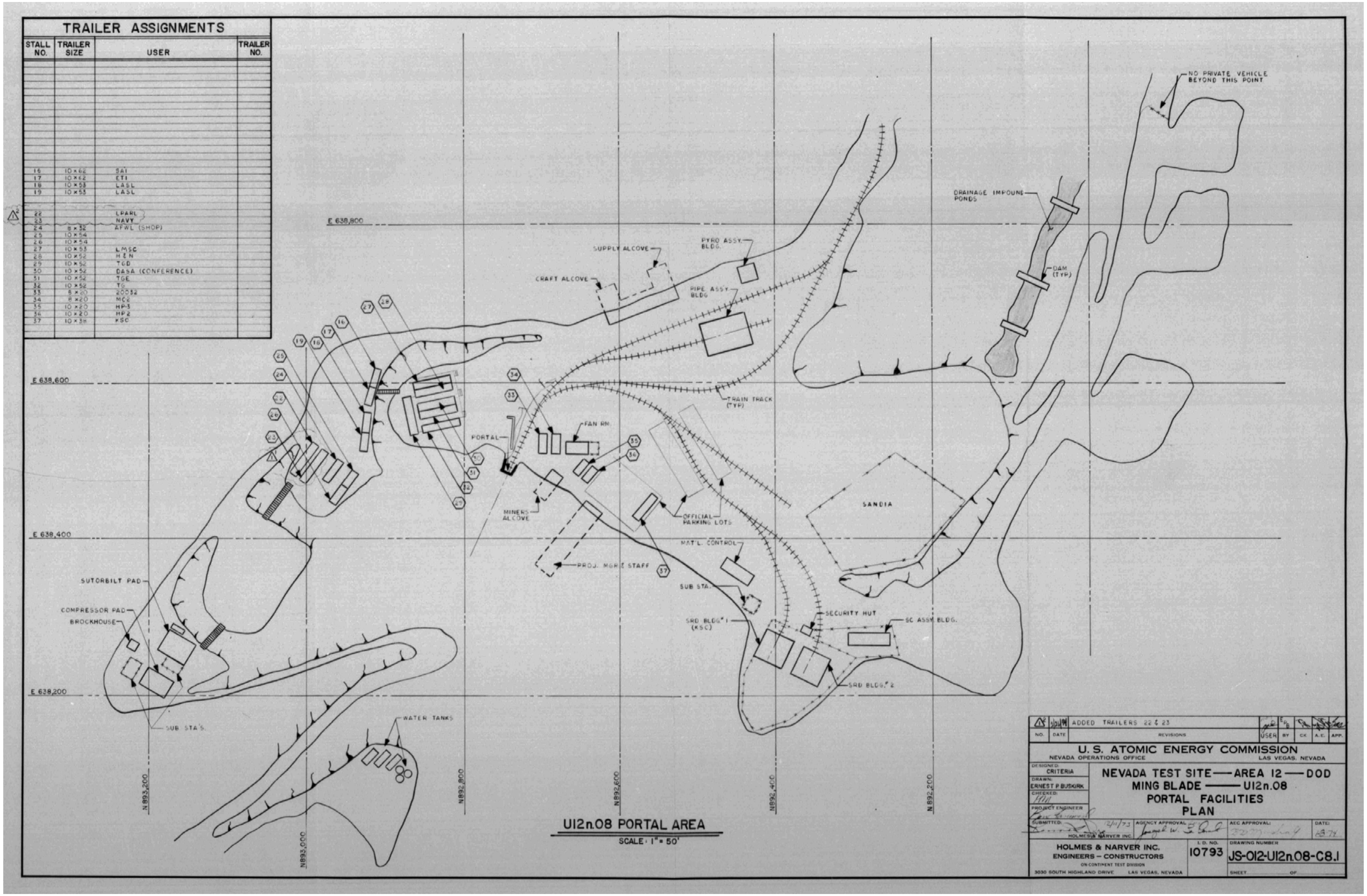


Figure 25. Plan of the U12n Tunnel portal area, 1974 (drawing JS-012-U12n.08-C8.1, on file at Archives and Records Center, Mercury, Nevada).

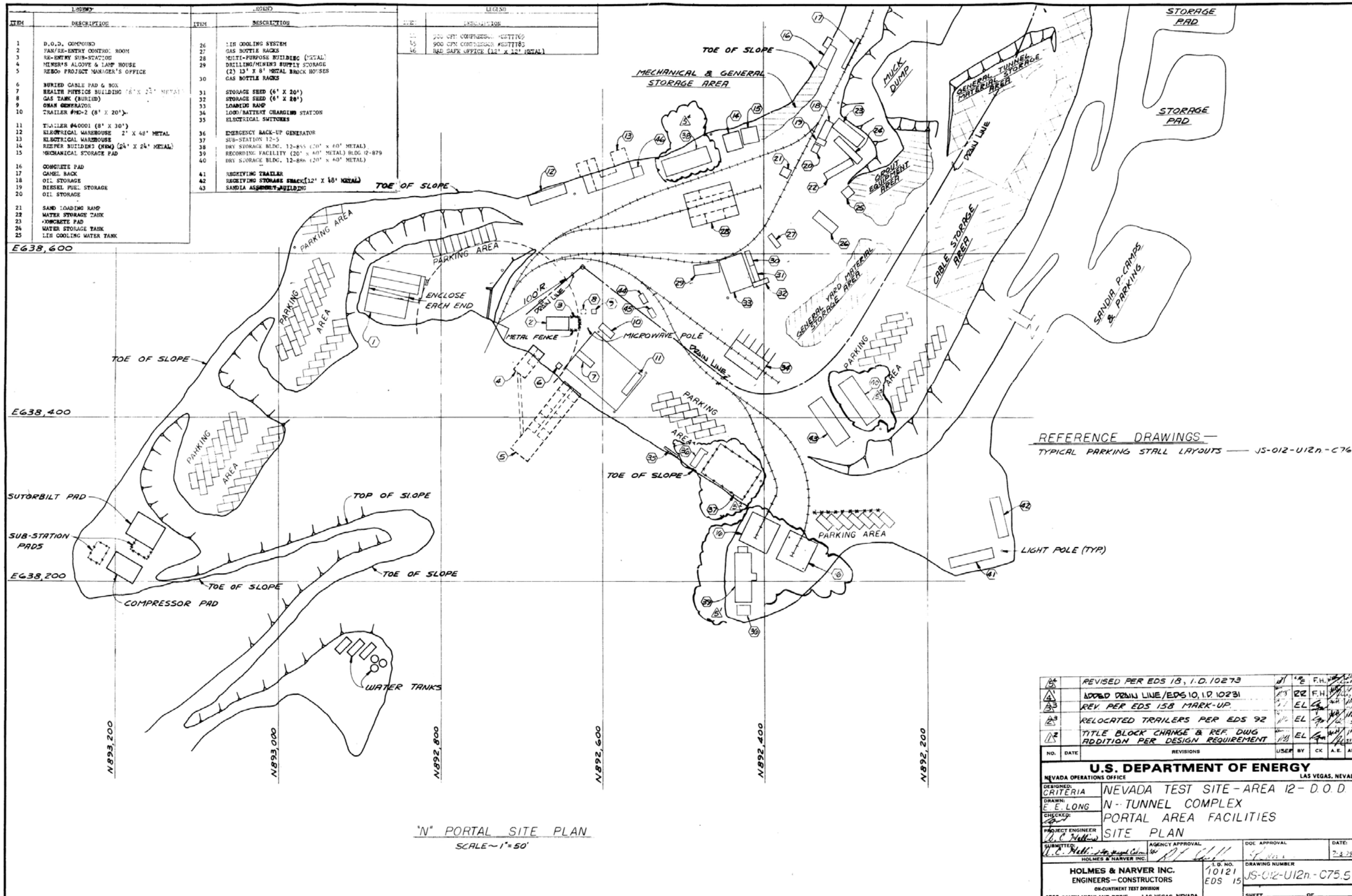


Figure 26. Plan of the U12n Tunnel portal area, 1979 (drawing JS-012-U12n-C75.5, on file at Archives and Records Center, Mercury, Nevada).

Figure 27. U12n Tunnel portal area, 1980 (photograph NF-1664, on file at Remote Sensing Laboratory).

Figure 28. U12n Tunnel portal area, 1986. The portal for the main drift is on the right and the portal for the extension drift is on the left (photograph NF-4752, on file at Remote Sensing Laboratory).

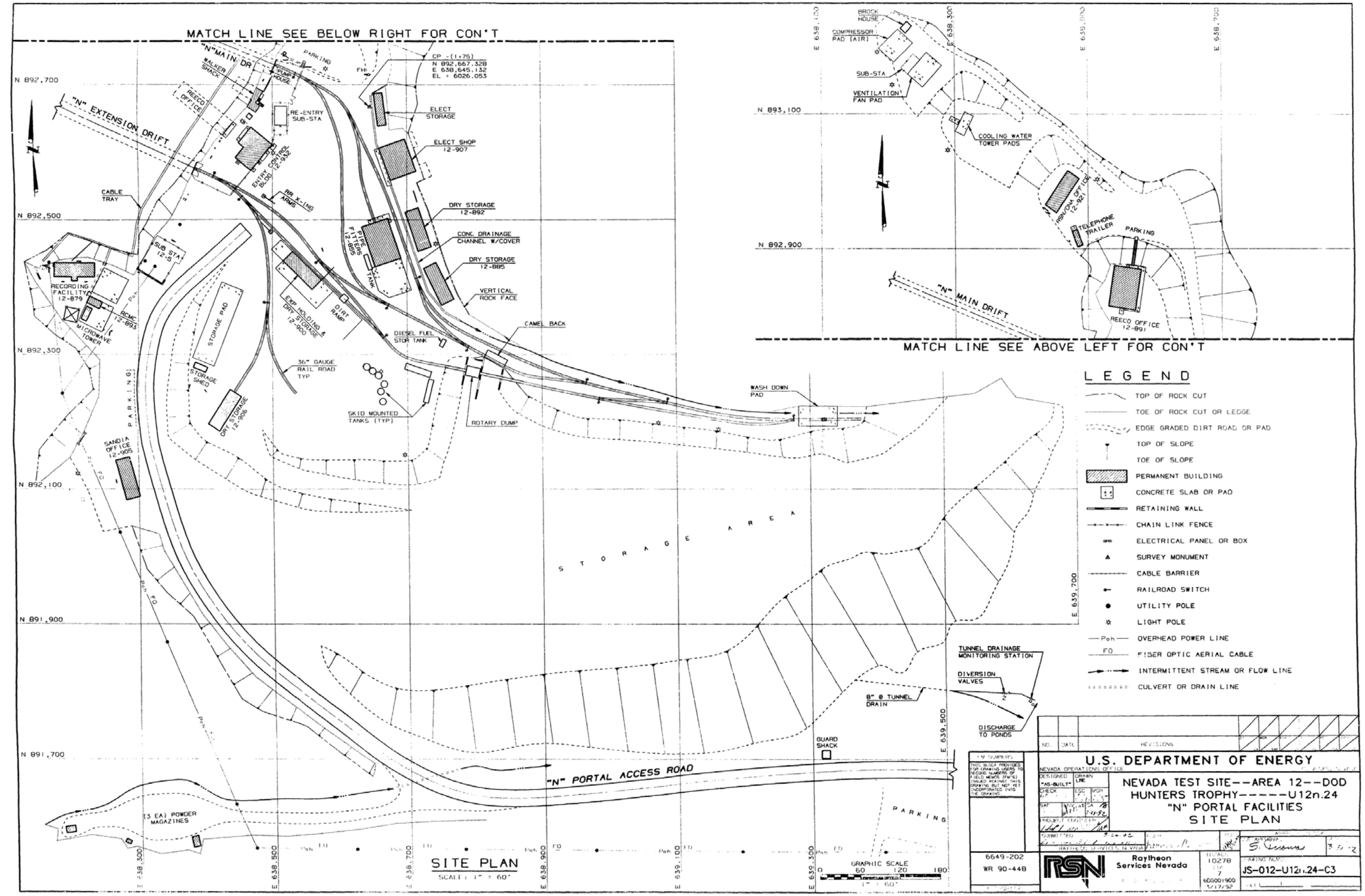


Figure 29. Plan of the U12n Tunnel portal area, 1992 (drawing JS-012-U12n.24-C3, on file at Archives and Records Center, Mercury, Nevada).

Figure 30. U12n Tunnel portal area, 1993 (photograph NF-13491, on file at Remote Sensing Laboratory, Nevada).

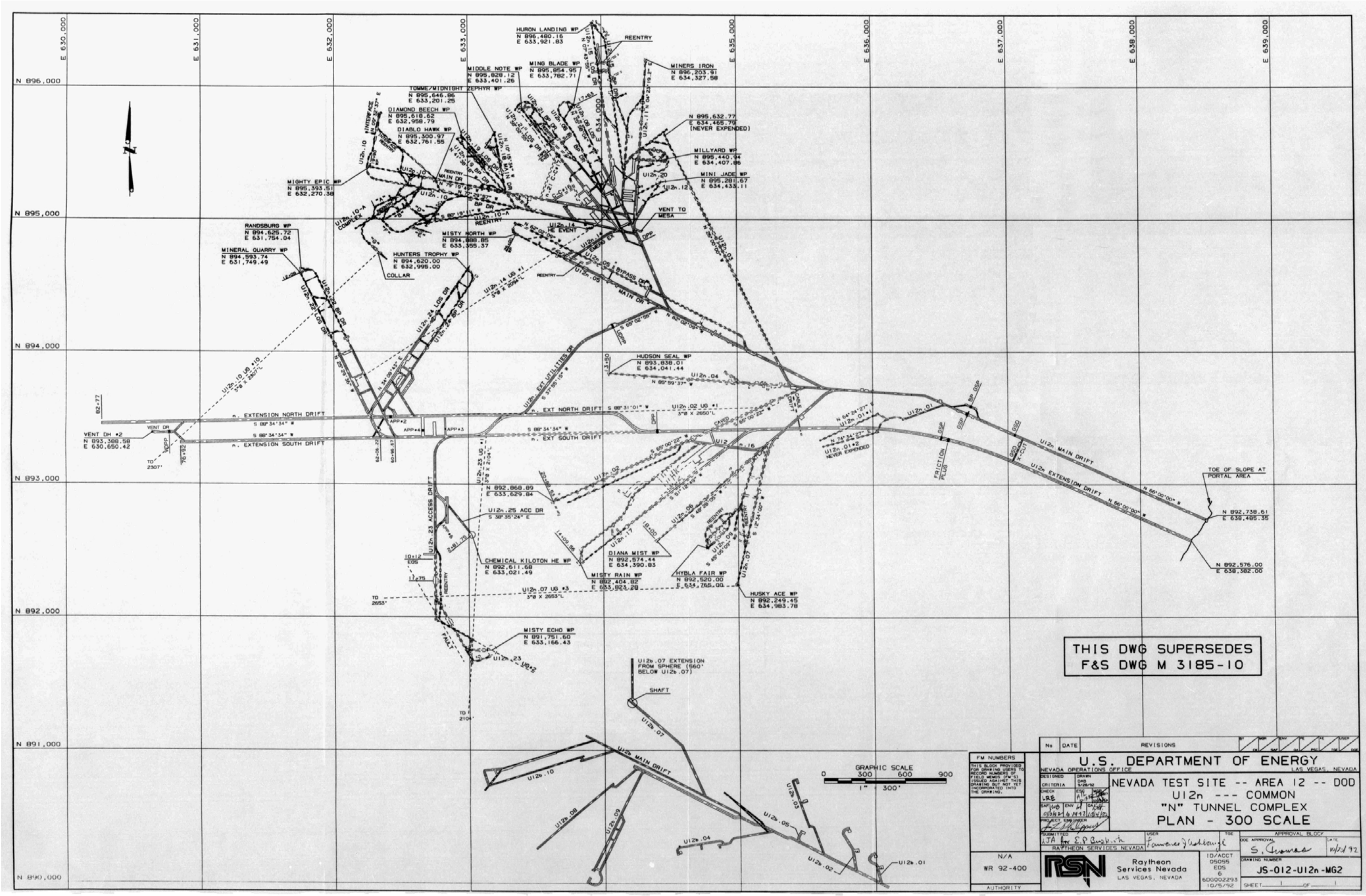


Figure 31. Drift plan of the U12n Tunnel, 1992 (drawing JS-012-U12n-MG2, on file at Archives and Records Center, Mercury, Nevada).

Figure 32. U12n Tunnel pond area, 1993 (photograph NF-13488, on file at Remote Sensing Laboratory, Nevada).

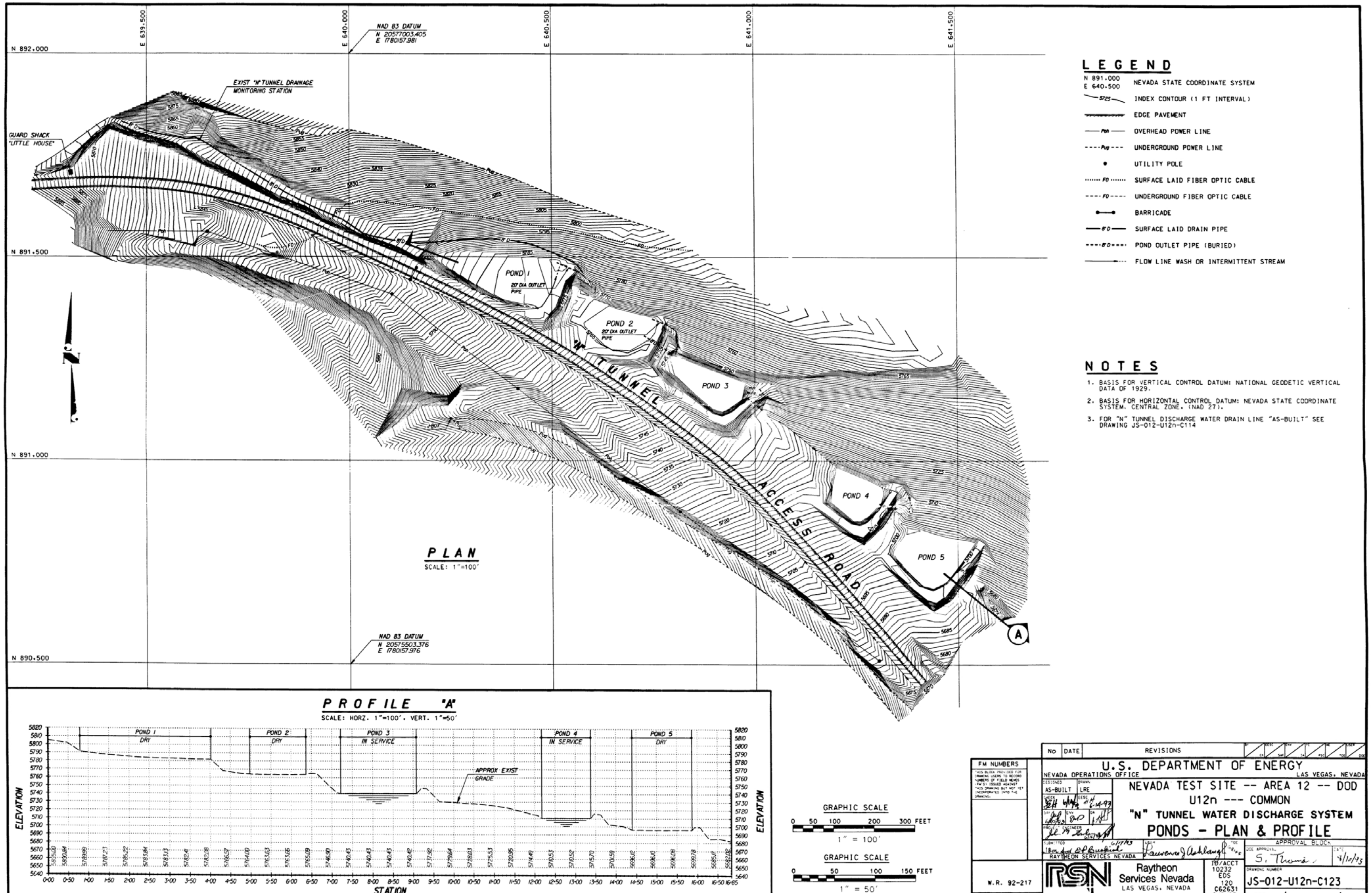


Figure 33. Plan and profile of the U12n Tunnel pond area, 1993 (drawing JS-012-U12n-C123, on file at Archives and Records Center, Mercury, Nevada).

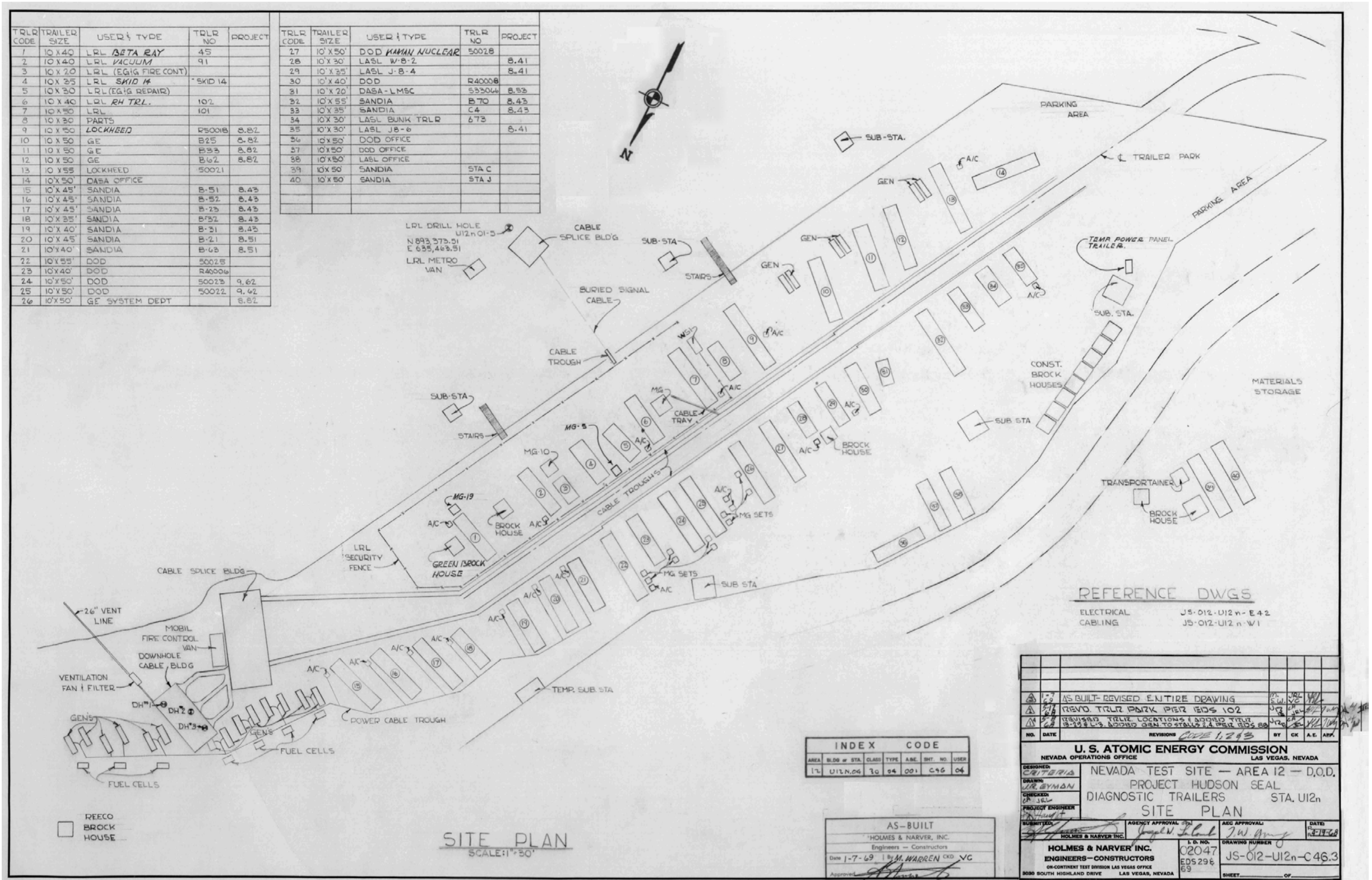


Figure 34. Plan of the U12n Tunnel mesa trailer park, 1968 (drawing JS-012-U12n-C46.3, on file at Archives and Records Center, Mercury, Nevada).

Figure 35. U12n Tunnel mesa trailer park, 1980 (photograph NF-1665, on file at Remote Sensing Laboratory).

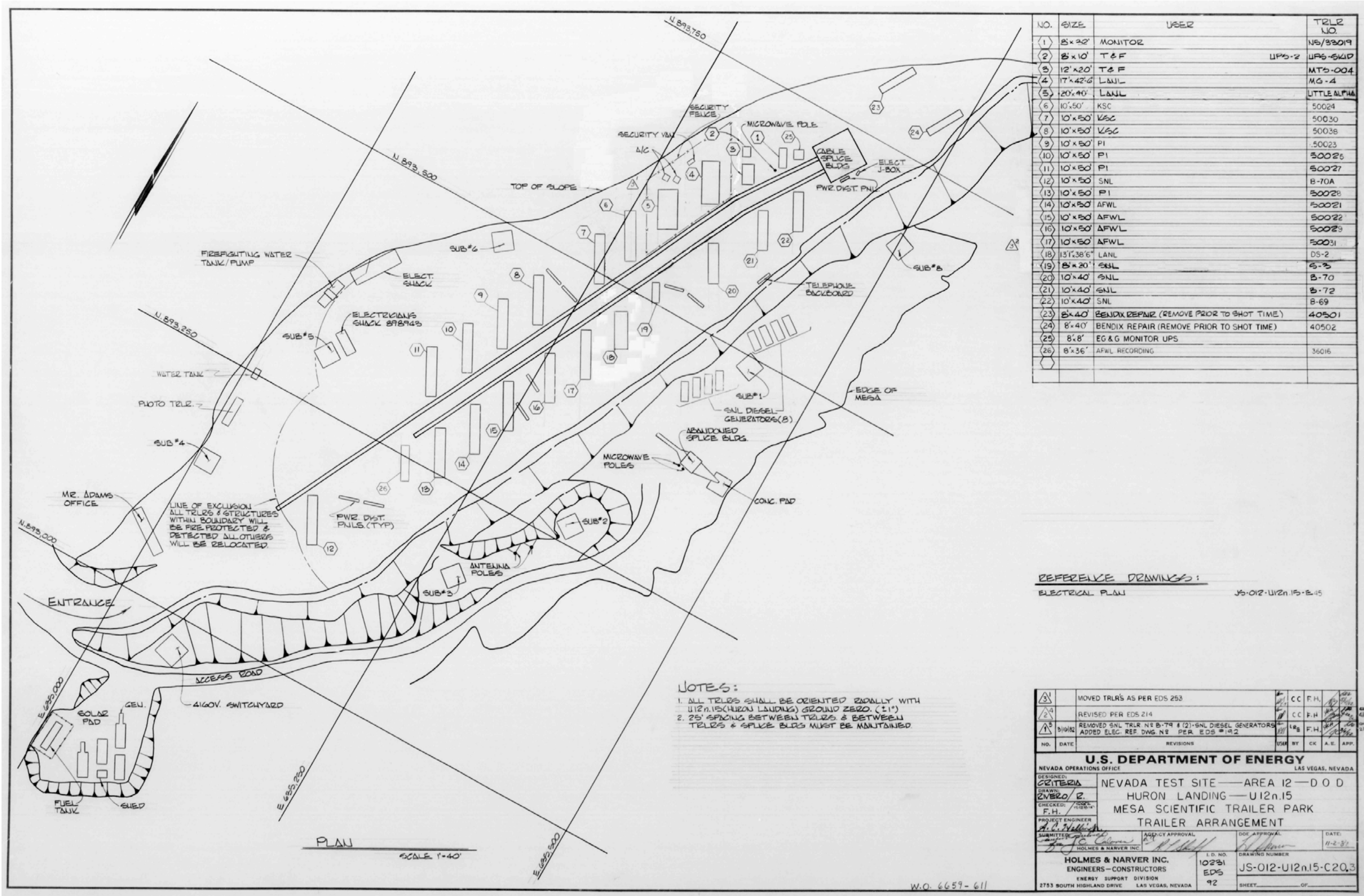


Figure 36. Plan of the U12n Tunnel mesa trailer park, 1981 (drawing JS-012-U12n.15-C20.3, on file at Archives and Records Center, Mercury, Nevada).

Figure 37. Alpine miner in tunnel, 1986 (photograph NF-4849, on file at Remote Sensing Laboratory).

Figure 38. Alpine miner excavating a cavity (photograph CJ-462-4, on file at Defense Threat Reduction Information Analysis Center, Albuquerque).

The U12n extension drift, the second drift starting from the portal, was begun in the summer of 1983 with a tunnel boring machine (Ashbaugh and Griffin 2009; Morrill and Kensok 1986:1). The tunnel boring machine was manufactured by the Robbins Company of Seattle, Washington in 1976 and was first used on the Chicago Tunnel and Reservoir Plan project (Morrill and Kensok 1986:9). It was moved in 1980 to Buffalo, New York for use on the Light Rail Rapid Transit project, where it was modified to a 18 ft 7 inch (5.66 m) diameter from an original 18 ft 2 inch (5.54 m) diameter. The machine was next used from December 1982 to January 1983, totaling 40 hours, to bore a 705 ft (215 m) long tunnel in Little Skull Mountain in Area 25 on the NNSS for the MX missile project sponsored by the U.S. Air Force (Morrill and Kensok 1986:12; Figure 39). It was then moved to the U12n Tunnel in May 1983 (Figure 40). The machine was 52 ft (15.8 m) in length, weighed 235 tons, had six 150 hp electric drive motors, 39 single disc cutters, and 2 twin disc cutters on the cutterhead. A trailing sled was attached to the back end of the machine to remove muck (Morrill and Kensok 1986:19). A conveyor on the machine moved the muck to the trailing sled and a belt conveyor moved it to the muck train. A muck car had an 18 cubic yard capacity and a full stroke of the cutterhead could load five of the cars. The boring machine when fully assembled with all the attachments was approximately 200 ft (61 m) long (Ashbaugh and Griffin 2009). A laser beam directed at fore and aft targets on the machine from a generator/transmitter mounted on the side or rib of the drift kept it properly aligned. At one time, the objective was to bore through Rainier Mesa and start another access drift and portal on the other side, and as such, would provide additional ventilation to the tunnel interior (Ashbaugh and Griffin 2009; Ristvet 2009). However, the 1992 testing moratorium ended this plan. The boring machine still remains at the end of the U12n extension drift to this day, 8,277 ft (2,523 m) from the portal. All fluids were drained from it prior to the tunnel being mothballed in 1994.

A total of 22 nuclear and 11 high explosive tests were carried out in the U12n Tunnel (Tables 1 and 2). The first nuclear test was in June 1967 and the last in September 1992. LLNL provided 12 of the nuclear devices and LANL 10 of them. All of the nuclear tests, except for two, were sponsored by DTRA. The other two, Tomme and Randsburg, were sponsored by LLNL. The overall objective of these tests was weapons effects, but several also attempted to prove the feasibility of low yield test beds which were less costly in terms of construction, material, and experiment recovery. Most of the nuclear tests utilized a tapered line-of-sight pipe and drift. The nuclear device was placed in an A-box attached to the small tapered end of the line-of-sight pipe. Three tests utilized a mined hemispherical cavity in which the nuclear device was placed. One test had a line-of-sight pipe and drift as well as a small cavity. Most of the tests were conducted individually; but on two separate occasions, two nuclear tests were conducted simultaneously in the same drift complex. On another occasion, two nuclear tests were conducted on the same day, but in different drift complexes. Finally, two tests were conducted in the same drift complex, but in different years.

The first two high explosive tests supported the nuclear testing in the tunnel. The next two high explosive tests were after the nuclear testing program ended and conducted by LLNL under the Vela Uniform program for seismic studies. The last seven high explosive tests were part of a series sponsored by DTRA for the Hard Target Defeat Program.

Figure 39. Tunnel boring machine at start of X tunnel in Area 25, 1982 (photograph MX-027-7, on file at Remote Sensing Laboratory).

Figure 40. Tunnel boring machine at start of the extension drift for the U12n Tunnel (photograph courtesy of Wayne Griffin).

Table 1. Nuclear Tests in U12n Tunnel.

LOCATION	TEST	OPERATIONS*	DATE
U12n.02	Midi Mist	Latchkey/Minute Gun	06/26/1967
U12n.04	Hudson Seal	Bowline/Minute Gun	09/24/1968
U12n.05	Misty North	Grommet/Minute Gun	05/02/1972
U12n.06	Diana Mist	Mandrel/Minute Gun	02/11/1970
U12n.07	Husky Ace	Arbor/Hussar Sword	10/12/1973
U12n.08	Ming Blade	Arbor/Hussar Sword	06/19/1974
U12n.09	Hybla Fair	Bedrock/Hussar Sword	10/28/1974
U12n.10	Mighty Epic	Anvil/Hussar Sword	05/12/1976
U12n.10a	Diablo Hawk	Cresset/Hussar Sword	09/13/1978
U12n.11	Miners Iron	Guardian/Hussar Sword	10/31/1980
U12n.12	Mini Jade	Phalanx/Hussar Sword	05/26/1983
U12n.15	Huron Landing	Praetorian/Hussar Sword	09/23/1982
U12n.15a	Diamond Ace	Praetorian/Distant Arbor	09/23/1982
U12n.17	Misty Rain	Grenadier/Hussar Sword	04/06/1985
U12n.18	Tomme/Midnight Zephyr	Phalanx/Distant Arbor	09/21/1983
U12n.19	Diamond Beech	Charioteer/Distant Arbor	10/09/1985
U12n.20	Mill Yard	Charioteer/Hussar Sword	10/09/1985
U12n.21	Middle Note	Musketeer/Hussar Sword	03/18/1987
U12n.22	Mineral Quarry	Aqueduct/Hussar Sword	07/25/1990
U12n.22a	Randsburg	Aqueduct	07/25/1990
U12n.23	Misty Echo	Cornerstone/Discus Wheel	12/10/1988
U12n.24	Hunters Trophy	Julin/Hussar Sword	09/18/1992

* Consists of the DOE/DoD operation designations.

Table 2. High Explosive Tests in U12n Tunnel.

LOCATION	TEST	DATE
U12n.09	Stemming Plan Test (SPLAT)	Mid 1974
U12n.14	Pre-Mill Yard	10/27/1984
U12n.25	On-Site Seismic Yield (OSSY-3)	10/30/1992
U12n.25	Chemical Kiloton	09/22/1993
U12n Extension	Dipole Hail #10	05/13/1997
U12n Extension	Dipole Hail #11	05/21/1997
U12n Extension	Dipole Hail #12	06/04/1997
U12n Extension	Dipole Hail #13	06/18/1997
U12n Extension	Dipole Hail #19	09/24/1997
U12n Extension	Dipole Hail #27	04/08/1998
U12n Extension	Dipole Hail #28	04/22/1998

U12n.01 Drift

The first test drift, U12n.01 (Figure 41), was constructed by LLNL in 1962 for the Sugar Cane nuclear test, but was later abandoned for operational reasons (Flangas 2009; Townsend et al. 2007). The U12n.01 drift started to the left off the U12n main drift at 2,140 ft (652 m) from the portal and was 1,328 ft (405 m) long. Although the U12n.01 drift was never used for a test, approximately 150 ft (46 m) of it was later utilized as an underground mechanics shop. A 10 ft (3m) long concrete plug was placed in the U12n.01 drift at 162 ft (49 m) from the U12n main drift.

U12n.02 Drift - Midi Mist

Midi Mist, conducted on June 26, 1967, was the first nuclear test in the U12n Tunnel. LLNL supplied the device and placed it at a depth of 1,230 ft (375 m) below the surface in the U12n.02 drift (AEC/NV 1968; Horton et al. 1984:183). Yield of the explosion was less than 20 kilotons (DOE/NV 2000). The test evaluated radiation effects on several different weapon systems.

When DTRA reopened the U12n Tunnel in 1965, they rehabilitated the U12n main and U12n.01 drifts, extended the U12n main drift, and mined the U12n.02 drift. Mining of the U12n.02 drift started on December 31, 1965 and was completed on December 30, 1966 (Bennett 1991; Ege et al. 1980:1). It consisted of a line-of-sight drift; a bypass drift was not constructed (Figures 42-44). The U12n.02 drift measured 2,109 ft (643 m) long and started to the left off the main drift at 3,160 ft (963 m) from the portal. The bearing was to the southwest at an upward grade of 0.5 percent. It was located in the tunnel bed 4 geologic unit and the working point fell within a zeolitized, calc-alkaline ash-fall tuff strata (Ege et al. 1980:5). The start of the drift where it left the main access drift measured 15.5 ft (4.7 m) wide and 13 ft (4 m) high and after a distance of about 224 ft (68 m) increased to 18 ft (5.5 m) wide and high. It maintained this size for another 1,264 ft (385 m) and then began to incrementally decrease to only 10 ft (3 m) wide and high toward the end. The working point for placement of the nuclear device was 20 ft (6.1 m) away from the end of the drift. At a 30 degree horizontal angle to the right of the working point extended a hook drift 80 ft (24 m) long, 9 ft (2.7 m) high, and 7 ft (2.1 m) wide. Opposite the hook drift and extending to the left of the working point, at a horizontal angle of 90 degrees, was the reaction history drift for LLNL (Figure 45). The reaction history drift was 120 ft (36.6 m) long, 9 ft high, and 8 ft (2.4 m) wide. At the end of the reaction history drift was a vertical cable hole to the mesa and the LLNL trailer park. A second LLNL cable hole was also completed for the Midi Mist test. The original beginning date for the cable hole was May 1962 when it was planned to be used on the canceled Sugar Cane test in the U12n.01. The hole, when finished in December 1966, was located at the end of a cable drift 444 ft (135 m) long, 7 ft (2 m) high, and 5.5 ft (1.5 m) wide that was mined off to the left and 157 ft (48m) from the start of the U12n.02 drift. The cable hole had a 10.5 in (26.7 cm) diameter casing that was grouted in place and the hole was stemmed after cable installation. The purpose of this cable hole was to support a Cloud Chamber experiment located about 50 ft (15m) from the U12n.02 drift. Three 20 inch (50.8 cm) diameter cable holes to the main diagnostics trailer park on the mesa were available in the cable alcove located off the main tunnel access drift. These three cable holes, drilled for the Midi Mist test, served the cabling needs for a number of subsequent tests as well, and contained 845 cables (Flangas 2009). About 6 million feet (1,136 miles or 1,829 km) of copper cable was used for the Midi Mist test (Figures 46-47). A total of 53 instrumentation trailers were used for the test and were stationed

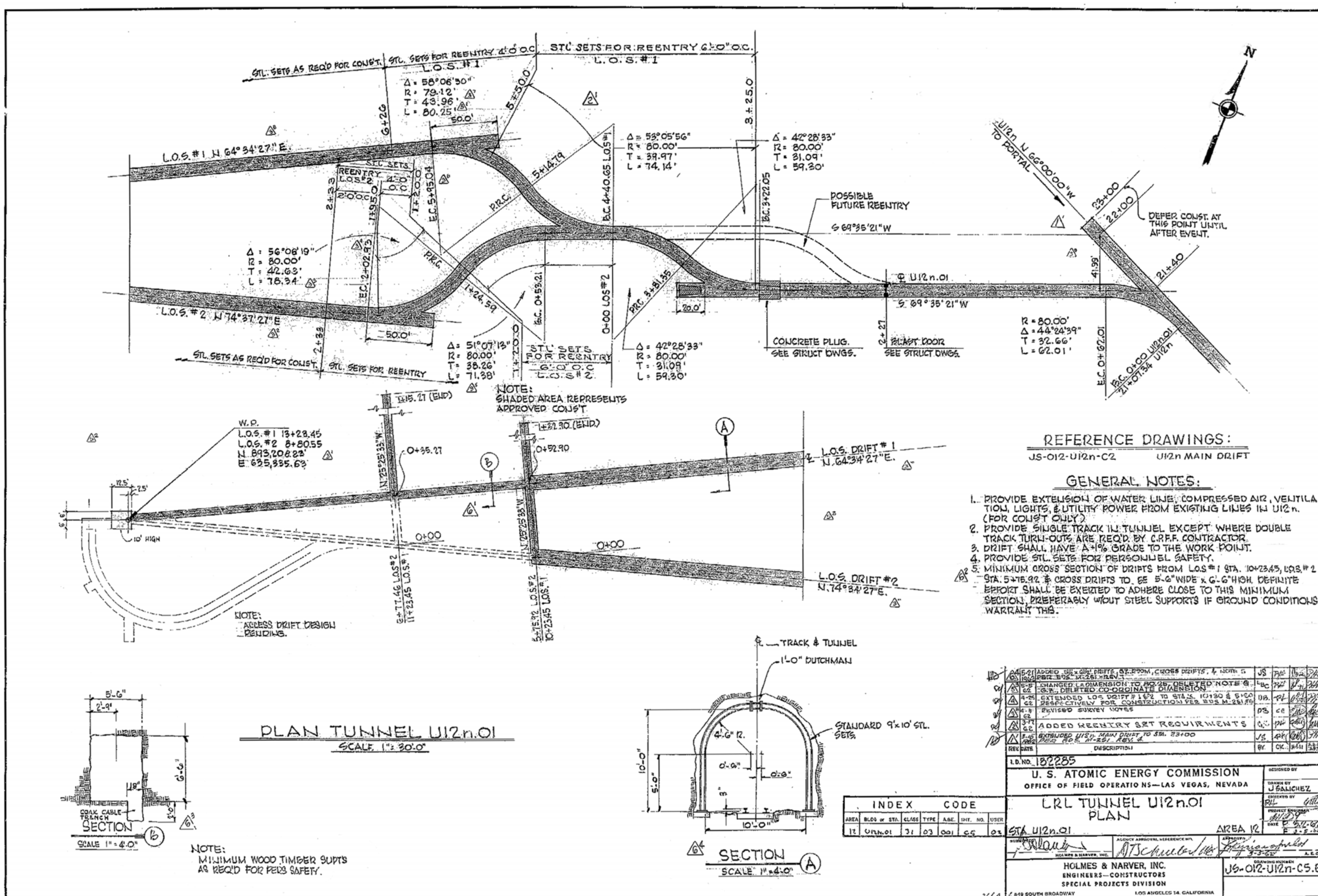


Figure 41. Plan of the U12n.01 drift, 1962 (drawing JS-012-U12n-C5.6, on file at Archives and Records Center, Mercury, Nevada).

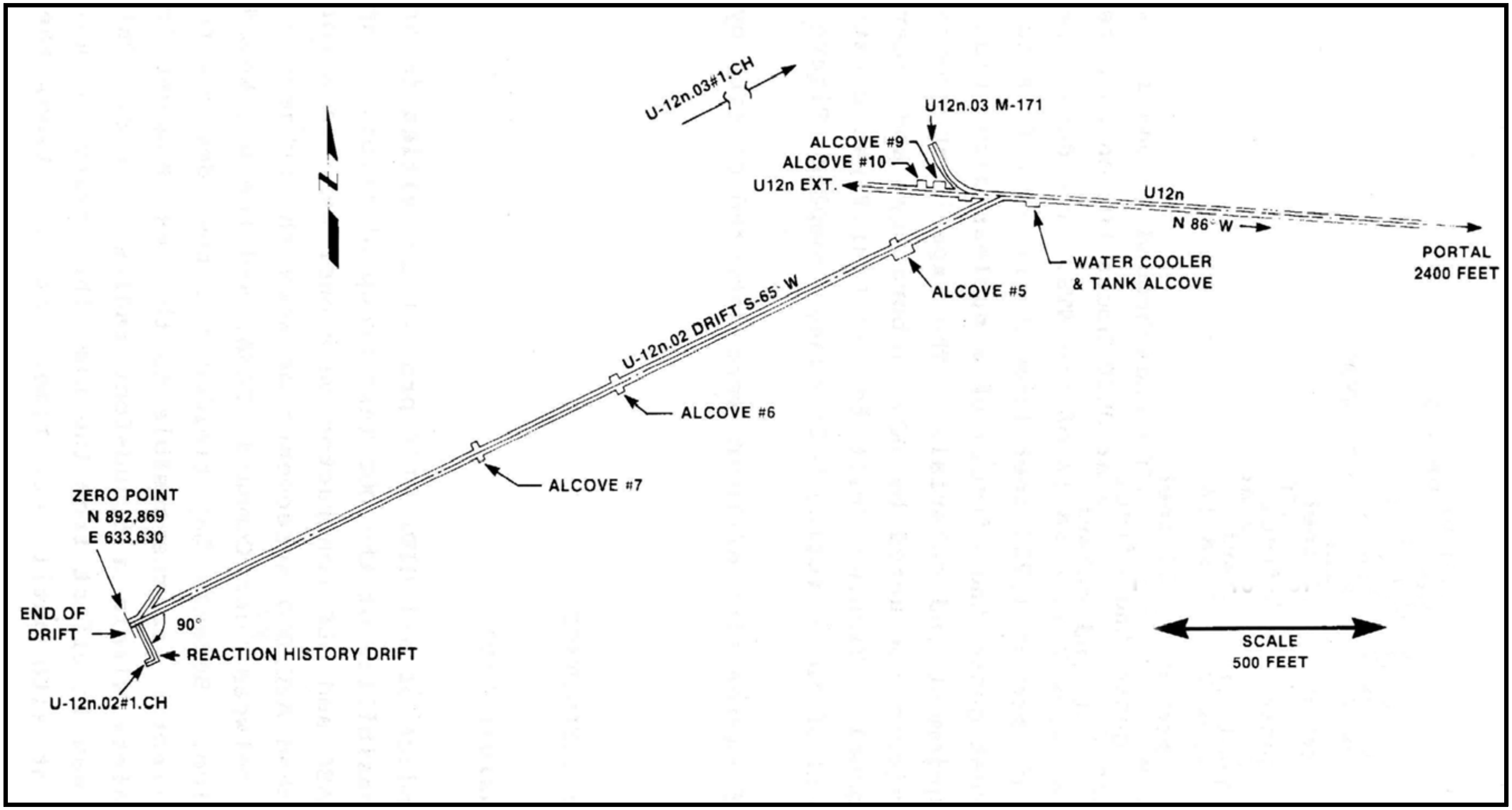


Figure 42. Plan of the U12n.02 drift for the Midi Mist test (Horton et al. 1984:184).

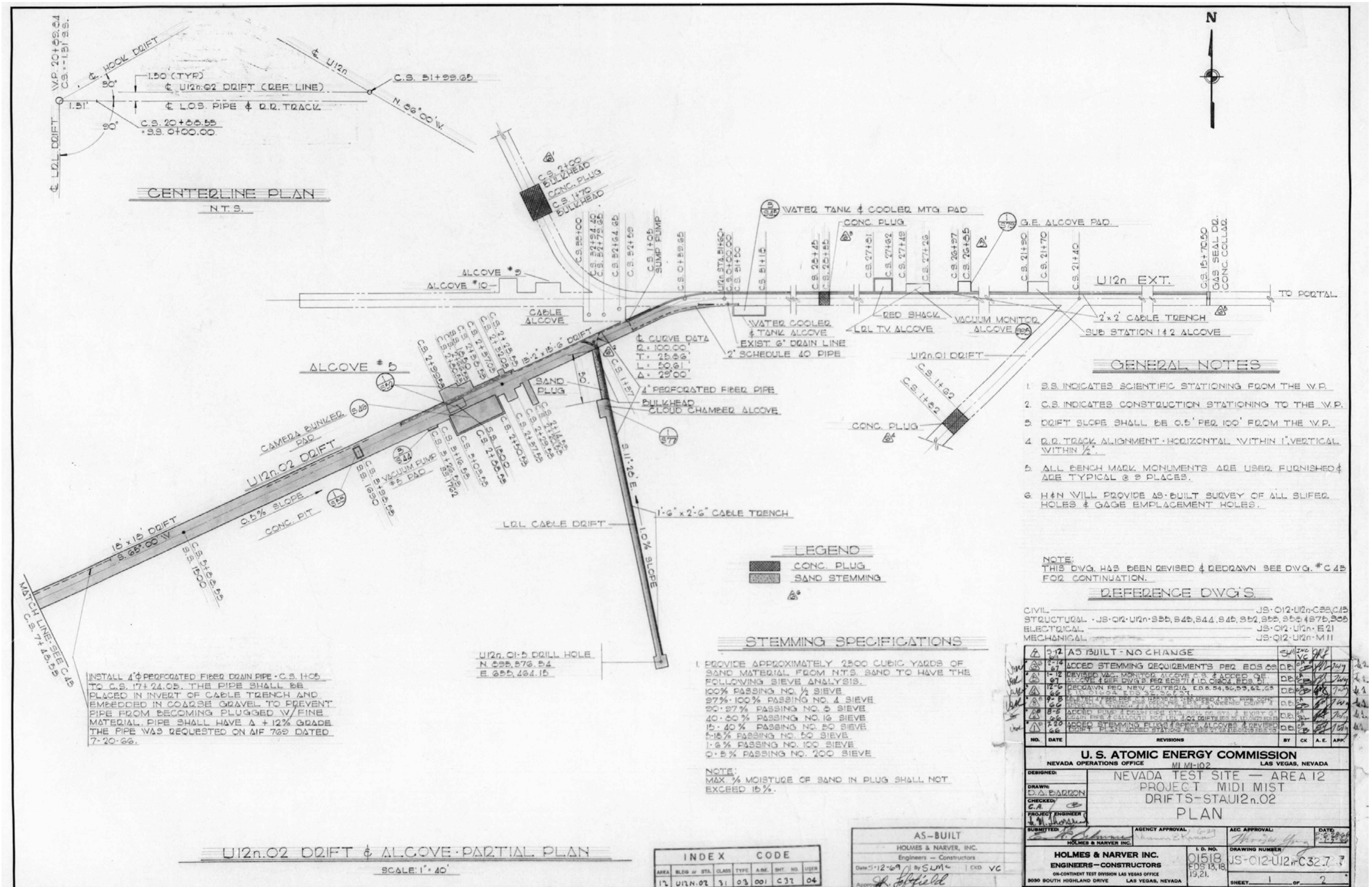


Figure 43. Construction plan 1 of 2 of the U12n.02 drift for the Midi Mist test, 1966 (drawing JS-012-U12n-C32.7, on file at Archives and Records Center, Mercury, Nevada).

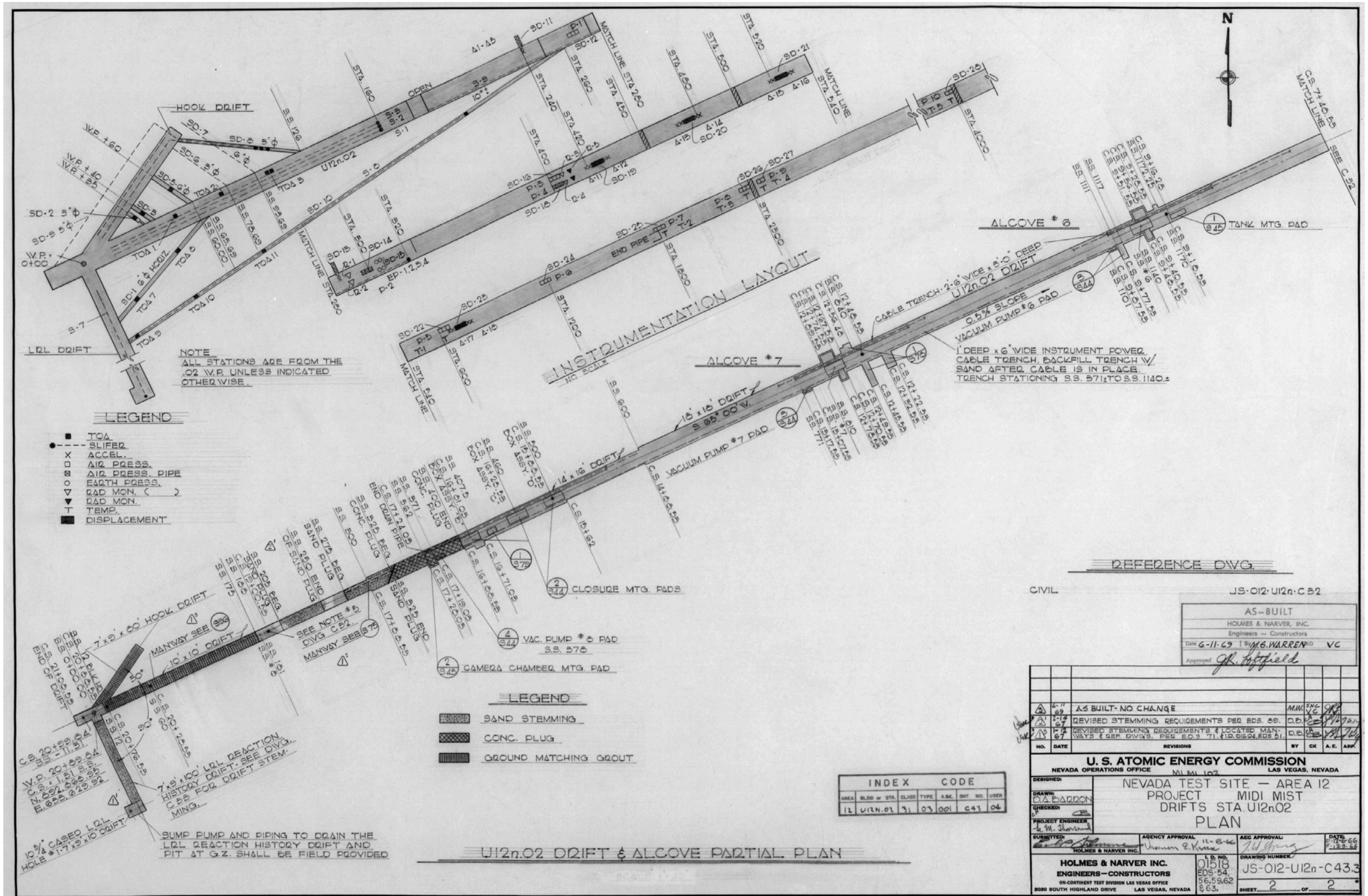


Figure 44. Construction plan 2 of 2 of the U12n.02 drift for the Midi Mist test, 1966 (drawing JS-012-U12n-C43.3, on file at Archives and Records Center, Mercury, Nevada).

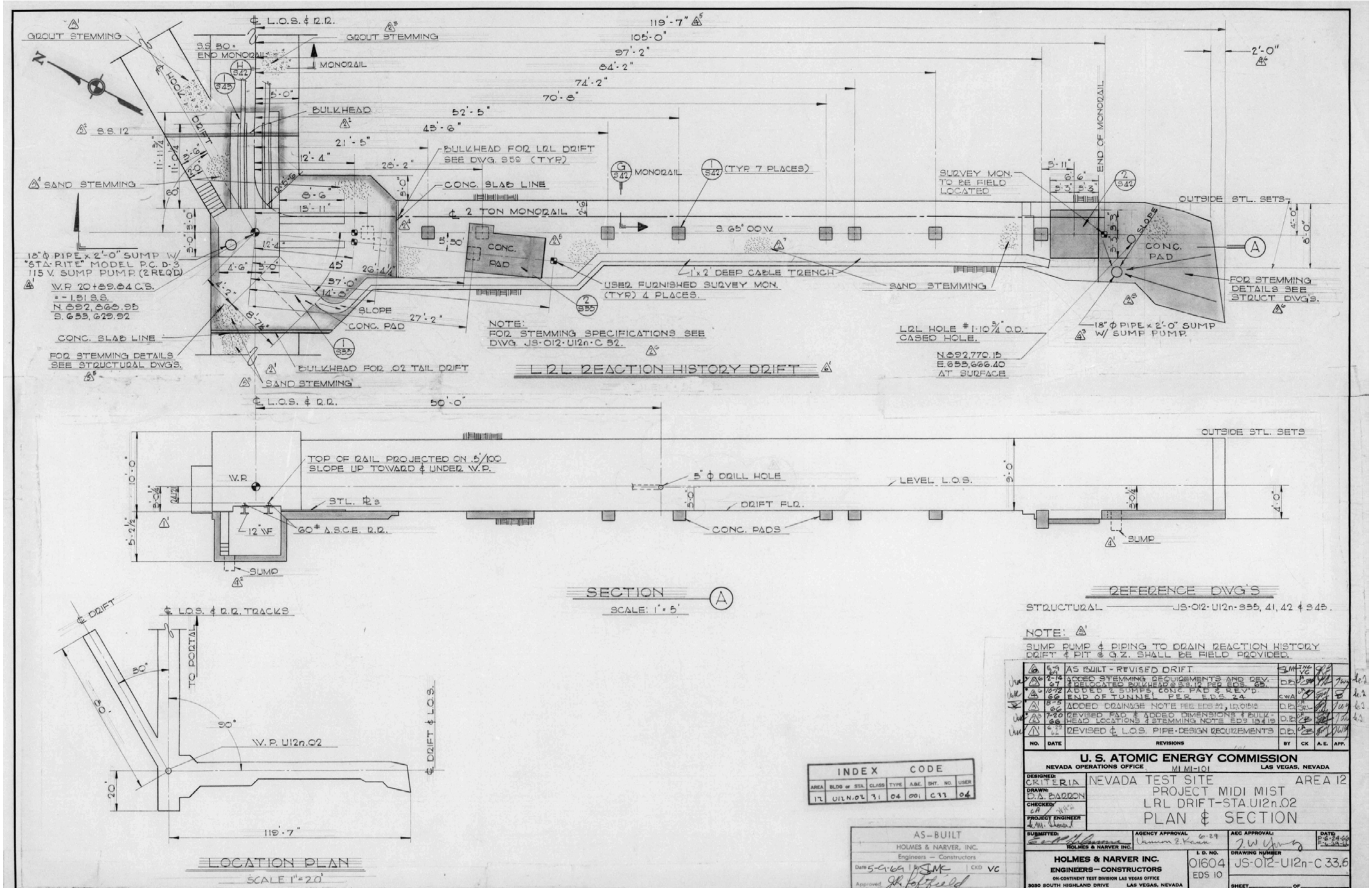


Figure 45. Construction plan of the reaction history drift in the U12n.02 drift, 1966 (drawing JS-012-U12n-C33.6, on file at Archives and Records Center, Mercury, Nevada).

Figure 46. Equipment in U12n Tunnel portal area for the Midi Mist test, 1967 (photograph N20010, on file at Archives and Records Center, Lawrence Livermore National Laboratory, California).

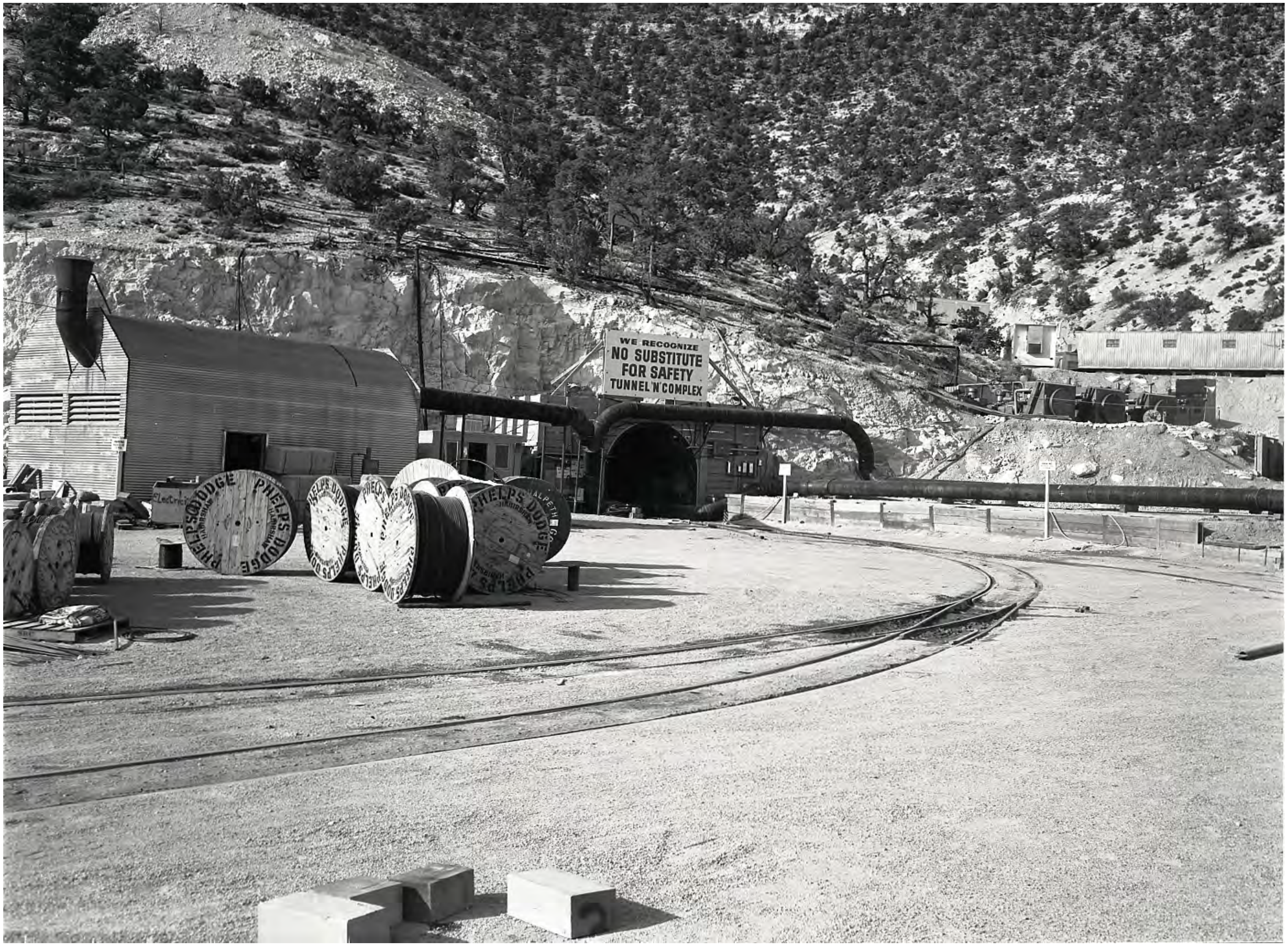


Figure 47. U12n Tunnel portal area for the Midi Mist test, 1967 (photograph N20011, on file at Archives and Records Center, Lawrence Livermore National Laboratory, California).

at three different locations: the LLNL trailer park on the mesa, the main diagnostics trailer park on the mesa, and at the portal trailer park (AEC/NV 1968; Horton et al. 1984:185).

The Midi Mist line-of-sight pipe was 1,800 ft (549 m) long. Following installation of the line-of-sight and stub pipes (Figure 48), installation of the experiments in the test chamber began. During experiment installation and alcove configuration many dry runs were conducted. Several months later a successful mandatory full power dry run was conducted and device insertion followed. Because there was no bypass drift, the device for Midi Mist was transported to the zero room on a specifically designed pushcart down a walkway along the right side of the line-of-sight drift, which was formed during pre-stemming of the line-of-sight pipe. Following insertion of the device at the working point, the reaction history drift and the zero room were stemmed with sand, while the hook drift was stemmed with rock matching grout. The walkway along the right side of the line-of-sight drift was then stemmed with rock-matching grout, sand, and concrete to match the pre-stemmed areas on the left side of the line-of-sight drift. The first 50 ft (15 m) of the Cloud Chamber drift was filled with sand and a 20 ft (6m) concrete plug was installed 115 ft (35 m) from the U12n.02 drift. A concrete blast plug, 30 ft (9 m) long, was placed in the U12n.03 drift at 170 ft (52 m) from its start to mitigate the possibility of a radioactive venting via the Aqueduct syncline in case of a containment problem underground. The plug was also designed to contain groundwater that entered the U12n.03 drift from flooding the rest of the tunnel. A 20 ft (6 m) long concrete plug was placed in the U12n.01 drift, 162 ft (49m) from the main drift. A concrete plug, 10 ft (3 m) long, was constructed in the main drift at 2,835 ft (864 m) from the portal. The gas seal door was 1,570 ft (479 m) from the portal. The final dry run was conducted several days after completion of the stemming operation. Button-up operations began after the successful final dry run.

The Midi Mist device was armed and the area cleared of personnel by about 9:00 on the morning of June 23, the day scheduled for the test (Horton et al. 1984:191). The test was delayed, however, and eventually cancelled by early afternoon. Arming parties returned to the tunnel and by 3:30 in the afternoon had disarmed the nuclear device. On June 26, 1967 the device was again armed and personnel cleared of the area. The Midi Mist device was detonated at 9:00 in the morning on June 26 and was successfully contained (Horton et al. 1984:192, 195). The cavity resulting from the test did collapse and a rubble-filled chimney formed above it (Townsend et al. 2007). In addition, rockfall from the mesa escarpment along with subsidence of road fill made the section of the Rainier Mesa Road fronting the mesa unpassable after the test (Danilchik 1967).

Remote area monitoring system units began recording high levels of radiation within the tunnel immediately after detonation. Units outside the tunnel detected normal background radiation levels. The level for normal background was 0.05 milliroentgens per hour (mR/h). Initial reentry teams went to the portal and mesa areas at 10:00 in the morning and had completed their surveys by 10:15 (Eubank 1976:31; Horton et al. 1984:192). They found only normal background radiation levels. Recovery of data on the mesa and at the portal commenced at 10:45 with the safe removal of film and tapes (Horton et al. 1984:193). Around 2:00 in the afternoon, workers disconnected cables at the portal, at the three cable holes for the mesa trailer park, at the cable hole near surface ground zero for the LLNL reaction history side drift, and at the cable hole for the Cloud Chamber experiment.

Controlled ventilation began just after 1:00 in the afternoon on the same day as the detonation to release radioactive effluents from the tunnel (Horton et al. 1984:192). The release continued for

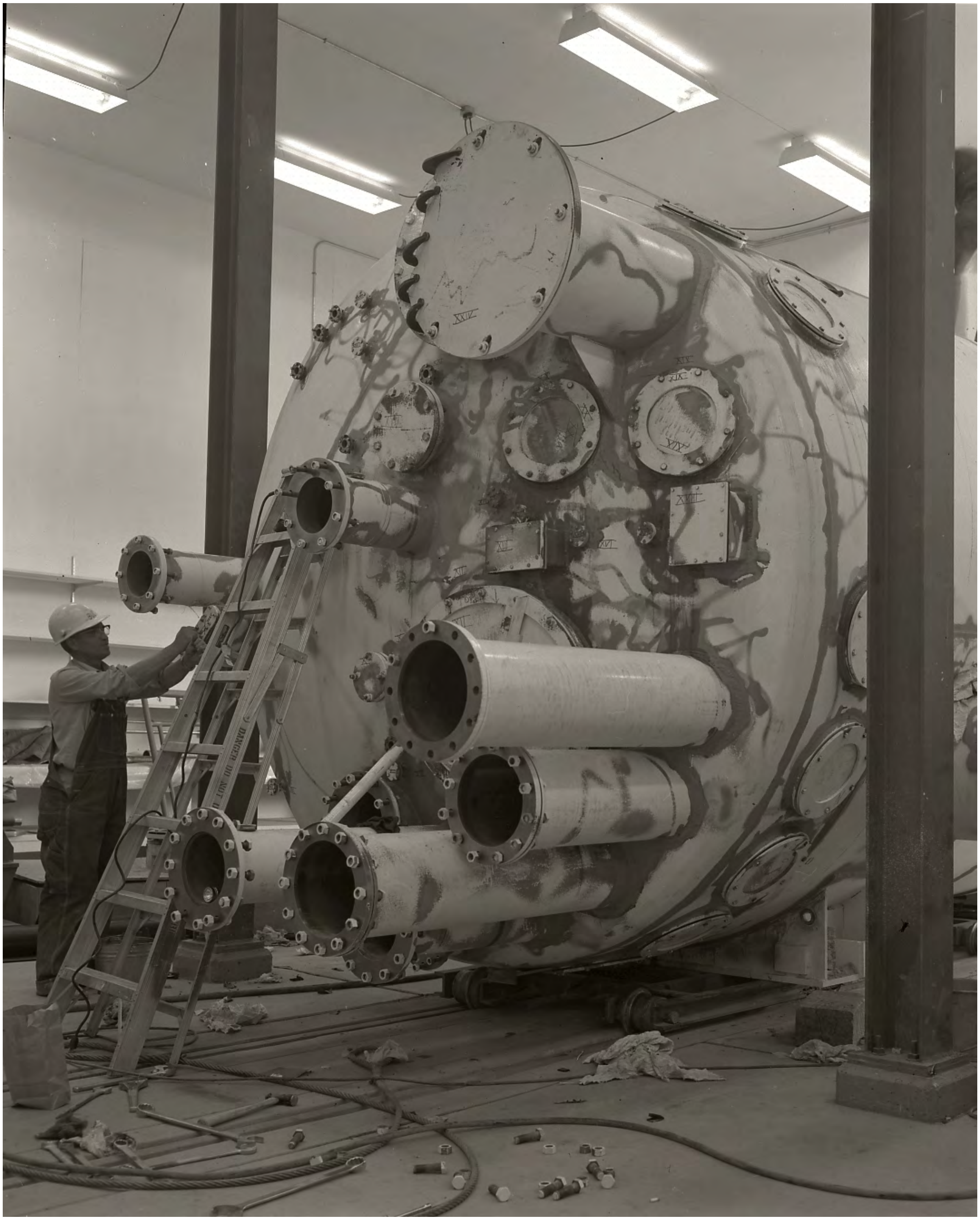


Figure 48. Test chamber for the Midi Mist test, 1967 (photograph N20830, on file at Archives and Records Center, Lawrence Livermore National Laboratory, California).

about 20 hours and into the next day, or D+1. The controlled ventilation ended at 9:00 in the morning on D+1 when readings taken at the vent lines indicated normal background radiation levels. Tunnel reentry began at 6:30 in the evening of June 27, or D+1, to the gas seal door (Horton et al. 1984:194). The door was opened and sand bags removed. Elevated radiation levels were detected at the door, but no explosive or toxic gases were present. Tunnel reentry continued the next day, or D+2, to inspect the tunnel and the U12n.02 drift and take readings and samples.

Post test reentry mining started on June 29, or D+3, to clear and repair the tunnel and the Midi Mist drift. When the repair work was finished, the recovery of experiments began. Experiment recovery was completed by July 14. Mining of a parallel reentry drift to investigate the stemming of the U12n.02 drift began in late July and continued until early December. The reentry drift was 1,055 ft (322 m) long, 10 ft (3 m) high and wide, and alongside the line-of-sight drift with about 50 ft (15 m) between the centerlines of the two drifts (Bennett 1991; Ege et al. 1980:1). The rock pillar between the drifts was 39 ft (12 m) wide. About 900 ft (274 m) of the line-of-sight pipe was removed during the reentry mining.

A post test drill hole (PS-1A) on the mesa was started July 16 and on July 20 reached the desired depth to take core samples (Horton et al. 1984:196). A sidetrack hole (PS-1AS) was started on July 20 from a beginning depth of 1,160 ft (354 m) below surface. Core samples were obtained the next day. All drilling operations were completed by July 22. From the first hole, 24 core samples were obtained; 21 core samples were obtained from the second hole.

U12n.03 Drift

Mining of the U12n.03 drift began in April 1966 and was completed in May 1967. It started 3,242 ft (988 m) from the portal and to the right off an extension of the main drift and was 2,166 ft (660 m) long (Ege et al. 1980:1). Although originally planned for the Dragon Mist test, the U12n.03 drift was not used because of its contact underground with the northeast-southwest oriented Aqueduct syncline that caused unstable geologic conditions and excessive water flow in the drift (Carroll and Kibler 1983:22; Ege et al. 1980:1; Ristvet 2009; Townsend et al. 2007). Later exploratory drill holes confirmed a general east to west orientation for excessive underground water flow in this part of Rainier Mesa and subsequent drifts skirted this area either to the north or south (Townsend 2009).

U12n.04 Drift - Hudson Seal

Hudson Seal was the second nuclear test in the U12n Tunnel and took place on September 24, 1968 in the U12n.04 drift. LLNL provided the nuclear device and emplaced it 4,650 ft (1,417 m) from the portal at a vertical depth of 1,130 ft (344 m) below the surface in zeolitic tuff (AEC/NV 1970a; Horton et al. 1985:145). Yield of the Hudson Seal test was less than 20 kilotons (DOE/NV 2000). The Hudson Seal test came about because of an NNSS delay in scheduling of the proposed Dragon Mist test in 1967 (Swift et al. 1969:10). The delay resulted in a reassessment of requirements and experiments, whereby the Dragon Mist test was combined with the Doe Foot test into a single test, Hudson Seal. As such, the Hudson Seal test met the objectives of both tests (DTRA 2002:381). Several drifts were investigated for the Hudson Seal test, including the U12e.10 and U12e.11 drifts in U12e Tunnel and the U12n.03 and U12n.04 drifts in U12n Tunnel (Swift et al. 1969:12). In fact, mining of the U12e.11 drift was started for the Hudson Seal test, but the U12n.04 drift was finally chosen, mostly due to the common facilities already in place at the U12n Tunnel.

Mining of the U12n.04 drift started July 17, 1967 and was completed on April 10, 1968 (AEC/NV 1970a; Bennett 1991). It consisted of a line-of-sight drift (Figures 49-50), beginning at the edge of the common cable alcove in the main drift, and extended west 1,360 ft (415 m) in length (AEC/NV 1970a). Only 1,160 ft (354m) of the U12n.04 drift required mining as the first 200 ft (61m) had been mined previously as an extension of the main drift in support of the Midi Mist event in the U12n.02 drift and for future activities planned for the U12n.03 drift. No bypass drift was constructed. The working point was 10.5 ft (3.2 m) from the end of the drift. The drift measured 16 ft (4.9 m) high and wide at the start to a distance of 750 ft (229 m) and then decreased incrementally to a final dimension of 10 ft (3 m) high and wide for a span of 180 ft (55 m) at the end before it connected to the zero room. The zero room measured 20 ft (6.1 m) long, 10.5 ft (3.2 m) to 12 ft (3.7 m) wide, and 10 ft high. At least 18 alcoves of various sizes and an assembly alcove for the first tunnel-and-pipe-seal closure were constructed. The assembly alcove angled northwesterly off the U12n.04 drift and was 194 ft (59 m) long and 18 ft (5.5 m) high and wide at the assembly area.

The Hudson Seal line-of-sight pipe was 1,100 ft (335 m) long (Swift et al. 1969:14). It contained two 10 ft (3 m) diameter test chambers and two tunnel-and-pipe-seals. The line-of-sight pipe and subsystems were installed by the mid summer of 1968 and the experiments were installed during late summer (Swift et al. 1969:19). Pre-stemming of the line-of-sight drift began following a successful pump down and leak check of the completed line-of-sight pipe system. During pre-stemming, a walkway was formed between the right side of the line-of-sight pipe and the right rib or side of the line-of-sight drift to facilitate delivery of the nuclear device to the working point. Water seeping into the drift became a concern during preparation of the test (Swift et al. 1969:40-41). The flow rate of the water into the zero room was two to three gallons per minute. A water control system to remove the water had to be installed and consisted of two submersible pumps in a sump pit in the zero room and two more pumps in sump pits near each of the tunnel-and-pipe-seals. The pumps were shut down and containment valves, remotely controlled from the control point, closed the drain line just before detonation. Data recording for the test included 28 instrumentation trailers at the mesa trailer park, 5 instrumentation trailers at the portal, and General Electric integrated recording packages (tape recorders) in the U12n.01 drift (Swift et al. 1969:16).

The first mandatory full participation dry run was conducted on August 21, 1968 and the second one on August 28 after installation of the high explosive experiments (Swift et al. 1969:42, 44). The nuclear device was inserted on September 3 and a successful hot dry run was conducted on September 6, with final button-up stemming operations commencing immediately afterward. The final vacuum system pump down on the line-of-sight pipe was started on September 11, but was interrupted because of an experiment malfunction. It continued again on September 18 when the problem was fixed. The Hudson Seal nuclear device was scheduled for detonation at 8:30 in the morning on September 24, 1968, but a number of technical problems delayed it until 10:05 (Horton et al. 1985:151).

Radiation readings in the remote area monitoring system monitor room at control point began immediately after detonation and ended on September 27, or D+3. All but three remote area monitoring system units registered normal background radiation levels. These three were in the

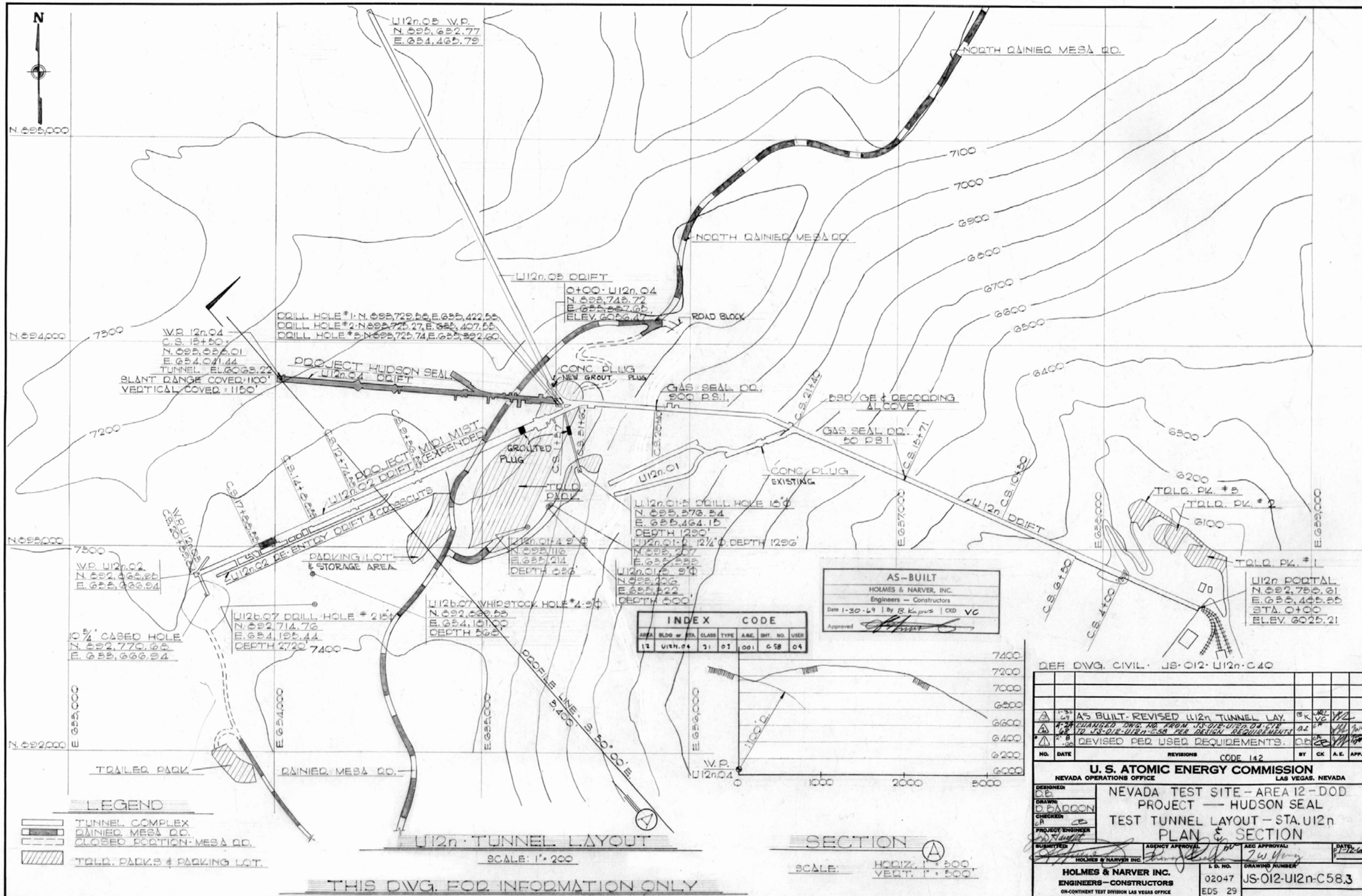


Figure 49. Area plan of the U12n.04 drift for the Hudson Seal test, 1968 (drawing JS-012-U12n-C58.3, on file at Archives and Records Center, Mercury, Nevada).

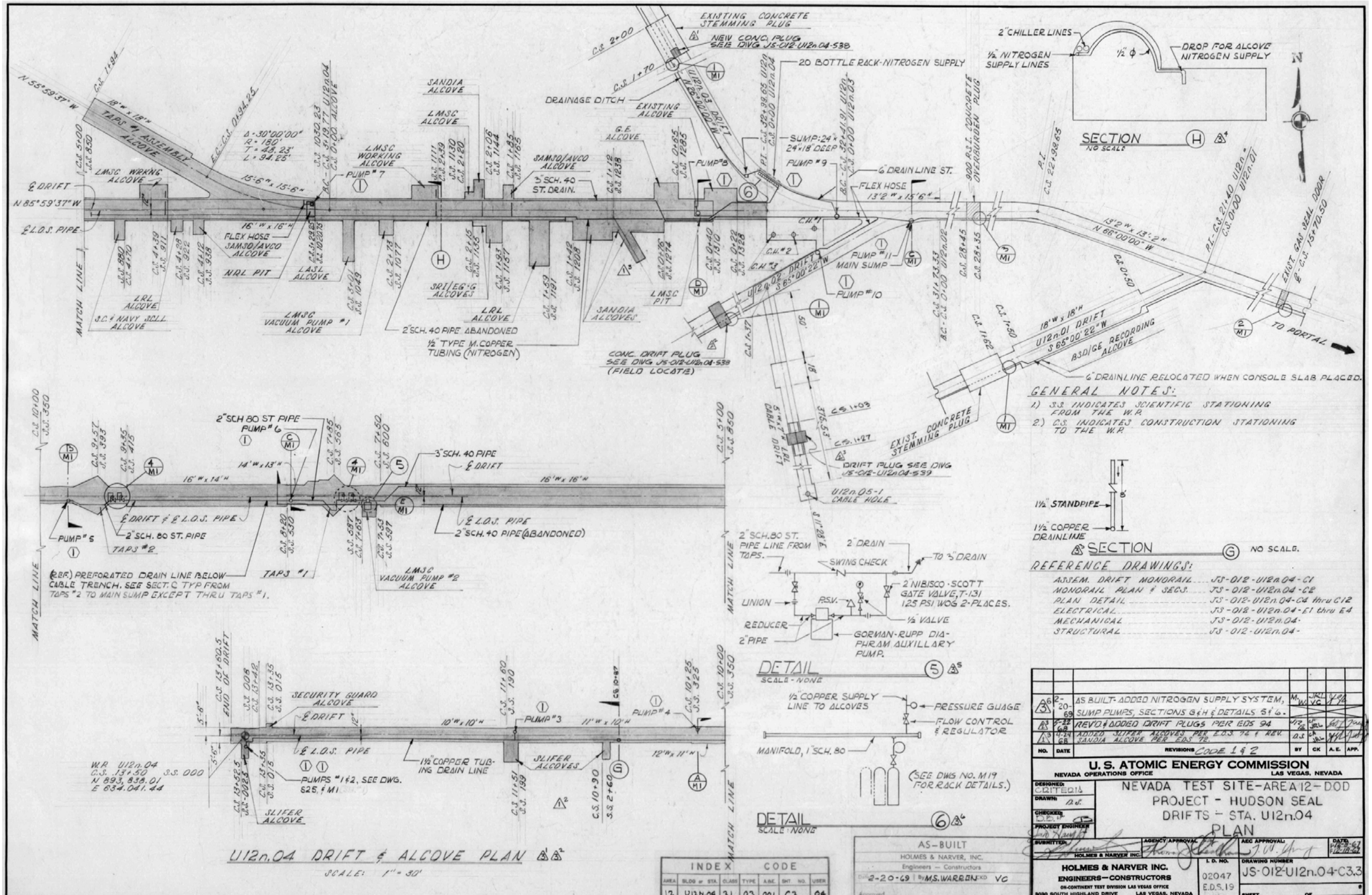


Figure 50. Construction plan of the U12n.04 drift for the Hudson Seal test, 1967 (drawing JS-012-U12n.04-C3.3, on file at Archives and Records Center, Mercury, Nevada).

tunnel and closest to the working point: one in the U12n.04 drift and two in the main drift. All three were on the working point side of the overburden plug located in the main drift at 2,835 (864 m) from the portal. The two units in the main drift began reading normal levels by midnight on September 24. The third unit in the U12n.04 drift had an initial reading of 800 roentgens per hour (R/h) one minute after detonation. It steadily decreased over time and read 17 R/h when all the units were secured on September 27, or D+3 (Horton et al. 1985:152). High readings like this were expected in the line-of-sight drift just after detonation.

All electric power to the tunnel, portal, and mesa trailer park was disconnected remotely from the DTRA monitor room at the control point within 10 minutes after detonation as planned (Swift et al. 1969:45). This safety procedure was implemented by DTRA to reduce the chances of electricity igniting explosive gases that were often present in the tunnel immediately following a test. The first reentry teams were dispatched to the mesa about 1.5 hours after detonation to conduct radiation surveys and damage assessment (Horton et al. 1985:152). They completed their work in about one hour and did not detect any radiation above normal background. The collapse of the cavity occurred approximately 2 hours and 46 minutes after detonation. About three hours after detonation, a reentry team was dispatched to survey the portal area. They completed their work in about an hour and did not find any radiation above normal background. Experimenters were then released to recover film and magnetic tape from instrumentation trailers on the mesa and at the portal. All initial recovery efforts were completed by early afternoon (Horton et al. 1985:153).

Reentry support personnel arrived at the U12n Tunnel portal in the early morning of September 25, or D+1. The DTRA reentry chief obtained the latest remote area monitoring system readings from the monitor room at control point, the weather forecast, and permission from the DOE test controller that was required to proceed with tunnel reentry operations. The reentry teams donned their personal protective equipment that included anti-contamination clothing and self-contained breathing apparatus. Radiation-safety and industrial hygiene personnel prepared monitoring equipment for the reentry teams. Each reentry team was given a detailed health and safety briefing prior to going underground. The first reentry team proceeded to the portal side of the gas seal door, located in the main drift 1,740 ft (530 m) from the portal, where they measured air quality conditions on the working point side of the gas seal door through a sample port. They reported the results to the reentry controller at the portal who granted permission for the team to continue. They opened the 30-inch containment valve on the vent line at the gas seal door to establish tunnel ventilation up to the portal side of the overburden plug in the main drift at 2,835 ft (864 m) from the portal. The team then opened the small personnel access door and inspected the working point side of the gas seal door for damage or water that may have accumulated. The team then proceeded to the main drift overburden plug where they repeated air quality measurements on the working point side of the overburden plug through a sample port and reported the results to the reentry controller. With the reentry controller's permission, the team opened the overburden plug tube turn containment doors on the portal and working point ends of the 36-inch crawl tube and the 30-inch vent tube, reestablished ventilation to the working point side of the plug, and removed the sandbags and vermiculite placed in the tubes during tunnel button-up. The reentry team then returned to the portal. A second reentry team was dispatched to the gas seal door to open the large trainway door and reestablish the rail lines through the doorway to facilitate train traffic in and out of the tunnel. A third reentry team proceeded to the overburden plug. They crawled through the 36-inch crawl tube in the plug and proceeded to the U12n.04 Hudson Seal drift complex. On the way, they checked tunnel conditions in the U12n.02 and

U12n.03 drifts, as well as the U12n.04 drift. Minor damage was observed in all three drifts, but no toxic or explosive gases were detected and radiation levels were less than 1 mR/h. With permission, they proceeded along the exterior of the Hudson Seal line-of-sight pipe in the U12n.04 drift to conduct an assessment of both the pipe and the drift for any signs of damage that could impact the impending recovery of experiments from the test chambers. At the same time, the team monitored air quality conditions in the line-of-sight drift. After completing the damage assessment, the team returned to the portal to end operations for the day. The next day, on D+2, a reentry team proceeded to the Hudson Seal test chamber and opened its access doors. Recovery of experiments began on September 26, or D+2, and continued until October 15, 1968. No reentry mining or drilling occurred and all observations on the conditions of the line-of-sight drift and pipe were made from the unstemmed portions of the drift (Townsend et al. 2007).

U12n.05 Drift - Misty North

Misty North was the fourth nuclear test in the U12n Tunnel. It was conducted on May 2, 1972 in the U12n.05 drift at a vertical depth of 1,234 ft (376 m) below the surface and 5,610 ft (1,710 m) from the portal (Horton et al. 1987:195). LANL provided the nuclear device and it had a yield of less than 20 kilotons (DOE/NV 2000).

Preparation for the test began at the tunnel on December 1, 1970. Shortly thereafter, on December 18, radioactive material vented to the atmosphere from the Baneberry nuclear test in northern Yucca Flat (Horton et al. 1987:197). As a consequence, additional safety procedures were enacted that affected work progress at all the tunnel sites. One safety measure required all personnel entering Area 12 to be dressed in full radex gear until radiation levels had decayed to normal background. A second safety measure required all non-essential personnel be removed from the forward areas during the execution of nuclear tests. Prior to the Baneberry event, workers could travel along the west side of Yucca Flat during a test. They could also continue to work in the forward areas, including the tunnels.

Mining of the U12n.05 drift was completed in November 1971. The U12n.05 drift branched to the right and northwest off the main drift. It consisted of a line-of-sight drift, a parallel bypass drift, and five crosscuts between them for access and delivery of key components and experiments to the line-of-sight pipe (Figures 51-52). The line-of-sight drift was 2,600 ft (793 m) long and 16 ft (4.9 m) wide and high for 710 ft (216 m) where it changed to 18 ft (3.5 m) wide by 16 ft (4.9 m) high. After another 350 ft (107 m) it changed to 16 ft (4.9 m) wide and high, and then slowly decreased in size over much of its length to a final dimension of 4 ft (1.2 m) wide and 8 ft (2.4 m) high for a short distance at the working point end. The line-of-sight pipe was 1,540 ft (469 m) long, ending at crosscut number one. It had four experiment stations (test chambers), a Sandia auxiliary closure, and a tunnel-and-pipe-seal. The Sandia auxiliary closure and tunnel-and-pipe-sea were for experiment protection. The bypass drift was about 2,696 ft (822 m) long including the curve to the working point. It measured 13 ft (4 m) wide and 11 ft (3.4 m) high at the beginning, decreased to 11 ft wide and high for approximately the last 500 ft (152 m) before the curve, and then increased to 13 ft wide and high for the curve. Common features in the tunnel reused for this test included the gas seal door, ventilation system, cable alcove, and downhole cable runs from the mesa trailer park. A new overburden plug had to be constructed and cable gas blocks were employed for the first time in the overburden plug (Horton et al. 1987:197).

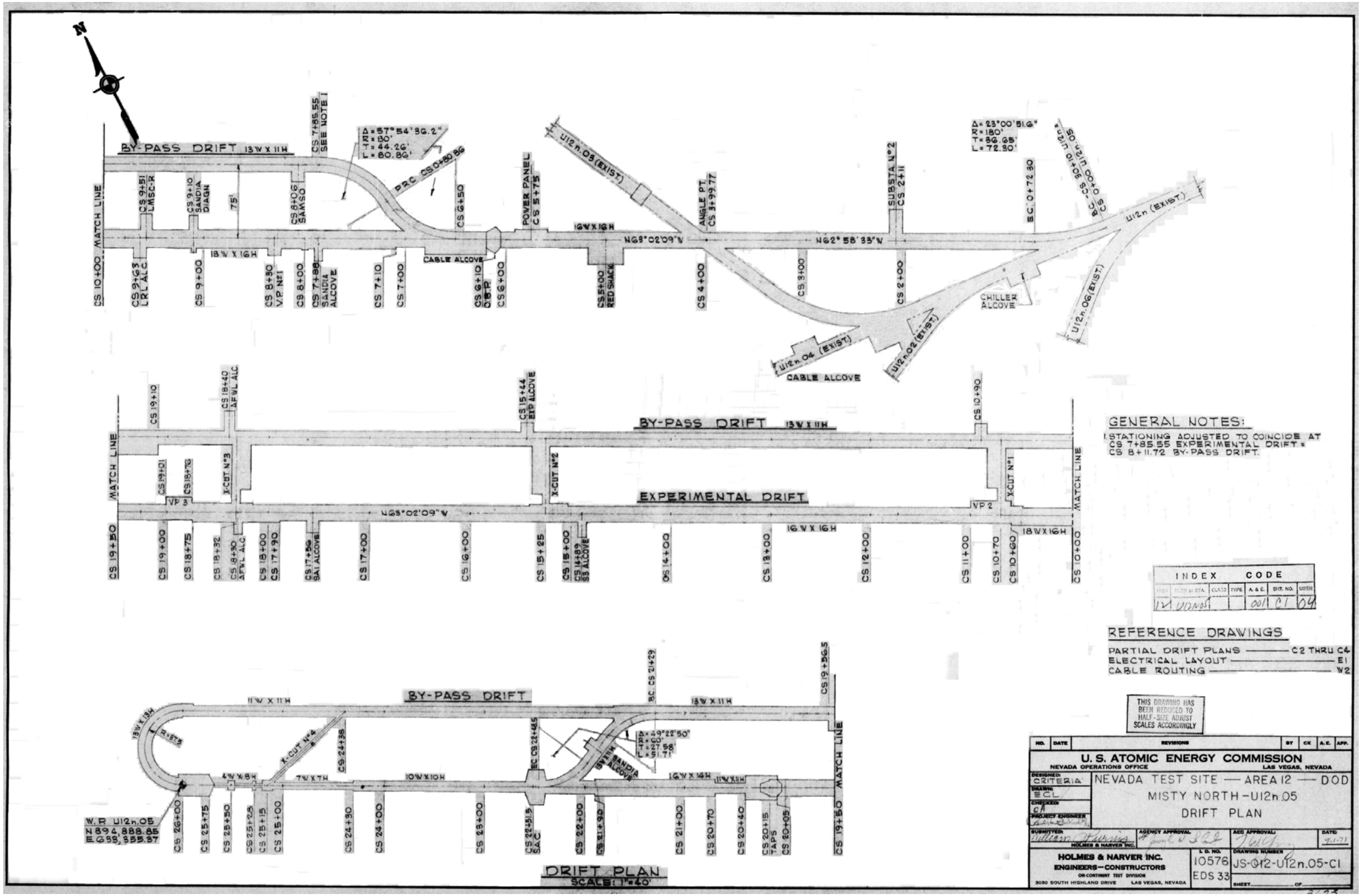


Figure 51. Construction plan of the U12n.05 drift for the Misty North test, 1971 (drawing JS-012-U12n.05-C1, on file at Archives and Records Center, Mercury, Nevada).

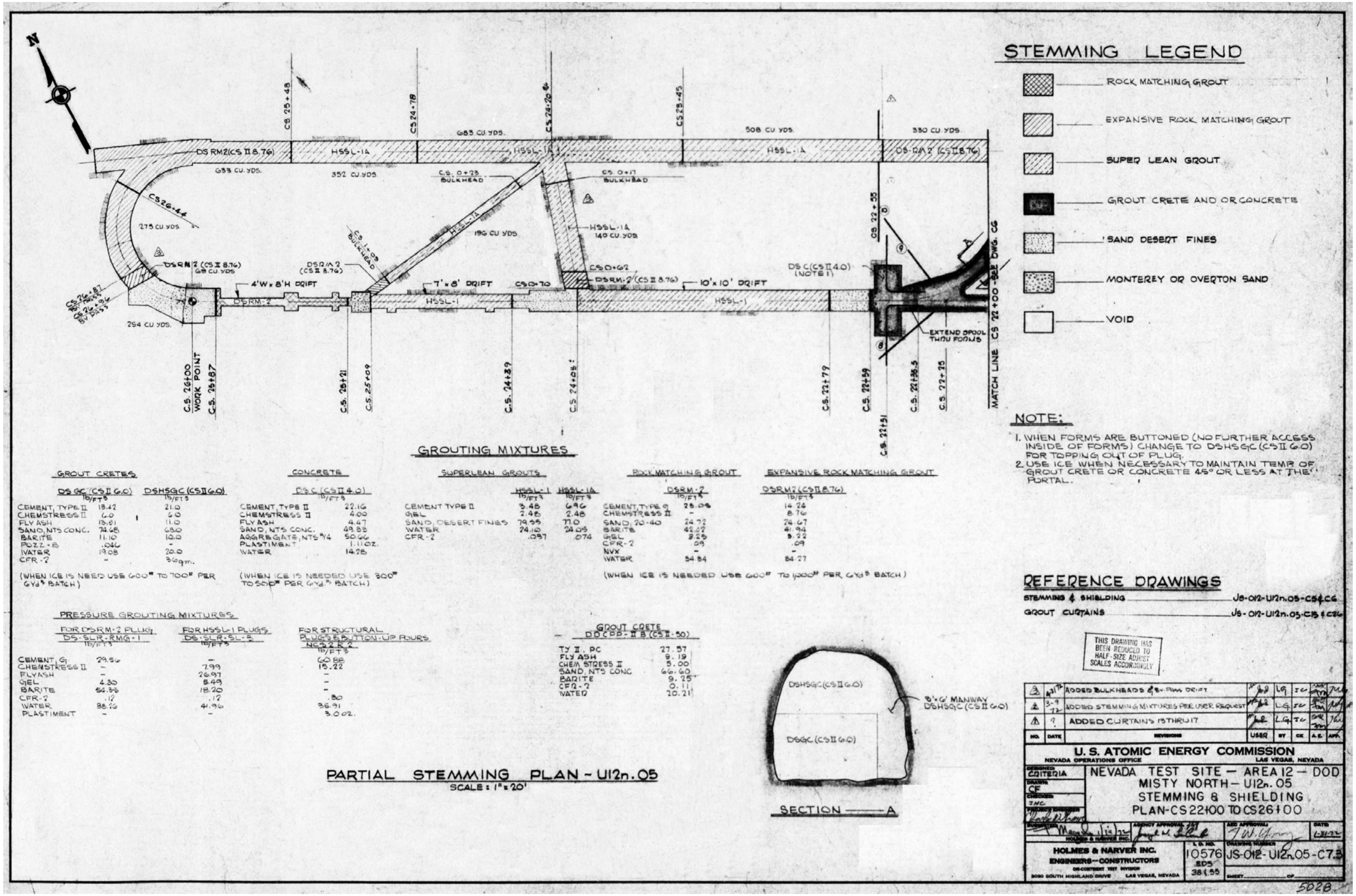


Figure 52. Stemming plan of the U12n.05 drift for the Misty North test, 1972 (drawing JS-012-U12n.05-C7.3, on file at Archives and Records Center, Mercury, Nevada).

While performing pressurized leak checks of the tunnel prior to button-up, minor leaks were detected around the gas seal door. These leaks were of such a nature that repair was uncertain; therefore, a 300 psi grout containment plug was quickly constructed on the working point side of the gas seal door in the main drift between 1,930 ft and 1,951 ft from the portal as an additional precautionary measure. The new plug, termed hasty plug for the Misty North and several following tests, was eventually redesigned as a reusable 500 psi gas seal plug.

Installation of all experiments was completed by March 2, 1972 (Horton et al. 1987:199). A successful signal dry run was conducted on the same day. On April 6, a successful mandatory full participation dry run was conducted and the nuclear device was installed on April 10. Due to the problems associated with pressure checking the gas seal door and building a new plug, unplanned security delays, and longer than anticipated time for placement of the stemming materials, the readiness date was postponed until May 2, 1972. The final dry run was conducted on May 1. Detonation of the Misty North device was set for 10:00 on the morning of May 2, 1972, but two delays due to technical problems postponed it until 12:15 in the afternoon (Horton et al. 1987:206). The cavity created by the explosion collapsed 11 hours and 11 minutes after detonation (Townsend et al. 2007).

After detonation, all but one of the remote area monitoring system units worked properly, with the highest radiation reading coming from a unit in the line-of-sight drift. Reentry teams dispatched to the portal and mesa areas two hours after detonation, completed the initial surveys of the two areas soon afterward. They detected only background levels of radiation. Data recovery was then conducted at the mesa trailer park. At the portal, workers turned on the ventilation system to ventilate the tunnel on the portal side of the gas seal door prior to work being terminated for the day.

Reentry support personnel arrived at the portal early the next day, May 3 or D+1. At control point, the DTRA reentry control chief obtained the latest remote area monitoring system readings from the monitor room, the weather forecast, and permission from the DOE test controller that was required for tunnel reentry operations. Gas sampling from within the tunnel found no toxic or explosive gasses present on the working point side of the containment plugs or in the line-of-sight and bypass drifts. The reentry teams donned personal protective equipment, including anti-contamination clothing and self-contained breathing apparatus. The radiation-safety and industrial hygiene technicians prepared monitoring equipment and helped ensure each reentry team member was properly dressed. Each reentry team was given a detailed health and safety briefing prior to proceeding underground. The first reentry team entered the tunnel and proceeded to the portal side of the gas seal door located in the main drift where they measured radiation, oxygen, and toxic and explosive gas (air quality) conditions on the working point side of the door through a sample port. They reported results to the reentry controller at the portal who then granted permission for the team to continue. They opened a 30-inch containment valve on the vent line to reestablish tunnel ventilation from the portal to the hasty plug. The reentry team then opened the small personnel access door and inspected the working point side of the gas seal door for any obvious signs of damage or water that may have accumulated. There were none. Utility air and water were also reestablished to the hasty plug by opening containment valves at the gas seal door. The team then slowly proceeded to the hasty plug where they measured air quality conditions on the working point side of the plug through a sample port and reported the results to the reentry controller. While the first team was at the hasty plug, a second reentry team was sent to the gas seal door to unbolt and open the large door and reinstall the rail line through the doorway. At the hasty plug, the first team, with the reentry controller's permission, opened the tube turn containment doors on the portal ends of the 36-inch crawl tube and the 30-inch vent tube that penetrated the plug, and removed sandbags and vermiculite placed in the tubes during tunnel button-up. The team reestablished ventilation through the hasty plug by sliding a ventilation line slip joint into the 30-inch vent tube. After completing their tasks, the two reentry teams returned to the portal, ending the activities for D+1, and the tunnel was left to ventilate up to the overburden plug. No reentry activities were scheduled for the next day, or D+2.

On May 5, or D+3, all reentry support personnel arrived at the portal and completed their normal preparations for reentry. With rail reestablished through the gas seal door, the first reentry team was able to ride a man train to the hasty plug. With permission, they crawled through the hasty plug and proceeded to the U12n.05 drift overburden plug. On the way to the overburden plug, they inspected portions of the U12n.01, U12n.06, U12n.04, U12n.02, and U12n.03 drifts that were used to support the Misty North test. The team returned to the portal and activities scheduled for D+3 were complete.

On May 6, or D+4, all portal preparations were again repeated prior to dispatching a reentry team underground to the portal side of the U12n.05 overburden plug. After arriving, they checked the air quality conditions on the working point side of the plug and reported the results to the reentry controller. With permission, they then opened the portal tube turn doors on the 30-inch vent tube and 36-inch crawl tube and removed the sand bags. They then opened the tube turn doors on the working point end of the tubes, connected a slip joint to the 30-inch vent tube, which established ventilation to the Misty North drifts. The team then proceeded through the overburden plug crawl tube and conducted an inspection of the Misty North line-of-sight and bypass drifts including the experiment stations 1 and 2 areas. The line-of-sight drift working point side of experiment station 2 was found to be in poor condition and the team did not proceed any further. Air quality measurements were collected both inside and outside the line-of-sight pipe and found to be at background levels. On May 8, or D+6, a scientific assessment team went into experiment stations 1 and 2 to inspect the condition of the experiments.

Mining through the hasty plug and overburden plug was started and completed on May 10, D+8, and the tunnel was made ready for experiment recovery on May 11, or D+9 (Horton et al. 1987:210). Experiments from stations 1 and 2 and from the auxiliary stations were all recovered by May 12, D+10. Miners started mining a reentry drift on May 15, D+13, to recover experiments from stations 3 and 4 located forward of crosscut 2, but were halted after 114 feet (35 m) because of unstable rock. The U12n.05 bypass drift was then rehabilitated to use as a reentry path to the forward experiment stations. The rehabilitation was completed by June 1 and all experiments were recovered from experiment stations 3 and 4 by June 6, or D+25. Reentry mining began the next day, June 7, to reach the Sandia auxiliary closure for evaluation and was successfully completed by August 1, 1972. Two probe holes were drilled into the collapsed chimney, but no core samples were obtained (Townsend et al. 2007). Elevated levels of toxic and explosive gases in the drill holes, which could not be vented, caused an early termination to the post test drilling.

U12n.06 Drift - Diana Mist

Diana Mist was the third nuclear test in the U12n Tunnel. It was successfully executed on February 11, 1970 in the U12n.06 drift at a vertical depth of 1,319 (402 m) below the surface (Horton et al. 1987:107). LANL supplied the nuclear device and it had a yield of less than 20 kilotons (DOE/NV 2000).

Mining of the U12n.06 drift began on February 11, 1969 and ended on October 17, 1969 (Bennett 1991; Horton et al. 1987:109). The U12n.06 drift reached 1,810 ft (552 m) in length (AEC/NV 1970b; Figures 53-54). No bypass drift was mined. A total of 17 alcoves and a large assembly drift were constructed. The assembly drift, beginning 610 ft (186 m) from the start of the drift and mined to the left, measured 220 ft (68 m) in length and 18 ft (5.5 m) in height and width. The assembly drift would later become the beginning of the U12n.07 line-of-sight drift mined for the Husky Ace test. Installation of the 1,110 ft (338m) long Diana Mist line-of-site pipe and the vacuum system began on September 5. Experimenter agencies installed their experiments in the test chamber between December 10, 1969 and February 4, 1970. Pre-stemming of the line-of-site pipe drift from the working point out to the end of stemming started as soon as a successful vacuum pump down and leak check were completed. During pre-stemming, a walkway was formed between the right side of the line-of-site pipe and the right rib of the line-of-site drift to facilitate delivery of the nuclear device to the working point. Grouting was completed early to allow the grout to cure, lowering the temperature enough to prevent any distortion during the critical X-ray alignment of experiments in the test chambers. Once the X-ray alignment was determined acceptable, final experiment components were installed, a successful final dry run was conducted, and the device was installed. Final stemming of the walkway and plugs was completed February 8, 1970. The total stemming volumes were as follows: 1,177 cubic yards (900 cubic meters) of concrete, 767 cubic yards (586 cubic meters) of sand, and 1,559 cubic yards (1,192 cubic meters) of grout (Flangas 2009). The sand was obtained from the shaker plant in Area 1 of the NNSS.

Arming the nuclear device and tunnel button-up were completed by the early morning of February 11, 1970 (Horton et al. 1987:115). After fixing several technical problems, the Diana Mist device was detonated at 11:15 in the morning. Radiation monitors in the remote area monitoring system monitor room at control point soon started showing movement. The highest radiation levels observed after detonation occurred in the line-of-sight drift as expected. One of the surface remote area monitoring system units on the mesa exhibited an unusually high reading, while all the other units on the mesa read normal background levels. It was later discovered during the initial reentry survey starting about an hour after detonation that a cable to the one unit with high readings had been crushed by a fallen rock. Hand held radiation reading surveys taken around this unit were at normal levels.

The morning of February 12, or D+1, reentry support personnel arrived at the portal early to begin preparations for reentry. The DTRA reentry chief obtained the latest remote area monitoring system readings from the monitor room at control point, the weather forecast, and permission that was required from the DOE test controller to proceed with tunnel reentry operations. Gas sampling from within the tunnel found no toxic and explosive gasses present on the working point side of the containment plugs and at the end of stemming in the line-of-sight or bypass drifts. The reentry teams donned their personal protective equipment that included anti-contamination clothing and

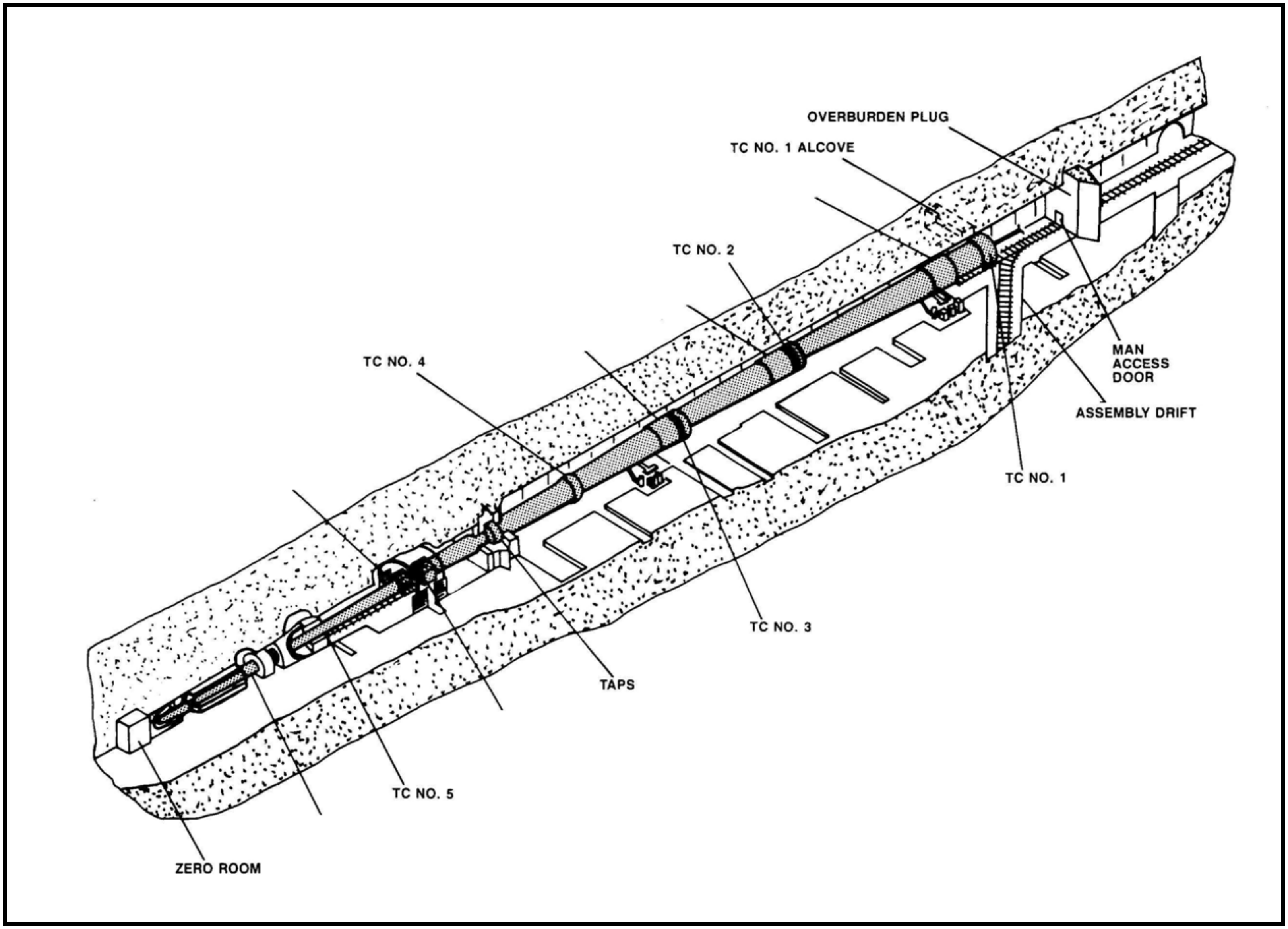


Figure 53. Sketch of the Diana Mist line-of-sight pipe in the U12n.06 drift (Horton 1987:119).

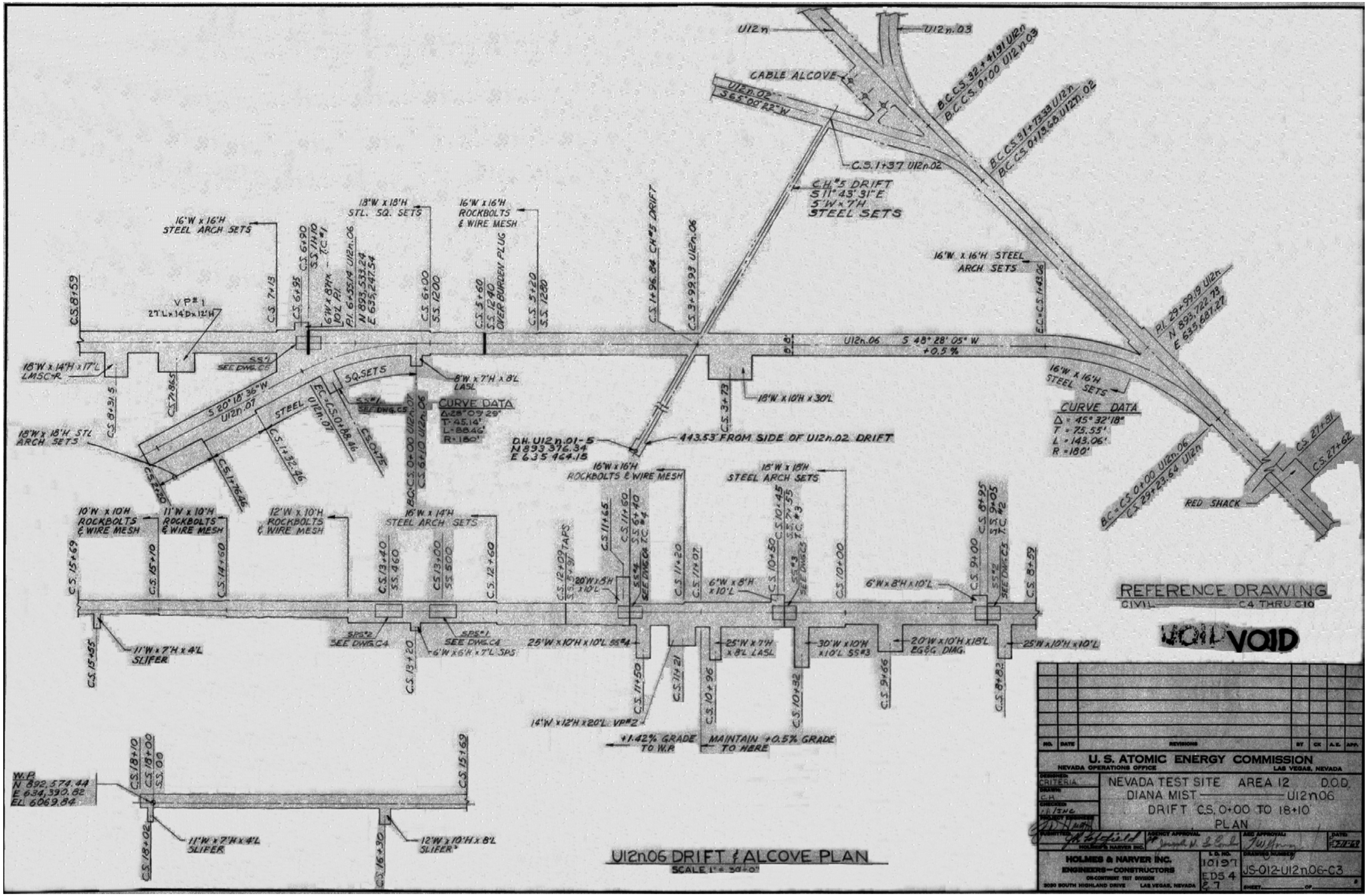


Figure 54. Construction plan of the U12n.06 drift for the Diana Mist test, 1969 (drawing JS-012-U12n.06-C3, on file at Archives and Records Center, Mercury, Nevada).

self-contained breathing apparatus. Radiation-safety and industrial hygiene technicians prepared the monitoring equipment for the reentry teams. Each reentry team was given a detailed health and safety briefing prior to proceeding underground. The first reentry team proceeded to the portal side of the gas seal door located in the main drift at 1,740 ft (530 m) from the portal where they collected air quality measurements on the working point side of the door through a sample port. They reported the results to the reentry controller at the portal who granted permission for the team to continue. They opened the 30-inch containment valve on the vent line at the gas seal door to establish tunnel ventilation up to the portal side of the overburden plug located at 560 ft (171 m) into the U12n.06 drift. The reentry team then opened the small personnel access door and inspected the working point side of the gas seal door for any water that may have accumulated. The team then proceeded to the overburden plug where again they took air quality measurements on the working point side of the plug through a sample port and reported the results to the reentry controller. With the reentry controller's permission, the team opened the U12n.06 overburden plug tube turn containment doors on the portal and working point ends of the 36-inch crawl tube and the 30-inch vent tube, reestablished ventilation to the working point side, and removed the sandbags and vermiculite placed in the tubes during tunnel button-up. The reentry team then returned to the portal. A second reentry team was dispatched to the gas seal door to open the large trainway door and reestablish the rail lines through the doorway to facilitate train traffic in and out of the tunnel. A third reentry team proceeded to the U12n.06 drift overburden plug. They crawled through the 36-inch crawl tube and proceeded to the U12n.06, Diana Mist test complex. On the way, they checked tunnel conditions in the U12n.02, U12n.03, and U12n.04 drifts and found them in good condition (Horton et al. 1987:118). With permission, they proceeded along the exterior of the Diana Mist line-of-sight pipe in the U12n.06 drift to conduct an assessment of the pipe, the test chambers, and the drift for any signs of damage that could impact the impending recovery of experiments from the test chambers. At the same time, the team monitored air quality conditions in the line-of-sight drift. The team returned to the portal after completing the damage assessment and operations for D+1 were terminated.

The next day, or D+2, the reentry team proceeded to the test chambers again and prepared them for recovery of experiments by opening the doors and establishing ventilation inside the line-of-sight pipe. High levels of toxic or explosive gases were detected inside all the test chambers; elevated levels of radiation were found at test chamber 4. Some experiment recovery was conducted in test chamber 3. No further reentry or recovery efforts were attempted for the next three days to allow the line-of-sight pipe to ventilate (Horton et al. 1987:121). By February 16, or D+5, air quality in the test chambers had improved. Full experiment recovery began the next day on February 17, or D+6, and the majority of the experiments were removed by February 20, or D+9. Additional experiment recovery efforts were conducted as appropriate until March 2 and other types of entries were made until March 18, 1970.

No post test reentry mining was conducted for the Diana Mist test. Post test drilling and core sampling into the collapsed Diana Mist chimney and cavity began in mid-November 1973, about three and a half years after the test (Horton et al. 1987:122; Townsend et al. 2007). One hole was drilled from the surface and two were drilled from the U12n.07 drift. The work was completed on December 7, 1973. A total of 51 core samples were obtained. In 1986, another hole was drilled from the U12n.17 drift. The purpose of the drill holes was to characterize the chimney and cavity, including size and composition.

U12n.07 Drift - Husky Ace

Husky Ace, the fifth nuclear test in the U12n Tunnel, was executed on October 12, 1973. LANL provided the nuclear device and placed it in the U12n.07 drift at a distance of 4,694 ft (1,431 m) from the portal. Yield of the explosion was less than 20 kilotons (DOE/NV 2000). Vertical depth of the test was 1,356 ft (413 m) below the surface (McDowell et al. 1987:147).

The U12n.07 drift complex was mined to the left and southward off the U12n.06 drift and consisted of a line-of-sight drift, a bypass drift, two crosscuts, an access drift, and a zero room (Figures 55-57). The line-of-sight drift was 1,180 ft (360 m) long, 18 ft (5.5 m) wide and high for the first 200 ft (61 m), and became incrementally smaller to a final width of 9 ft (2.7 m) and a height of 10 ft (3 m) at the zero room. The bypass drift, shorter than the line-of-sight drift, started left off the U12n.06 drift and paralleled the line-of-sight drift until it turned left and joined the line-of-sight drift at 322 ft (98 m) from the working point. It did not intersect with the zero room as did some other tests in the tunnel. The bypass drift measured 12 ft (3.7 m) wide and 11 ft (3.4 m) high for the first 663 ft (202 m) and then 9 ft wide and 11 ft high for the remaining 37 ft (11 m). Two crosscuts connected the line-of-sight and bypass drifts together for access to test chambers 2 and 3, and were later used as experimenter alcoves. An access drift was mined between the line-of-sight and bypass drifts to facilitate installation of the first DNA auxiliary closure. The line-of-sight pipe system measured 966 ft (294 m) long and included two DNA auxiliary closures, a tunnel-and-pipe-seal, and three test chambers. Stemming extended out 600 ft (183 m) from the working point.

Common tunnel elements used for the test included equipment and structures at the portal, the main drift, tunnel ventilation and electrical power systems, the mesa trailer park, and the downhole cable system from the mesa trailer park to the cable alcove within the tunnel (McDowell et al. 1987:149). Workers constructed a new overburden plug and a hasty plug in the main drift. The vacuum pumps came from the previously executed Diamond Sculls test in the U12t Tunnel (McDowell et al. 1987:150). By early September 1973, the line-of-sight pipe, electrical equipment, experiment cables to the mesa, and stub pipes were installed. Installation of experiments was completed in early October.

The first underground test of the newly designed Recorder and Oscilloscope Sealed Environmental System (ROSES) was conducted during the Husky Ace test (Sites and Wetzel 1975). The test consisted of a single aluminum container, measuring 7 ft (2.1 m) wide, 7.5 ft (2.3 m) high, and 11.7 ft (3.6 m) long, with six removable instrumentation racks. It was located in the U12n.06 drift, 984 ft (300 m) from the working point and 180 ft from the intersection of the U12n.06 and U12n.07 drifts. The objectives of the test were to measure the effect of signal noise and variation on different types of cables and configurations attached to the ROSES unit; evaluate the shock mounting, air conditioning, and gas purging systems of the unit; and determine degrading of oscilloscope data due to delays in data recovery.

Test personnel successfully conducted a mandatory full participation dry run in late September. Soon after, the nuclear device was inserted and final button-up stemming operations began. The final dry run was on October 9 (McDowell et al. 1987:157). The arming party, button-up team, and security started the final tunnel button-up after experimenters completed work late that evening. The button-up teams worked all night and departed the portal the morning of October 10. Unfavorable wind

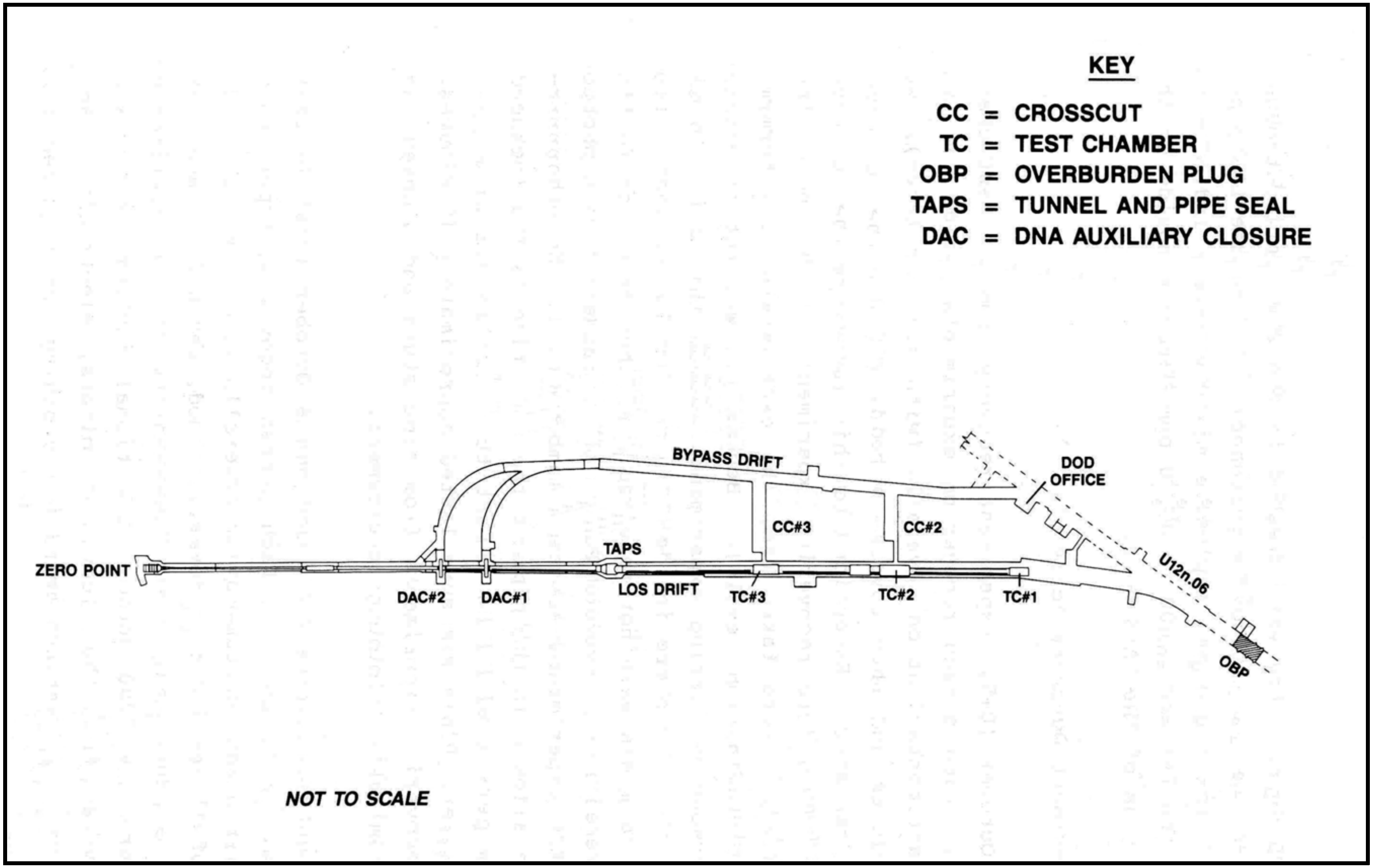


Figure 55. Plan of the U12n.07 drift for the Husky Ace test (McDowell et al. 1987:165).

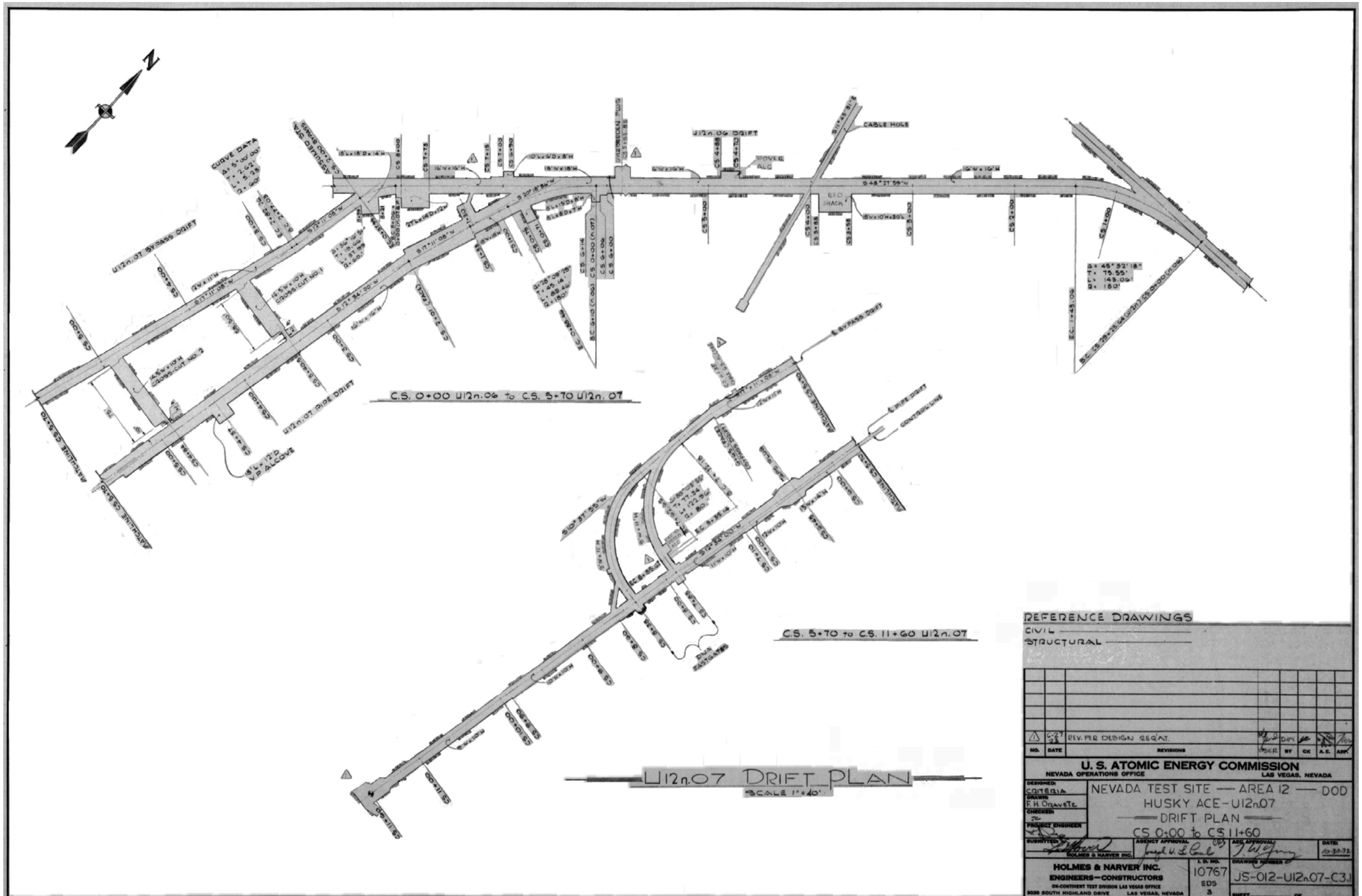


Figure 56. Construction plan of the U12n.07 drift for the Husky Ace test, 1972 (drawing JS-012-U12n.07-C3.1, on file at Archives and Records Center, Mercury, Nevada).

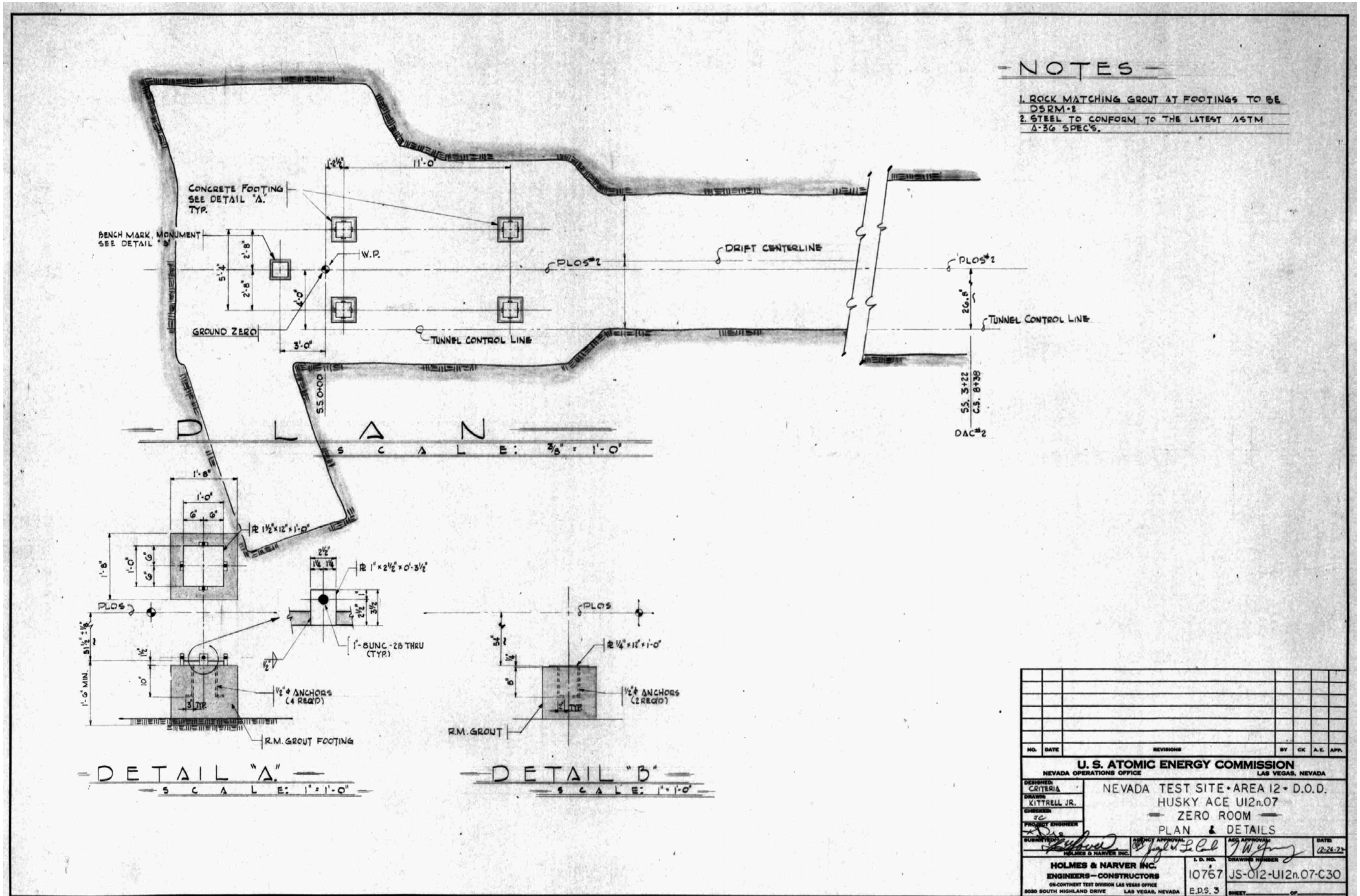


Figure 57. Construction plan of the zero room in the U12n.07 drift for the Husky Ace test, 1972 (drawing JS-012-U12n.07-C30, on file at Archives and Records Center, Mercury, Nevada).

conditions, however, delayed the test for two days. With the return of favorable weather conditions, the Husky Ace test was executed at 10:00 in the morning on October 12, 1973. The cavity collapsed 2 hours and 16 minutes after detonation (Townsend et al. 2007). Four remote area monitoring system units on the surface at the mesa trailer park and two units underground closest to the working point in the line-of-sight drift failed at detonation. The underground unit next in line and near test chamber 3 in the line-of-sight drift registered the highest level of radiation for the test: 650 R/h at two minutes after detonation. All the units except for the one with the highest reading were at normal background radiation levels within five hours after detonation.

Initial reentry was made to the mesa trailer park and portal about 1.5 hours after detonation (McDowell et al. 1987:158). The surveys for both areas were completed in approximately 30 minutes and no elevated radiation levels were detected. Data recovery at the mesa and portal began soon afterward. Tunnel reentry operations began early the next day, October 13 or D+1. The reentry control chief received current radiation readings from the remote area monitoring system monitor room at control point. He also received a weather briefing and approval from the DOE test controller to proceed with tunnel reentry. Reentry support personnel started preparations at the portal for tunnel reentry. After donning their equipment, the first team received a health and safety briefing prior to proceeding underground to the portal side of the gas seal door. There they measured air quality conditions on the working point side of the door through a sample port. They reported the results to the reentry controller at the portal who granted permission for the team to continue. The reentry team then opened the 30-inch vent line containment valve to establish ventilation to the portal side of the hasty plug. Next, they opened the small personnel door in the gas seal door to determine if any water had accumulated behind the plug. There was none. The team then crawled through the small door and proceeded to the portal side of the hasty plug. They checked air quality conditions on the working point side of the hasty plug and determined that nothing exceeded background levels. With the reentry controller's permission, the team opened the tube turn doors on the portal end of the 30-inch ventilation and 36-inch crawl tubes, removed sand bags from the tubes and reestablished ventilation forward to the overburden plug. The team then crawled through the hasty plug and proceeded to the overburden plug, checking all side drifts along the way. They established a fresh air station in the U12n.06 drift, which meant that tunnel ventilation was adequate and a self contained breathing apparatus was not required. After establishing the fresh air station the team returned to the portal and work for the day was done.

On October 14, D+2, the same preparations were repeated before dispatching the reentry team to the portal side of the overburden plug. After collecting air quality samples from the working point side, the team received permission to open the tube turn doors, remove the sand bags, and establish ventilation to the working point side of the plug. The team then crawled through the overburden plug. They walked down the Husky Ace line-of-sight drift, inspecting the condition of the tunnel and line-of-sight pipe and monitoring the air quality. The line-of-sight drift outside test chambers 1 and 2 had only background radiation readings. However, elevated radiation and levels of toxic and explosive gasses were present outside test chamber 3. Radiation readings inside test chamber 3 were 600 mR/h. The two crosscuts were inspected. The first one was in good condition, but the alcoves in the second crosscut had damage and the tunnel had partially collapsed (McDowell et al. 1987:163). The team returned to the portal and operations were terminated for the day.

On October 15, D+3, two tasks were undertaken. A work team opened the large door at the gas seal door and reestablished rail lines through the doorway. At the same time a reentry team returned to the Husky Ace drifts to complete the assessment in the remaining areas. Radiation readings in test chamber 3 were 90 mR/h and there were no toxic or explosive gasses present. The teams returned to the portal completing work for the day. On October 16, D+4, workers mined the concrete out of the hasty plug and the overburden plug and reestablished the rail line. The first recovery of experiments in test chambers 1 and 2 began late on D+4. The next day, on D+5, recovery took place in all three test chambers and a majority of the experiments were recovered within 48 hours (McDowell et al. 1987: 166).

Reentry mining consisted of mining a drift from the bypass drift to the line-of-sight drift, then parallel along the line-of-sight drift, with a crosscut to the first DNA auxiliary closure (Townsend et al. 2007). The objective of the post test mining was to evaluate the three closures, the stemming, and the performance of each during the test (McDowell et al. 1987:168). The mining began February 28, 1974 and finished April 7, 1975. The two DNA auxiliary closures, 394 ft (120 m) of line-of-sight pipe, and two test chambers were removed. The vacuum pumps were recovered for future use. No post test drilling was conducted.

U12n.08 Drift - Ming Blade

Ming Blade, conducted on June 19, 1974 in the U12n.08 drift, was the sixth nuclear test in the U12n Tunnel. LANL supplied the nuclear device and the yield was less than 20 kilotons (DOE/NV 2000). Vertical depth of the test was 1,276 ft (389 m) below the surface (McDowell et al. 1987:172).

Mining of the U12n.08 drift began on June 18, 1973 (McDowell et al. 1987:174). It started to the right off the U12n.05 drift in a northwesterly direction. The Ming Blade test complex included a line-of-sight drift, a bypass drift, seven crosscuts, and three short pipe drifts next to the working point (Figures 58-59). Also constructed were a new overburden plug, a new cable overburden plug, and a new hasty plug. Some of the existing facilities utilized included the mesa trailer park, the underground cable alcove, three vertical cable holes between the mesa trailer park and the underground cable alcove, and the support structures and equipment at the portal. Mining of the Ming Blade drift was interrupted for a couple of weeks in late September 1973 to provide support for final button-up of the Husky Ace test in the U12n.07 drift. The U12n.08 line-of-sight drift started 1,256 ft (383 m) into the U12n.05 main drift and crossed the U12n.05 bypass drift. It was 1,762 ft (537 m) long from the beginning to the working point and measured 14 ft (4.3 m) wide and 16 ft (4.9 m) high at the beginning and then decreased incrementally to a final dimension of 7 ft (2.1 m) wide and high at the end. The bypass drift turned off the line-of-sight drift at 650 ft (198 m) from the beginning. It started to the left in a reverse S curve and then paralleled the line-of-sight drift until the end where it extended further away from line-of-sight drift to form a half circle, which connected to the end of the line-of-sight drift and to the zero room. The bypass drift measured 13 ft (4 m) wide and high at the start, narrowed to 9 ft (2.7 m) wide and high in the middle, and increased to 10 ft (3 m) wide and high for the circle at the end. A cable drift, 5 ft (1.5 m) wide and 7 ft high, was mined between the bypass drift and the line-of-sight drift. The bypass drift and zero room were completed in late February.

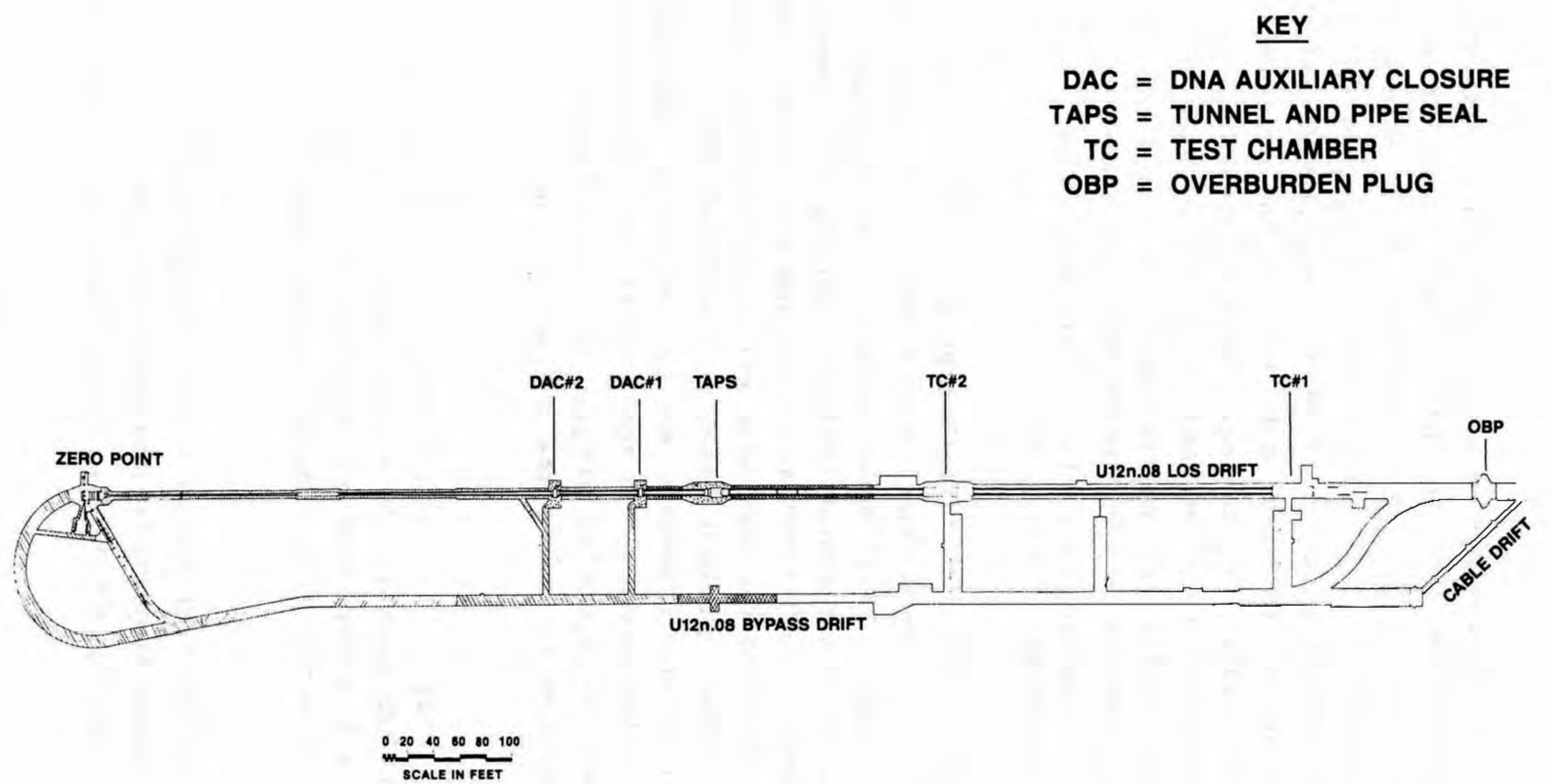


Figure 58. Plan of the U12n.08 drift for the Ming Blade test (McDowell et al. 1987:187).

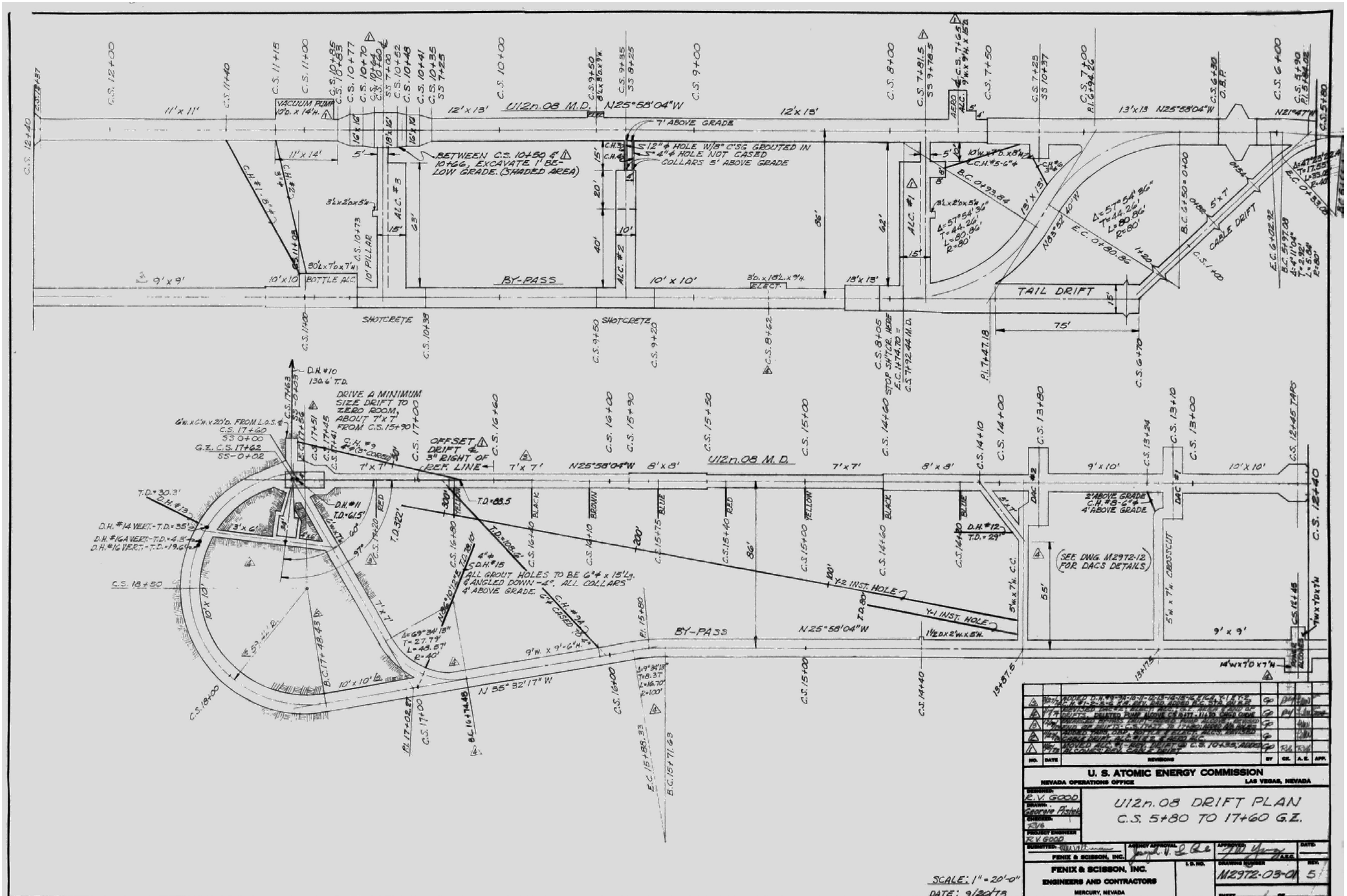


Figure 59. Construction plan of the U12n.08 drift for the Ming Blade test, 1973 (drawing M2972-03-01.5, on file at Archives and Records Center, Mercury, Nevada).

Installation of the line-of-sight pipe began in early February 1974 and included a muffler, two DNA auxiliary closures, a tunnel-and-pipe-seal, and two test chambers (McDowell et al. 1987:175). Installation of the pipe was completed in early April. A new overburden plug was constructed between 608 ft (185 m) and 639 ft (195 m) in the line-of-sight or main drift. A cable overburden plug, 90 ft (27 m) long, 7 ft (2.1 m) high, and 5 ft (1.5 m) wide, was constructed in a cable drift mined from the 584 ft (178 m) mark in the U12n.08 line-of-sight drift to the portal end of the U12n.08 tail drift. Approximately 550 gas blocked signal cables were routed through the cable overburden plug to the cable alcove in the U12n.04 drift to connect to existing cables in the alcove. From the cable alcove, most of the cables were routed up the three cable drill holes to the mesa trailer park. Based upon requirements, some cables could also be routed from the cable alcove to recording trailers at the portal. The U12n.08 overburden plug and cable overburden plug would later be used for nine additional tests. To record the Ming Blade test, ROSES units were placed underground and instrumentation trailers were placed at the mesa trailer park.

The experiments began to be moved into position in the drift in late April 1974 and were all installed and properly aligned by mid May. A mandatory full participation dry run was conducted on June 4, but was unsuccessful (McDowell et al. 1987:176). A successful mandatory full participation dry run was conducted the next day, with insertion of the nuclear device and button-up stemming operations started the following day. A labor dispute at the NNSS on June 6 interrupted and slowed the button-up stemming operations, which were ultimately carried out by supervisors and non-striking personnel. Final stemming of the drift complex was completed on June 12. A final dry run was conducted the morning of June 18. When the run was declared successful, the experimenters reconfigured their experiments from dry run mode to test ready mode. As they completed their work the alcoves were buttoned-up with the help of the button-up team. When all alcoves had been buttoned-up, the button-up team, accompanied by the device arming party and security personnel, began the final and critical electrical and mechanical systems button-up of the tunnel complex. They completed their tasks early in the morning of June 19.

On the morning of June 19, 1974, the Ming Blade nuclear test was executed (McDowell et al. 1987:182). The cavity collapsed 52 minutes after the detonation (Townsend et al. 2007). Radiation readings at the remote area monitoring system monitor room in the control point indicated movement just after detonation and the only readings above background were in the line-of-sight pipe and drift. All the units, however, except for the one on the mesa furthest away from the working point went off line at the time of detonation (McDowell et al. 1987:183). This may have been due to ground shock. Two units came back on line immediately, seven were back within a minute, and all but one of the remaining units were back on line within 20 minutes. The one unit that did not come back on line was damaged by tunnel collapse. The greatest radiation levels, as expected, came from the units in the line-of-sight drift nearest to the working point and at the end of stemming. The closest unit recorded the highest reading of 900 R/h one minute after detonation, but eventually decreased to 155 mR/h on June 20, or D+1, when the units were secured (McDowell et al. 1987:184).

The initial reentry surveys at the portal and mesa trailer park took place about one hour after detonation and were concluded within 20 minutes. No elevated radiation levels above background were detected. Shortly afterward, data recoveries were conducted at the portal and mesa and completed within three hours. Tunnel reentry began the next day on June 20, or D+1. Reentry personnel arrived at the portal and the reentry team began donning their anti-contamination suits for manned reentry. The radsafe and industrial hygiene technicians started setting up their equipment and the reentry control chief contacted the remote area monitoring system monitor room at control point for the latest readings. The only activity reported was a slightly elevated radiation reading inside the line-of-sight pipe. The weather forecast was good and the DOE test controller gave the required approval to start the manned tunnel reentry. Remote readings taken at the portal were from the working point sides of the gas seal door, hasty plug, and overburden plug, the end of stemming, and inside the line-of-sight pipe at the two test chambers. The reentry controller briefed the first reentry team on the current conditions in the tunnel. The team also received a health and safety briefing. They then entered the tunnel and proceeded to the portal side of the gas seal door. They sampled the air quality on the working point side of the door and reported it to the reentry controller at the portal. The team had observed water seeping from under the gas seal door when they arrived. A pre-staged pump was used to pump the water to the retention ponds at the portal. The team then opened the small personnel door and installed another pump on the working point side. They then opened the containment valve in the 30-inch vent line to establish ventilation to the portal side of the hasty plug. The team crawled through the door and walked to the hasty plug where water was again present and pre-staged pumps were started to pump the water to the retention ponds. The team then sampled the air quality on the working point side of the plug and reported the results to the reentry controller. With approval, the team opened the tube turn doors on the 30-inch vent tube and the 36-inch crawl tube thereby establishing ventilation to the portal side of the U12n.08 overburden plug. At the same time the first team was working at the gas seal plug, a second team proceeded to the gas seal door. They unbolted and opened the large trainway door and reestablished rail lines through the doorway. Both reentry teams then returned to the portal. Following a briefing on conditions in the tunnel, a third reentry team went underground to the portal side of the U12n.08 overburden plug. At the plug they took the required readings from the working point side and transmitted the data to the portal. With permission, they opened the portal and working point tube turn doors and established ventilation through the overburden plug to the Ming Blade complex. Upon crawling through the plug, they discovered water on the working point side where they started a pump to remove the water to the portal. The reentry team then proceeded further into the Ming Blade drift complex and to the test chambers. The team opened the doors to both test chambers. Slightly elevated radiation levels and toxic gas were detected inside. Ventilation was subsequently established inside the pipe to mitigate the elevated levels.

Once the initial reentry teams finished, a scientific assessment team entered the line-of-sight pipe (McDowell et al. 1987:188). The scientific assessment team inspected the two test chambers and then the tunnel-and-pipe-seal to verify it had closed properly. Data recovery was also started at the instrumentation alcoves. Removal of the hasty plug and the overburden plug was completed on June 24, or D+5. Recovery of experiments began on June 25, D+6, and was completed by July 8, 1974 (McDowell et al. 1987:189). The tunnel-and-pipe-seal door was opened on July 8 and DNA auxiliary closure 2 was inspected from within the line-of-sight pipe. The drift was secured until November 5, 1974, when post test mining started to remove all line-of-sight stub pipes, test chambers, the line-of-sight pipe to the tunnel-and-pipe-seal, the tunnel-and-pipe-seal, and the DNA auxiliary closure 2 (McDowell et al. 1987:189). Work in the U12n.08 drift was terminated on December 13, 1974.

Post test drilling into the chimney was initiated on August 4, 1975 (McDowell et al. 1987:190). Objectives of the drill holes were to record the dimensions, shape, and composition of the chimney. Two holes were drilled toward the chimney from the interior of the U12n.08 drift (Peterson, Lagus, and Lie 1993; Townsend et al. 2007). Both holes started in the same drill hole, but at different angles. One hole was horizontal and 446 ft (136 m) long, while the second was at an incline of 33 degrees and 535 ft (163 m) long. A third hole (U12n.08 PS #1) was drilled vertically from the mesa surface and above the working point to a depth of 525 ft (160 m). All three drill holes were about 4 inches (10 cm) in diameter. This work was completed October 10, 1975 (McDowell et al. 1987:191). A subsequent study of the chimney using the same drill holes was started on February 25, 1976 and finished March 5, 1976. Later, two chimney pressurization studies on July 6 and 20, 1976, made use of the drill holes (Peterson, Lagus, and Lie 1993). Tracer gas was injected into the inclined interior hole for a number of hours. Air samples were then taken at the other two drill holes to determine how fast the gas moved through the chimney. Air sampling stations were also set up around the mesa drill hole to determine if gas seeped from the chimney. Objectives were to assess the air-filled void volume, gas permeability, and the extent of fracturing in the chimney.

U12n.09 Drift - Hybla Fair and SPLAT

The Hybla Fair nuclear test was conducted in the U12n.09 drift on October 28, 1974. The nuclear device was provided by LLNL and was less than 20 kilotons in yield (DOE/NV 2000) Vertical depth of the test was 1,326 ft (404 m) below the surface (McDowell et al. 1987:195). The objective of the test was to evaluate the potential of low yield nuclear weapons effects tests in smaller and less expensive test beds (DTRA 2002:384; Kent and Patch 1977:7; Townsend et al. 2007). In addition to the nuclear test, a stemming plan test, and a hydrofracture experiment were conducted after the drift was completed and several months before the Hybla Fair test was executed.

Mining of the U12n.09 drift complex began in mid March 1974 (Bennett 1991) and concluded about mid May (McDowell et al. 1987:195). The main components of the Hybla Fair complex consisted of a line-of-sight drift, a bypass drift, three crosscuts, and a zero room (Figures 60-62). The U12n.09 drift started to the right off the U12n.07 bypass drift in a southwest direction. The 12n.09 main drift split after approximately 112 ft (34 m) from the start, made an S curve, and ended at 226 ft (69 m) where the line-of-sight drift began. The line-of-sight drift continued another 214 ft (65 m) to the back of the zero room, 9 ft (2.7 m) beyond the working point. The bypass drift continued straight from the split in the 12n.09 main drift until it curved back to the line-of-sight drift and intersected the zero room. The line-of-sight drift measured 205 ft (63 m) to the center of the zero room. At the start it was 10 ft (3 m) wide and high and then expanded to 13 ft (4 m) wide and high for the stub pipe and test chamber areas. It then began to decrease incrementally to the zero room where the final dimension was 4 ft (1.2 m) wide and 7 ft (2.1 m) high. The zero room consisted of a hemispherical cavity, with a cylindrical sub-cavity excavated approximately 8 ft (2.4 m) below the working point. The nuclear device was placed on an elevated platform supported by metal I-beams. The line-of-sight pipe, including the test chamber, was 125 ft (38 m) long, with stub pipes extending straight approximately another 100 ft (30 m) from the end of the test chamber. The bypass drift measured 10 ft wide and high at the start and then 12 ft (3.7 m) wide and 8 ft high from where it began to curve back to the line-of-sight drift and the zero room. An overburden plug was placed in the U12n.09 main drift just before it split for the line-of-sight and bypass drifts.

A mandatory full participation dry run for the Hybla Fair test on October 15, 1974 failed (McDowell et al. 1987:206). A second mandatory full participation dry run later that day proved successful. Device insertion and button-up stemming operations began the next day. A final dry run was

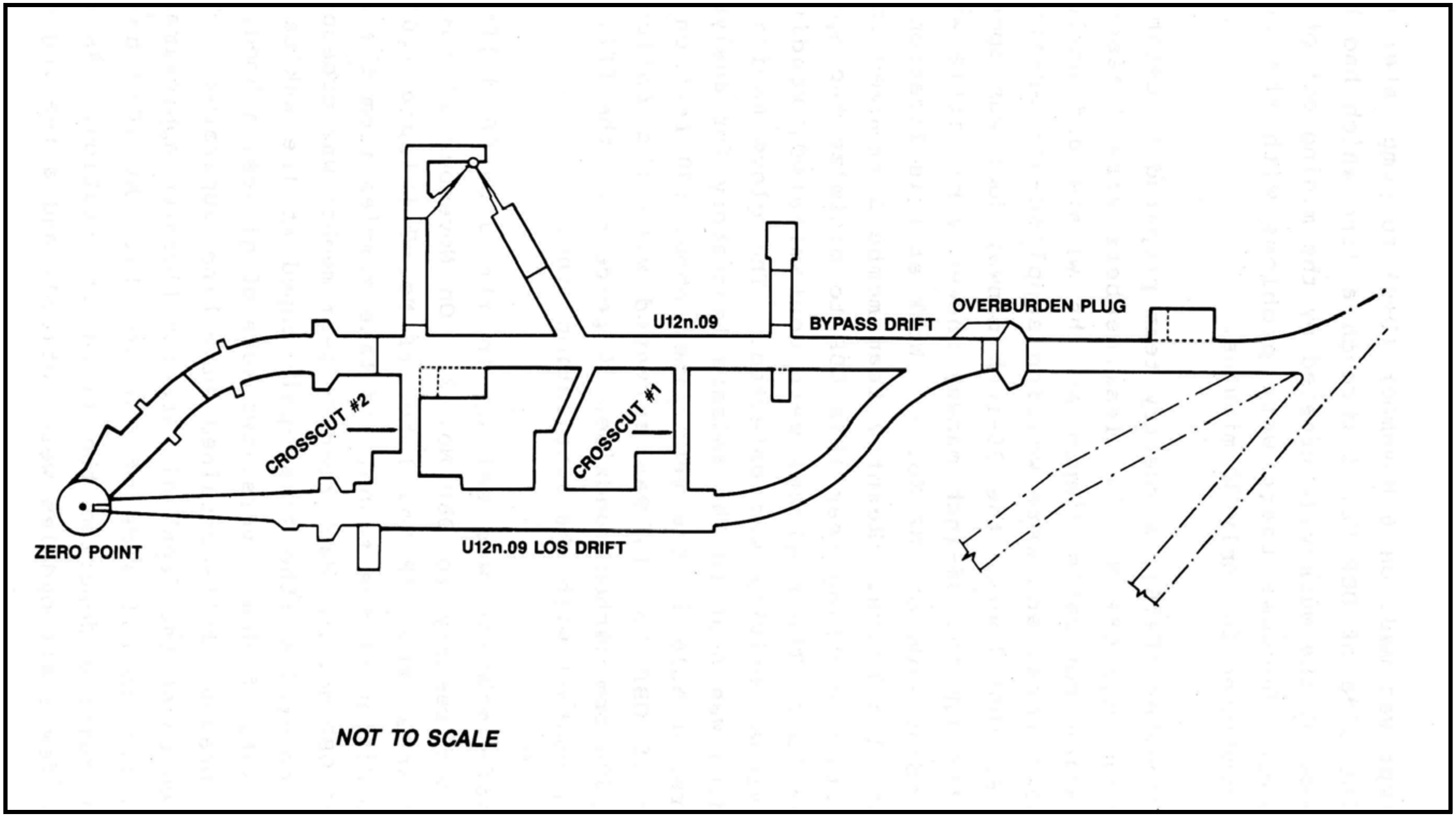


Figure 60. Plan of the U12n.09 drift for the Hybla Fair test (McDowell et al. 1987:212).

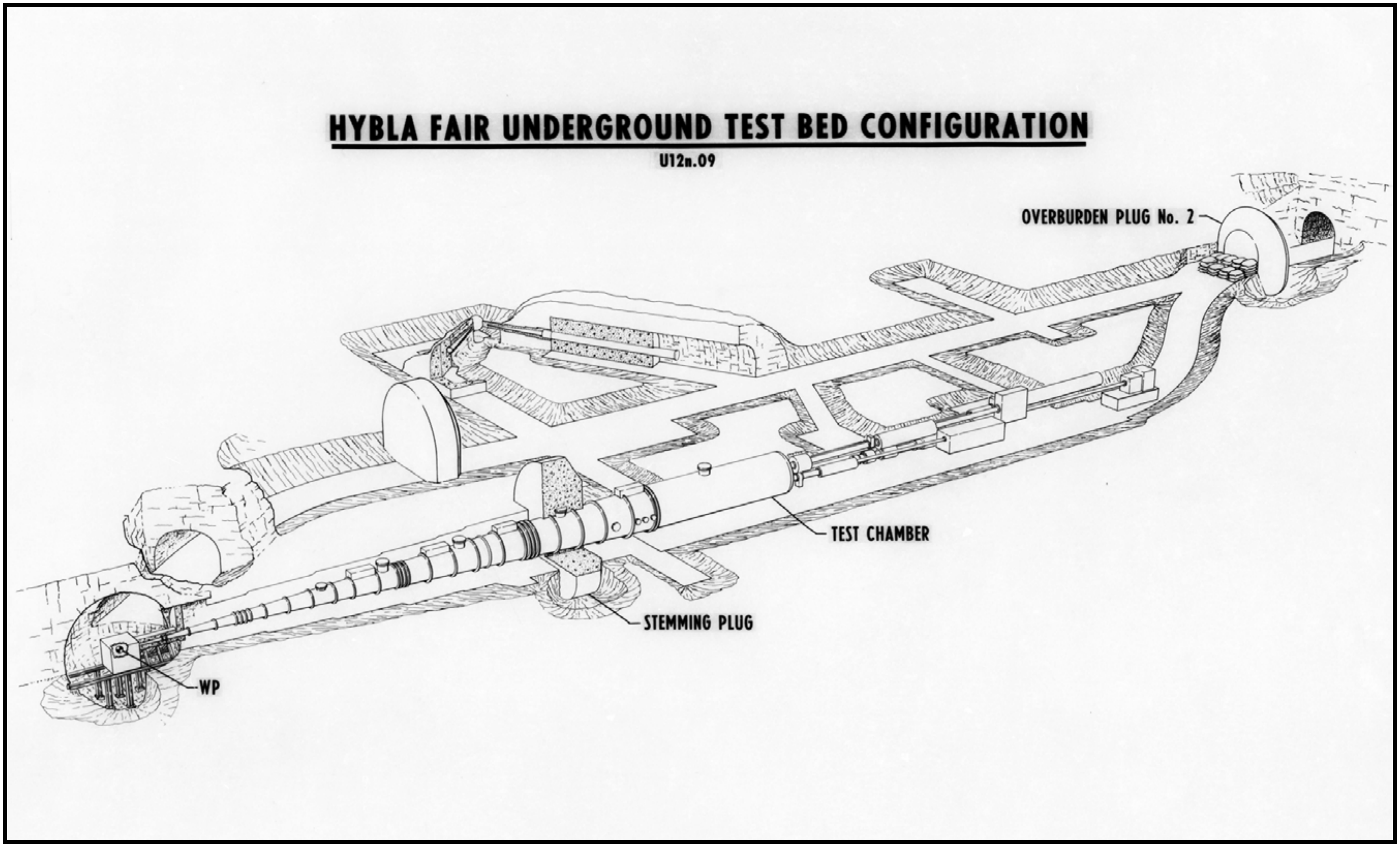


Figure 61. Schematic of the U12n.09 drift for the Hybla Fair test (drawing on file at Archives and Records Center, Mercury).

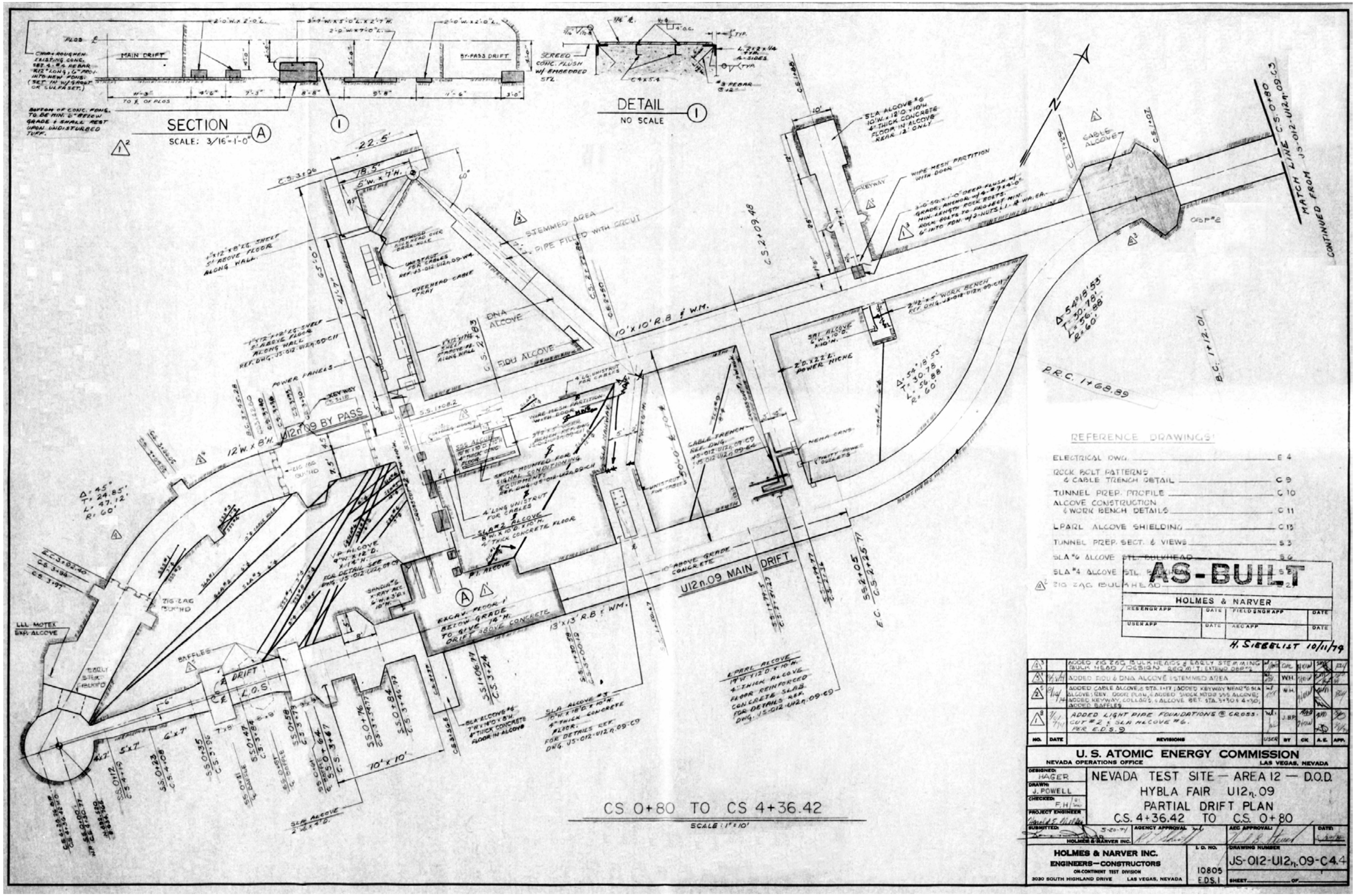


Figure 62. Construction plan of the forward area in the U12n.09 drift for the Hybla Fair test, 1974 (drawing JS-012-U12n.09-C4.4, on file at Archives and Records Center, Mercury, Nevada).

performed on October 25 in order to execute the test the following day, but inclement weather postponed it. Another final dry run took place on October 27 and permission was granted to arm the nuclear device and all personnel exited the area. The Hybla Fair nuclear test was executed on the morning of October 28, 1974.

At detonation, 15 of the 20 surface remote area monitoring system units on the mesa went off line and two units at the end of stemming in the line-of-sight drift and closest to the working point were incapacitated (McDowell et al. 1987:207). Two units closest to the working point in the bypass drift indicated radiation levels above their maximum limit of 1,000 R/h and 100,000 R/h, respectively. Remote area monitoring system units positioned between the overburden plugs in the U12n.09 drift and the U12n.06 drifts also detected elevated levels of radiation, with two units reaching 175 R/h. No elevated radiation levels were detected on the portal side of the U12n.06 overburden plug, indicating that radiation from the Hybla Fair nuclear test had been contained within the tunnel and did not escape to the atmosphere.

About two hours after the detonation, initial reentry teams surveyed the portal and mesa surface areas for radiation (McDowell et al. 1987:208). The surveys did not detect any radiation levels above normal background. Consequently, data recovery efforts were conducted at both locations and finished by early afternoon. Tunnel reentry began the next day, October 29 or D+1. The tunnel reentry personnel arrived at the portal, with the reentry teams putting on their personal protective equipment, the work team lining up the equipment that would be used underground, and the industrial hygiene and radsafe technicians setting up their equipment and providing support. The reentry control team reviewed radiation, toxic and explosive gas conditions on the working point side of the gas seal door, hasty plug, U12n.06 overburden plug, U12n.09 overburden plug, and the Hybla Fair line-of-sight pipe drift. Readings at the gas seal door and hasty plug were normal. Radiation levels at all other locations were elevated. This information was compared to similar readings from the monitor room at control point. Tunnel reentry began after a review of the data, getting a weather briefing, and receiving permission from the DOE test controller to proceed. Following their health and safety briefing, the first reentry team went underground to the portal side of the gas seal door. They collected air quality measurements from the working point side of the door and with the reentry controller's permission, opened the small man door where they found some water on the working point side. The first team went through the opening and walked to the portal side of the hasty plug. After collecting air quality measurements on the working point side and getting permission to proceed, the team opened the tube turn doors, established ventilation, and crawled through. While the first reentry team was on their way to the U12n.06 overburden plug, a work team proceeded to the gas seal door. At the gas seal door, they opened the large trainway door, reinstalled the rail, and started draining the water. The work team then returned to the portal as the first reentry team made its way to the portal side of the U12n.06 overburden plug where they took measurements on the working point side and transmitted them to the reentry controller at the portal. They had made their way to the U12n.06 overburden plug by way of a man train that was left on the working point side of the hasty plug. No elevated gases or radiation levels were detected on the portal side of the U12n.06 overburden plug, but slightly elevated levels of radiation were found on the working point side (McDowell et al. 1987:210). The reentry team also inspected the ROSES units and the cable splice alcove and found no elevated radiation levels or any toxic and explosive gases. Shortly later, initial data recovery was performed at the ROSES units.

Work to remove the hasty plug in the main drift started on October 30, or D+2, and continued until completed on November 4, or D+7. No other work, except for gas sampling at the U12n.06 overburden plug, was conducted until November 13, or D+16, when ventilation was established through the plug (McDowell et al. 1987:211). Reentry resumed on November 15, or D+18, through the U12n.06 overburden plug to the U12n.09 overburden plug. Elevated radiation levels were detected over the route between the plugs and ranged from 13 mR/h to 80 mR/h (McDowell et al. 1987:213). Some data tape was recovered from an experimenter's alcove. Gas samples collected from the working point side of the U12n.09 overburden plug on November 19 and 20, D+22 and 23, still detected elevated radiation levels, and work began on removing the U12n.06 overburden plug. On November 21, D+24, work started to rehabilitate the tunnel and decontaminate the area between the two overburden plugs (McDowell et al. 1987:214). Survey and rehabilitation of the DNA auxiliary closure area in the U12n.07 drift started on December 9 so a probe hole could be started from this area into the U12n.09 drift (McDowell et al. 1987:215). The drill hole was completed on December 19, 1974, but problems with the presence of toxic and explosive gases developed and the hole was sealed (McDowell et al. 1987:216). Similarly, work at the U12n.09 overburden plug was discontinued because of toxic and explosive gases and elevated radiation levels. By the middle of January 1975, gas levels were low enough to continue work in the drift and recovery of equipment was conducted in a few alcoves (McDowell et al. 1987:217).

Reentry mining began on January 31, 1975 and continued to the middle of August. As the mining progressed, much of the exposed surfaces had to be sprayed with sealant to affix the radiation and lower the exposure rates (McDowell et al. 1987:218). On several occasions, miners and others recovering equipment had to be decontaminated. The average exposure rate for all workers was 3 mR/h. Recovery of data and equipment was conducted in the Sandia Laboratories alcove in May. In June, reentry mining started to the U12n.09 line-of-sight drift. The drift was reached by the end of the month and work then started in the drift and continued until August 15, 1975 when all reentry work ended (McDowell et al. 1987:220, 222). On December 1, core drilling into the cavity was conducted and a sandbag plug was started to seal the drift. All operations in the U12n.09 drift ended on December 15, 1975.

Prior to the Hybla Fair nuclear test, a high explosive Stemming Plan Test (SPLAT) in mid 1974 was also conducted in the U12n.09 drift (Defense Nuclear Agency 1974), and was similar to the one carried out in the U12t Tunnel (Muma et al. 1974). It was located in a drift off to the right of the Hybla Fair bypass drift, approximately 65 ft (20 m) from the bypass drift and 110 ft (34 m) along the bypass drift from the working point (Figure 63). The SPLAT was conducted to validate the Hybla Fair low yield stemming plan design and to assist in the development of the best gage layout for the nuclear test.

SPLAT consisted of two short drifts off the U12n.09 bypass drift. The first drift was the SPLAT crosscut drift, mined perpendicular to the U12n.09 bypass drift. The 7 ft (2.1 m) high and wide drift was 65 ft (19.8 m) long from the center line of the bypass drift to the end of the crosscut. A 5 ft (1.5 m) wide and 7 ft high extension turned to the right off the end of the crosscut and was mined 22.5 ft (6.9 m) long from the center line of the crosscut to the end of the extension. This portion of the drift housed the high explosive canister centered in the right rib of the drift and extended into a semicircular notch with an 18 inch (46 cm) radius. The centerline of the notch was 4 ft (1.2 m) from the end of the drift extension. A second drift off the U12n.09 bypass drift was termed the SPLAT

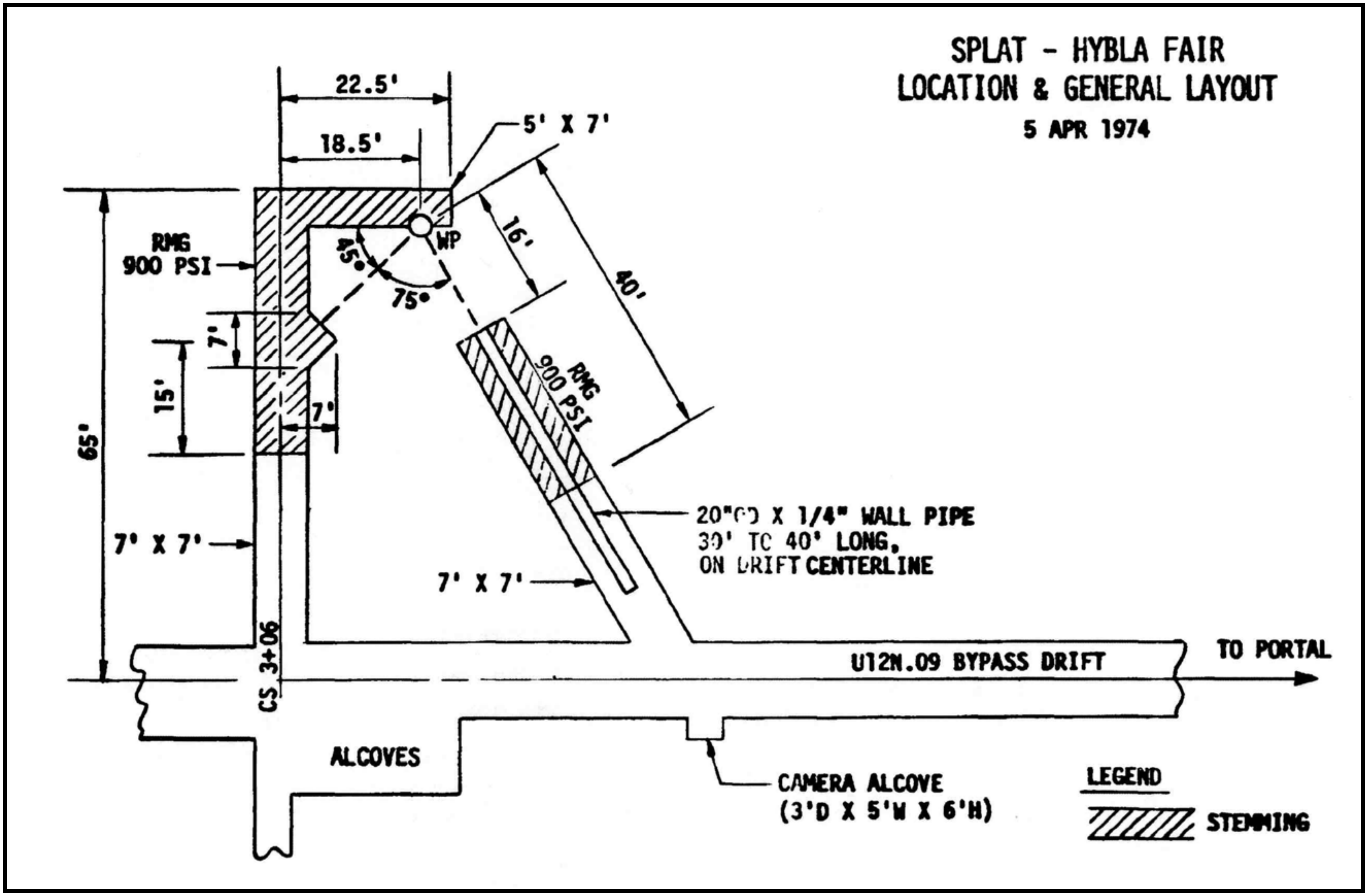


Figure 63. Plan of the high explosive stemming plan test in the U12n.09 drift (Defense Nuclear Agency 1974).

angle drift. It turned off the bypass drift at a 60 degree angle and aimed toward the SPLAT working point. The angle drift was 53.28 ft (16.2 m) long from the center line of the bypass drift and 7 ft wide and high.

Two small line-of-sight pipes were installed in drill holes aimed toward the SPLAT working point. The first hole, or the one on the left, originated from the working point face of a triangular-shaped notch that was mined on the right rib of the crosscut drift. The centerline of the triangular-shaped notch was located 45 ft (13.7 m) from the centerline of the U12n.09 bypass drift. The second hole was from the center of the angle drift's face and aimed at the working point. The first hole was about 17.25 ft (5.3 m) long and the second hole was about 14.5 ft (4.4 m) long. The holes were drilled in steps starting at 12 inches (30.5 cm) in diameter at the edge of the working point cavity and increasing in 6 inch (15.25 cm) increments at the 1/4 points of each hole to 36 inches (91.5cm) in diameter. Scaled line-of-sight pipes, the length of each hole, were grouted in place after being installed along the centerlines of the holes. The pipe on the left butted to the grout in the notch and the one on the right butted to a 20 inch (6.1 cm) diameter, 1/4-inch walled steel pipe that extended down the drift for about 40 ft (12.2 m). This pipe was filled with grout. The drifts were partially filled with 900 psi (6.2 mpa) rock-matching grout. SPLAT was successfully conducted and the data were used to help design the stemming plan for the Hybla Fair nuclear test.

In July 1974, an alcove in the U12n.09 bypass drift was used for drilling a hole in a hydrofracture experiment by the U.S. Geological Survey (Miller 1976; Smith et al. 1981:12). The drill hole was one in a series of 10 drill holes, with the other nine in the U12e and U12t tunnels. The objective of the experiments was to obtain in-situ stress values of the geologic formations.

U12n.10 Drift - Mighty Epic

Mighty Epic, conducted on May 12, 1976 in the U12n.10 drift, was the eighth nuclear test in the U12n Tunnel. It was also the first of two nuclear tests in the same drift complex, the other was Diablo Hawk. The objective for the double tests was to use as much of the tunnel configuration as possible from the first test in the second test for cost-savings in both money and time. LLNL supplied the Mighty Epic nuclear device and it had a yield of less than 20 kilotons (DOE/NV 2000) Vertical depth of the test was 1,306 ft (398 m) below the surface (Brady et al. 1989:91). The purpose of the test was weapons related and for ground shock effects on hardened structures.

The U12n.10 drifts started in a northwest direction off the U12n.08 drift and began initially with mining of the bypass drift in late November 1974 (Bennett 1991; Fairer and Townsend 1983:4). Mining of the line-of-sight drift began in early December. The line-of-sight drift measured 2,014 ft (614 m) long and 16 ft (4.9 m) wide and high at the start and decreased incrementally over its length to 8 ft (2.4 m) wide and high at the zero room (Figures 64-65). The line-of-sight pipe measured 1,800 ft (549 m) long (Brady et al. 1989:93). Containment and experiment protection mechanisms in the pipe consisted of a muffler, two DNA auxiliary closures, and a tunnel-and-pipe-seal. The line-of-sight pipe contained four test chambers, one diagnostic stub pipe system, and two discrete scatterer stations. The bypass drift, at 2,012.5 ft (613 m) in length, was nearly as long as the line-of-sight drift. It measured 11 ft (3.4 m) wide and high the entire length. Three structure drifts, designated A, B, and C, were excavated at an angle to the left off the bypass drift, with lengths of 302 ft (92 m), 372 ft (113 m), and 390 ft (119 m), respectively. A and B drifts were mined 11 ft (3.4 m) wide and high

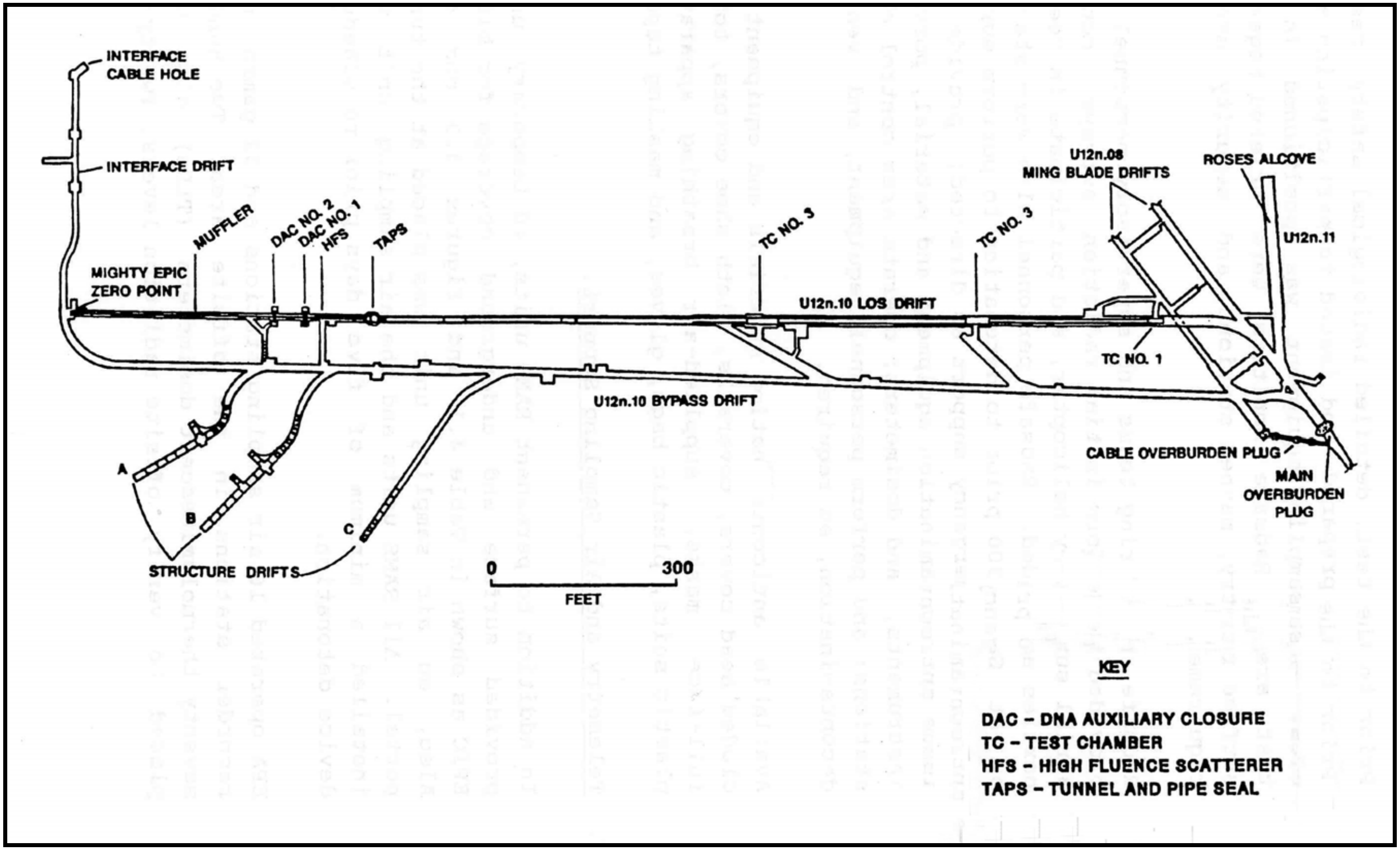


Figure 64. Plan of the U12n.10 drift for the Mighty Epic test (Brady et al. 1989:95).

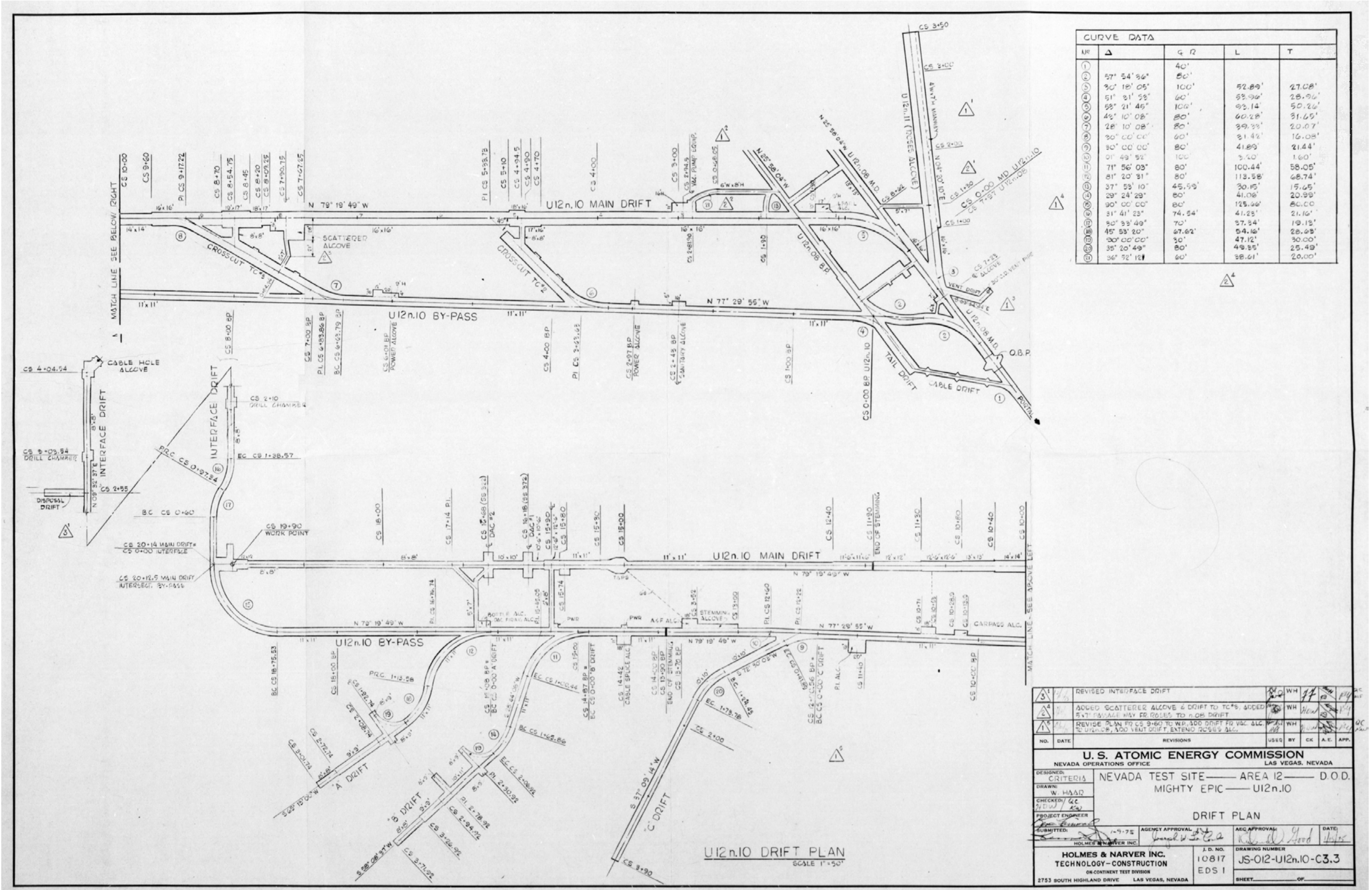


Figure 65. Construction plan of the U12n.10 drift for the Mighty Epic test, 1975 (drawing JS-012-U12n.10-C3.3, on file at Archives and Records Center, Mercury, Nevada).

at the beginning and decreased incrementally to 8 ft (2.4 m) wide and high at the end. C drift was mined 10 ft (3 m) wide and high at the beginning and decreased to 8 ft wide and high at the end. Four crosscuts connected the line-of-sight and bypass drifts together, with two of the crosscuts providing access to the test chambers and the other two providing access to the line-of-sight drift opposite the structures drifts (Brady et al. 1989:94). An interface experiment drift was mined at a right angle off the end of the line-of-sight drift and started behind the zero room. It measured 405 ft (123 m) in length, 8 ft wide and high the entire length. The interface experiment drift had a cable hole alcove at the end that was mined to intersect a cable hole drilled from the surface. Recording Oscilloscope Sealed Environment System (ROSES) units for underground recording were located in the U12n.11 drift. Instrumentation trailers for recording data were also stationed at the portal and on the mesa.

A total of 14 exploratory holes were drilled to site the nuclear device in the U12n.10 drift and for understanding the response of the surrounding geology to the nuclear explosion (Fairer and Townsend 1983; Carroll et al. 1983). Three vertical holes were drilled from the mesa surface to below the tunnel level: UE-12n # 3 was 1,409 ft (429 m) deep, UE-12n # 8 was 1,784 ft (544 m) deep, and UE-12n # 9 was 1,550 ft (472 m) deep. Drill hole UE-12 # 9 had an instrument package located near the bottom of the hole. All three holes were grouted to the surface. Three more vertical holes were drilled downward from the floor (invert) of the interface drift to depths of approximately 50 ft (15 m) to locate the Tertiary/pre-Tertiary interface. A final three vertical holes were drilled from the experiment support drifts to characterize the underlying Tertiary/pre-Tertiary interface and reached depths of 451 ft (137 m), 336 ft (102 m), and 607 ft (204 m). A total of five horizontal holes were drilled. The first horizontal hole was drilled from the U12n.05 drift. The second horizontal drill hole started from the face of the U12n.10 bypass drift at about 450 ft (137 m) from the beginning and was drilled toward the working point, reaching a depth of 1,401 ft (427 m). The other three horizontal drill holes also started from the U12n.10 bypass drift. Two of them were designed to characterize the geology of the A and C structure drifts prior to mining and the third hole characterized the pillar region between the Mighty Epic line-of-sight and bypass drifts.

On May 12, 1976, just after midnight, everyone had vacated the tunnel and immediate area except for the arming party, the microwave timing party, the final button-up team, and security (Brady et al. 1989:101). Permission was granted to arm the nuclear device. Button-up was delayed, however, because of problems with some of the experiments (Brady et al. 1989:102). With the problems solved and button-up completed, all personnel left the tunnel area by 10:30 in the morning. Upon favorable wind conditions, the Mighty Epic device was detonated at 12:50 in the afternoon. The cavity did not collapse until some weeks had passed (Townsend et al. 2007). Townsend et al. (2007) indicate the extended collapse time may have been due to a relatively strong geologic medium. The Mighty Epic test was the first one located in the northwest portion of the U12n Tunnel and the surrounding rock was not sufficiently weakened from previous nuclear tests.

Radiation readings at the control point monitor room began increasing immediately after detonation (Brady et al. 1989:102; Mullen and Eubank 1977:17-18). The remote area monitoring system units at the portal and just inside the tunnel entrance were knocked offline by electromagnetic pulse, but recovered after some minutes had passed. Those units in the line-of-sight drift provided the highest radiation readings, as expected. The unit closest to the end of stemming in the line-of-sight drift was inoperable as a result of the detonation. All the other units indicated normal background radiation levels. By the time all the units were secured on May 14, or D+2, radiation levels for the units inside the line-of-sight drift with the highest readings had decreased 80 to 90 percent from the original levels.

Initial reentry surveys for the main and interface trailer parks on the mesa and the portal area began about one hour after detonation. All the surveys were completed within one hour and no radiation levels above normal background detected. Remote gas sampling from inside the tunnel found a small amount of toxic gas on the working point side of the U12n.08 overburden plug and a small amount of toxic gas and a slightly elevated radiation level inside the line-of-sight pipe (Brady et al. 1989:103). Data recoveries were conducted at the portal and mesa.

After additional remote gas sampling, reentry into the tunnel began on May 13, or D+1. Initially, a work team proceeded to the gas seal door, opened the personnel access door, and established ventilation to the portal side of the hasty plug. The work team also set up a pump to remove water from the invert or floor of the drift on the working point side of the gas seal door. Next, the first reentry team entered the tunnel and proceeded to the hasty plug where they opened the tube turn doors on the 30-inch vent tube and the 36-inch crawl tube and established ventilation to the U12n.08 overburden plug. No toxic or explosive gases or elevated radiation levels were detected on the working point side of the overburden plug. After opening the tube turn containment doors and reestablishing ventilation to the working point side of the overburden plug, the reentry team then proceeded to the Mighty Epic line-of-sight pipe and test chambers. They found elevated radiation levels and toxic gases inside the first three test chambers (Brady et al. 1989:104). They did not detect elevated radiation levels or toxic and explosive gases in the U12n.11 ROSES area. Late on D+1, Data recovery began in the ROSES and stub pipe areas and mining commenced to remove the hasty plug (Brady et al. 1989:105).

On May 14, or D+2, a scientific assessment team entered the tunnel to survey the line-of-sight pipe from the first test chamber to the tunnel-and-pipe-seal. They detected elevated levels of radiation and toxic gases at the first three test chambers and at the tunnel-and-pipe-seal. They also noted a water leak at the tunnel-and-pipe-seal door and a work team was dispatched to pump the water from the portal side the tunnel-and-pipe-seal. Water soon became a major problem in both the line-of-sight and bypass drifts, which delayed the mining of both the hasty plug and the overburden plug (Brady et al. 1989:106). On May 17, or D+5, mining resumed to remove the two plugs and was completed the next day (Mullen and Eubank 1977:18). Elevated readings were still detected in the test chambers and at the tunnel-and-pipe-seal. On May 19, D+7, the readings became low enough to recover experiments from the scatterer alcove (Brady et al. 1989:107). The elevated radiation and gas levels continued to fall in the three forward test chambers and line-of-sight pipe and by May 28, 1976, all experiments were recovered from the test chambers.

On June 1, 1976, D+20, workers opened the tunnel-and-pipe-seal door and installed a pump to remove water draining from the working point side of the door (Brady et al. 1989:108). A couple of hours later, personnel made their way to the first DNA auxiliary closure and found the pipe in good condition. The DNA auxiliary closure, however, had not completely closed. At test chamber 4 a slightly elevated radiation level and toxic and explosive gases were detected. Recovery of experiments from this test chamber was completed by June 3, D+22.

Post test reentry mining began on June 7, 1976 from the U12n.10 bypass drift. Objectives of the reentry mining were to recover experiments, the line-of-sight pipe, and equipment for use on the subsequent Diablo Hawk nuclear test, and to obtain core samples. Six reentry drifts were mined: the A and B structures reentry drift, the A structure crosscut, the B structure crosscut, the bypass reentry drift, DNA auxiliary closure 1 crosscut, and the interface reentry drift (Brady et al. 1989:109). Mining of the drifts was accomplished with the drill-and-blast technique. A probe hole was drilled 18 to 22 ft (5.5 to 6.7 m) into the face of the drift before each round of drilling and blasting for early detection of water, toxic or explosive gases, and radiation. The muck from each round was also surveyed for radiation before its removal from the tunnel. If the radiation level of the muck was above normal background, the muck was stored underground to allow the radiation to decay. The first five reentry drifts were completed by the early part of September 1976. In the later part of September, mining of the interface reentry drift began from the bypass reentry drift where it crossed the line-of-sight drift. Work on the drift continued until April 7, 1977.

With objectives to characterize the chimney, one post test core hole was drilled vertically from the mesa surface and two were drilled within the tunnel from the U12n.10 bypass drift (Brady et al. 1989:110; Townsend et al. 2007). One drill hole from within the tunnel was horizontal, while the second was at a 26 degree incline. Drilling of the first hole within the tunnel started on August 17, 1976 and ended on August 25. It reached a depth of 226 ft (69 m). The mesa drill hole was started on August 23, completed on September 4, and was capped on November 10, 1976. The second drill hole from within the tunnel was started October 14, 1976 and was completed on October 28, 1976, with a total depth of 175 ft (53 m). Valves were installed on both the underground drill holes to prevent air flow into and out of the cavity. A third underground core hole was started on November 5, 1976 from the end of the bypass reentry drift toward the interface drift. It was completed November 10, 1976.

U12n.10a Drift - Diablo Hawk

Diablo Hawk was the ninth nuclear test in the U12n Tunnel and the second in the U12n.10 drift complex as part of a project to cut costs by using as much of the drift as possible for the second test (Brady et al. 1989:142; Ploss 1978:1). Mighty Epic was the first test in the drift complex. The Diablo Hawk test, in the U12n.10a drift, was executed on September 13, 1978 and had a yield of less than 20 kilotons (DOE/NV 2000). LLNL provided the nuclear device and set it at a vertical depth of 1,273 ft (388 m) below the surface. The test subjected military materials and equipment to a nuclear detonation, evaluated different container-type cylindrical structures against ground shock, and an electromagnetic pulse experiment.

Early planning for two successive tests in the 12n.10 drift complex required the line-of-sight and bypass drifts to be mined longer than usual (Townsend et al. 2007). This enabled the Diablo Hawk and Mighty Epic working points to be in the same line-of-sight drift, with the Diablo Hawk working point sited 500 ft (152 m) closer to the portal (Figures 66-67). In addition, the location of the Diablo Hawk working point provided a different angle of shock loading to the structures area than that provided by the Mighty Epic test (Fuhriman 1979:3; Ristvet 2009). Approximately 750 ft (229 m) of the line-of-sight pipe, the diagnostic alcoves, the structure drifts area, the vacuum scatterer system, the vacuum pumping systems, and the mechanical, electrical, and cable systems from the previous Mighty Epic test were reused for the Diablo Hawk test (Fuhriman 1979:1; Ploss 1978:37). The DNA

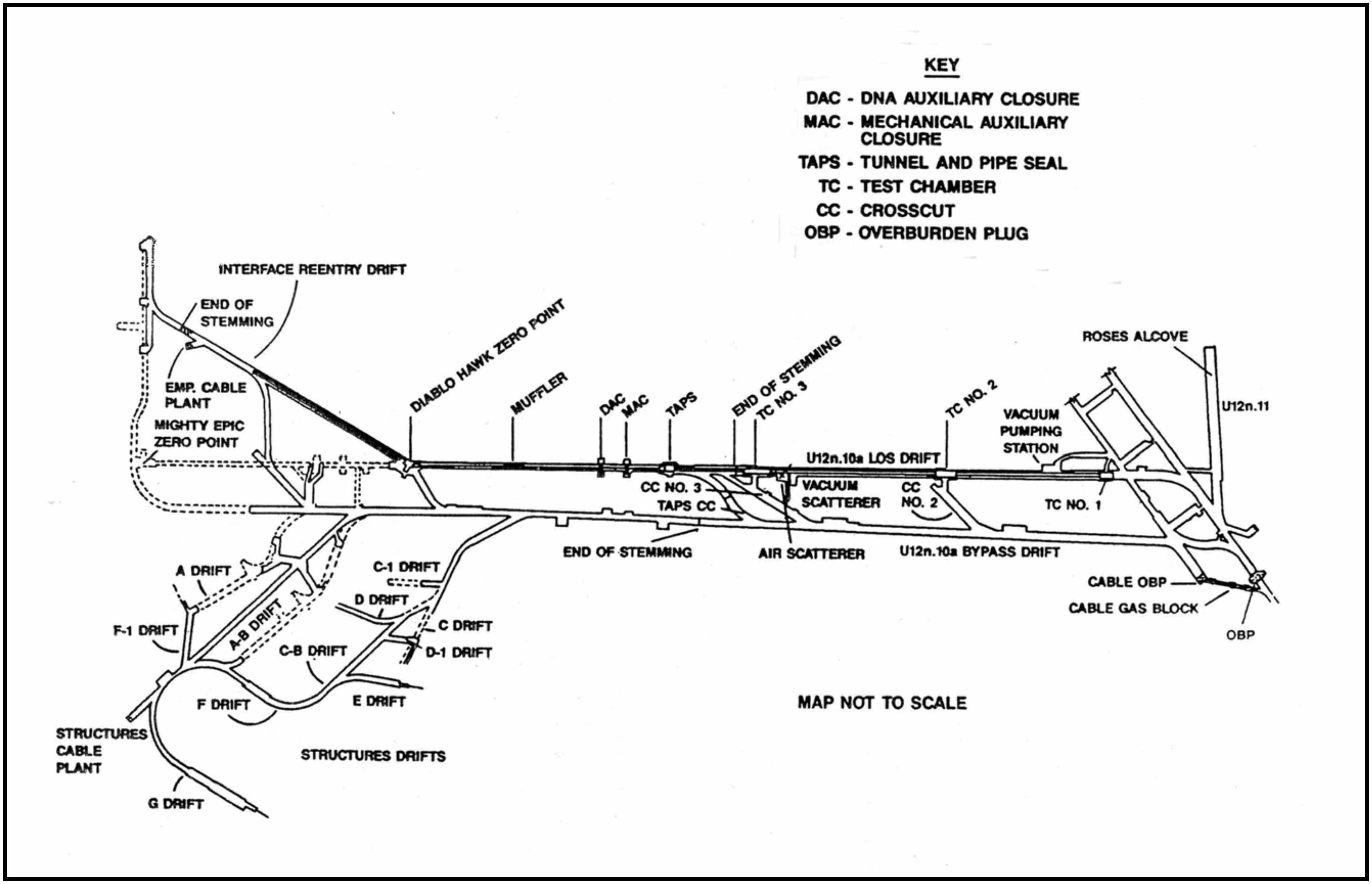


Figure 66. Plan of the U12n.10a drift for the Diablo Hawk test (Brady et al. 1989:146).

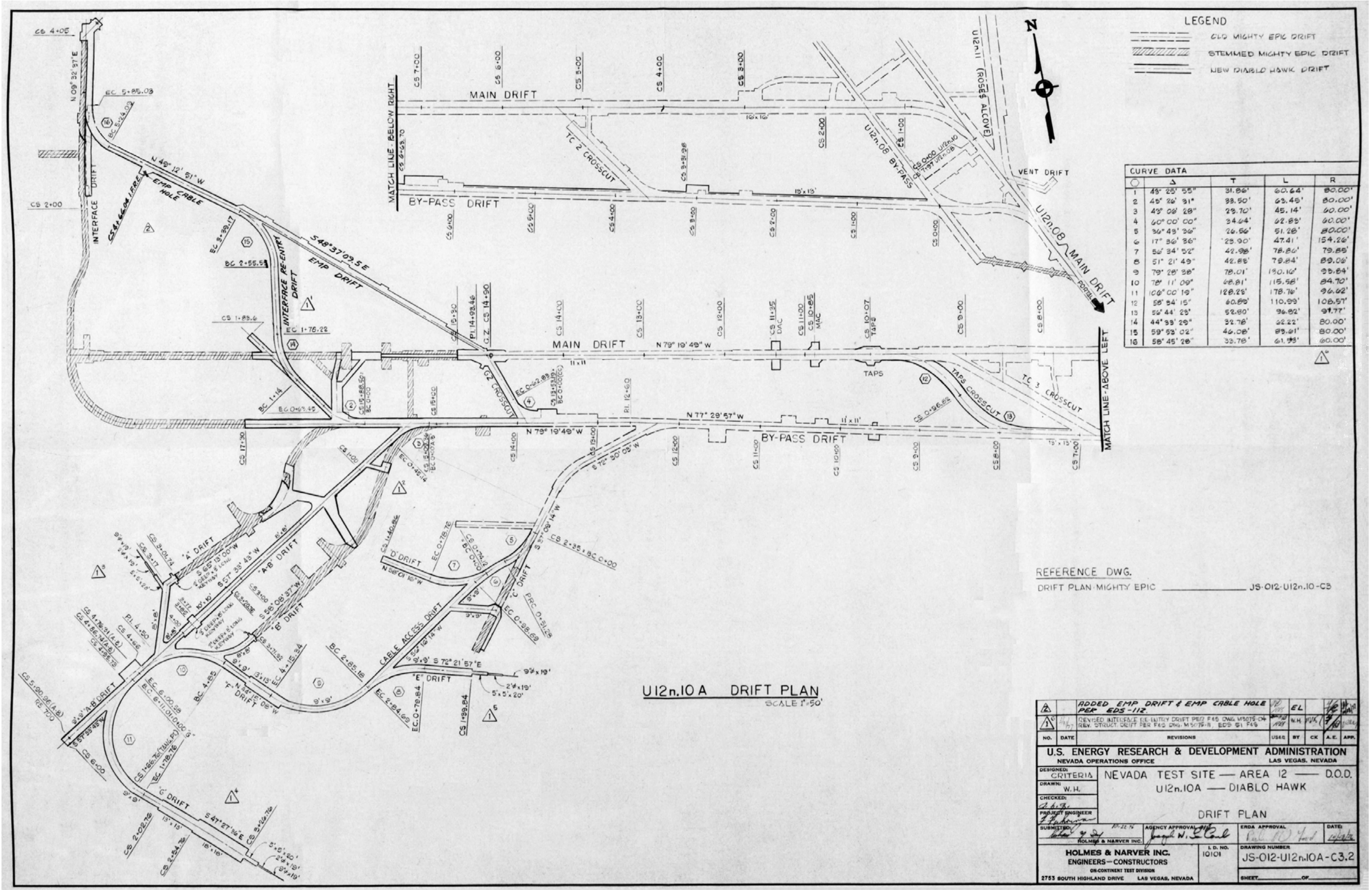


Figure 67. Construction plan of the U12n.10a drift for the Diablo Hawk test, 1976 (drawing JS-012-U12n.10a-C3.2, on file at Archives and Records Center, Mercury, Nevada).

auxiliary closure and five pipe sections were refurbished from the Husky Ace test conducted in the U12n.07 drift in 1973.

Work on the drift complex for the Diablo Hawk test began on May 24, 1976, only two weeks after the Mighty Epic test (Bennett 1991). Mining was comparatively less because both the line-of-sight and bypass drifts had already been constructed. New mining consisted of a crosscut between the working point and the bypass drift, a new drift from the working point to the interface reentry drift for the electromagnetic pulse experiment, a crosscut for the new tunnel-and-pipe-seal, a crosscut for the scatterer area, enlarged alcoves for test chambers 2 and 3, a new cable gas block alcove in the bypass drift, enlargement of the bypass drift at the portal end for inserting a larger tunnel-and-pipe-seal, and mined spaces in the line-of-sight drift to accommodate each of the closure locations and the working point (Fuhriman 1979:3). The structures area off the bypass drift was also rehabilitated (Fuhriman 1979:2). The A-B drift was mined between the original A and B structure drifts and drifts D through G were mined at right angles to the original drifts. A cavity filled with water was located in the D drift and water-filled tanks, or bladders, were placed in the C, D, and E drifts. As a requirement for an experiment, the A-B drift was stemmed with sand and saturated with water (Fuhriman 1979:16).

The main line-of-sight pipe for Diablo Hawk was 1,310 ft (399 m) long and included one muffler, one DNA auxiliary closure, one modified auxiliary closure, one tunnel-and-pipe-seal, two bellows decouplers, three test chambers, and stub pipes at the second and third test chambers (Fuhriman 1979:1). The line-of-sight pipe was 6.5 inches (16.5 cm) in diameter at the working point and 8.25 ft (2.5 m) in diameter at test chamber 1. The line-of-sight pipe sections from test chamber 1 to test chamber 3 were reused from the Mighty Epic test, whereas new pipe replaced the pipe sections from test chamber 3 to the working point. A second line-of-sight pipe was installed from the working point to the electromagnetic pulse experiment located in the interface reentry drift (Fuhriman 1979:2). This pipe measured 347 ft (106 m) long and the first 70 ft (21 m) was steel and the remaining 277 ft (85 m) was concrete. It measured 8.75 inches (22 cm) in diameter at the working point and 3 ft (91 cm) in diameter at the experiment end.

Instrumentation trailers at the U12n Tunnel mesa trailer park, the structures pad, and the electromagnetic pulse experiment pad were used on the mesa to record the Diablo Hawk test (Fuhriman 1979:1; Figure 68). ROSES units in the U12n.11 drift, in the U12n.05 drift, and in the U12n.10 bypass drift recorded the test underground. Two new cable holes to the mesa were drilled for the tests and a cable plant was established at the bottom of each hole (Fuhriman 1979:3, 7-8). One of the new cable holes at the end of the A-B drift served the structures area. It was 700 ft from the working point, 1,355 ft (413 m) deep, and 3 ft (91 cm) in diameter with a 25.25 inch (64 cm) inside diameter casing. A total of 187 cables were inserted in the cable hole. The second new cable hole, located in the interface reentry drift, served the electromagnetic pulse experiment. It was 466 ft (142 m) from the working point, 1,330 ft (405 m) deep, with a 30 inch (76 cm) diameter hole and a 19 inch (48 cm) interior diameter casing. A total of 73 cables were inserted in this cable hole. A new cable splice building was constructed at the main trailer park on the mesa (Fuhriman 1979:13). A new office trailer pad was being constructed adjacent to the main mesa trailer park as well, but was not completed in time for the test and the U12e Tunnel trailer park was used instead for the office trailers (Fuhriman 1979:14).

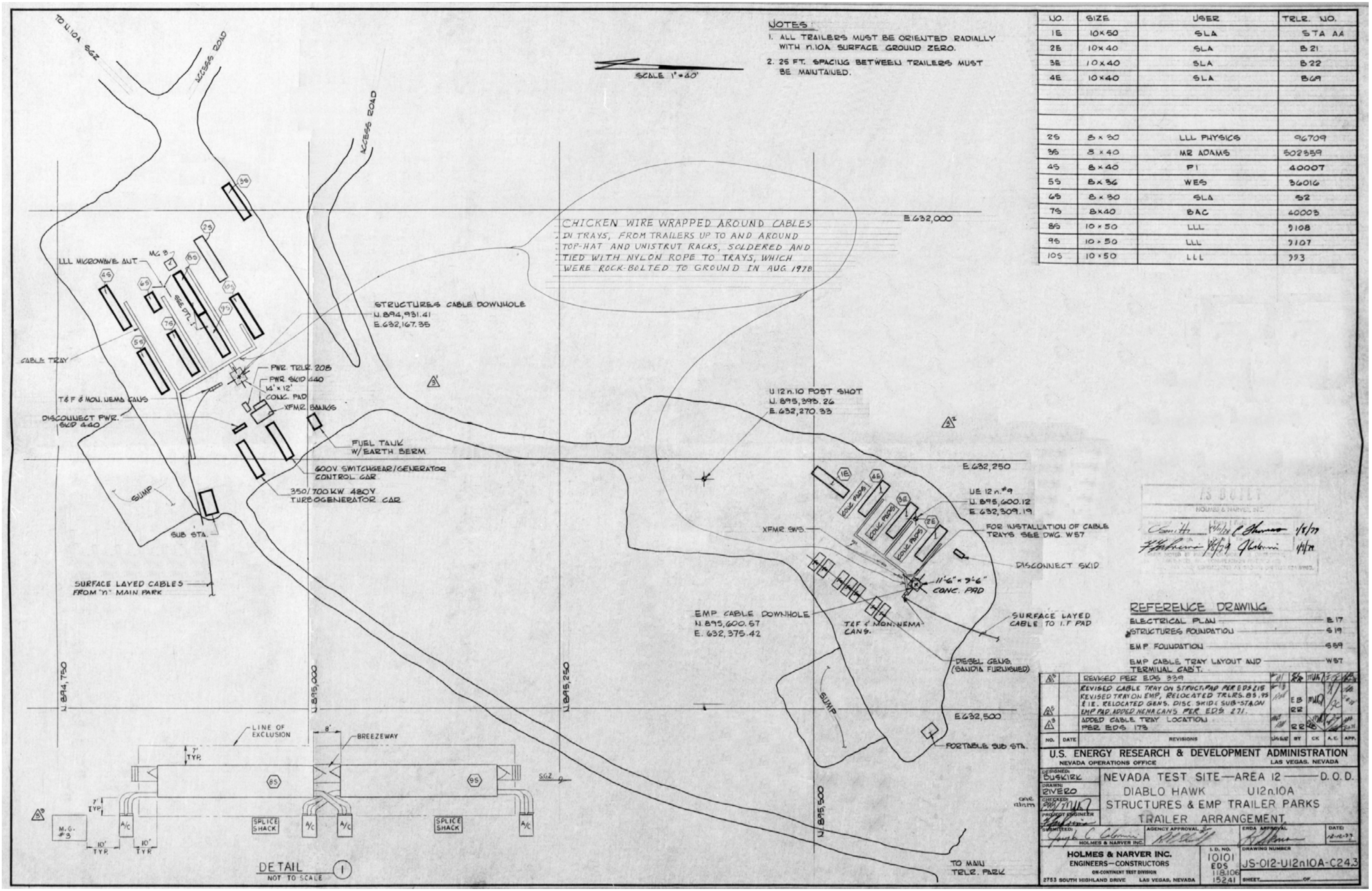


Figure 68. Plan of the U12n Tunnel structures and EMP mesa trailer parks for the Diablo Hawk test, 1979 (drawing JS-012-U12n.10A-C24.3, on file at Archives and Records Center, Mercury, Nevada).

After successfully completing all the dry runs and button-up stemming operations, the test was made ready for execution in the early hours of September 13, 1978 (Brady et al. 1989:154). Permission was granted to arm the nuclear device and final button-up of the tunnel was completed. The device was detonated at 8:15 in the morning. The cavity collapsed 34 minutes later (Townsend et al. 2007). All remote area monitoring system units except for three located nearest the working point in the line-of-sight drift read background radiation levels after the detonation. These three units at one minute after detonation had readings of 1,000 R/h, 400 R/h, and 600 R/h, respectively, but radiation levels soon began to decrease and, at the end of two days, the units read 45 mR/h, 36 mR/h, and 58 mR/h, respectively (Brady et al. 1989:155).

Reentry to survey the portal and mesa areas for radiation began one hour after detonation. Areas inspected on the mesa included the main trailer park, the electromagnetic pulse experiment pad, the structures pad, and the U12n.08 vent hole. All surveys were completed in about one hour and did not find any radiation levels above background. Remote gas sampling did not detect toxic or explosive gases in the line-of-sight drift, but elevated radiation levels were detected inside the line-of-sight pipe. Ventilation was established remotely to the portal side of the hasty plug and data recovery commenced at the mesa and portal instrumentation trailers.

Reentry to the tunnel interior began on September 14, or D+1 (Brady et al. 1989:156). After remote gas sampling, a work team entered the tunnel, proceeded to the gas seal door, and opened the personnel door. The first reentry team then made their way through the gas seal door to the hasty plug, opened the tube turn containment doors, and reestablished ventilation to the overburden plug. They then proceeded through the hasty plug crawl tube to the U12n.08 overburden plug, checked air quality on the working point side of the plug, opened the tube turn containment doors, and reestablished ventilation to the rest of the tunnel. The reentry team then proceeded through the overburden plug to test chamber 3 and noted little structural damage to the drift along the way. The team then proceeded to test chamber 2 and opened a ventilation exhaust valve on top of the line-of-sight pipe near the chamber. Then, they opened the door to the chamber slightly and detected elevated radiation levels and toxic and explosive gases inside (Brady et al. 1989:157). The team next proceeded to the test chamber 1 and the ROSES area and found no elevated radiation levels or toxic and explosive gases. Recovery of some experiments data by the experimenters was allowed at the stub pipe area in the line-of-site drift and in the ROSES in the U12n.11 alcove.

On September 15, or D+2, the reentry team again made their way to the test chambers. They found elevated radiation levels and toxic and explosive gases inside the third test chamber, and elevated radiation levels and toxic gas inside the second test chamber. They closed all doors to the test chambers and some experiments were recovered from the stub pipe area and the scatterer alcove. Rehabilitation started on the line-of-sight and bypass drifts after removal of the hasty and overburden plugs (Brady et al. 1989:158). The structure of the main line-of-sight pipe had little damage and remained intact (Ploss 1978:12). Displacement of the pipe was minimal. All experiments were recovered by September 28, 1978, D+15, and some equipment was removed later. Meanwhile, work continued on investigating the closures, with the tunnel-and-pipe-seal first, then the modified auxiliary closure, and finally, the DNA auxiliary closure. This work finished on November 2, 1978.

Extensive post test reentry mining, particularly in the structures area and around the closures, continued into the next year (Brady et al. 1989:160). A total of 12 reentry drifts were mined: 10 for the structures area and 2 in the line-of-sight drift for the closures (Brady et al. 1989:162). Slightly elevated levels of radiation and toxic and explosive gases occurred in both areas. By November 13, 1979, security gates limiting access to the structure reentry drifts were finished and in place; the tunnel-and-pipe-seal was removed by November 16; and cleanup and final removal of equipment were completed by December 3, 1979. No mining or drilling was conducted to investigate device performance or to characterize the chimney (Brady et al. 1989:168; Townsend et al 2007).

U12n.11 Drift - Miners Iron

Miners Iron, the tenth nuclear test in the tunnel, was executed on October 31, 1980 in the U12n.11 drift. The nuclear device, supplied by LANL, had a yield of less than 20 kilotons (DOE/NV 2000). Vertical depth of the test was 1,306 ft (398 m) below the surface and 6,282 ft (1.19 miles or 1.91 km) from the portal (Brady et al. 1989:193; Hollins 1981:16). The Miners Iron test, as with all other DTRA tests was designed to study the effects of a nuclear weapon on military hardware. The Miners Iron test was also used to evaluate a new high speed, fiber optics, data transfer system (DTRA 2002:387). The fiber optic system would eventually be used to quickly transfer experiment data from underground to the portal and eventually to the control point monitor room for quicker post test analysis.

Siting the U12n.11 drift in the tunnel complex was done in a way that allowed the maximum use of existing facilities. For example, before its use on the Miners Iron test, the U12n.08 overburden plug was used on the Ming Blade, Mighty Epic, and Diablo Hawk tests, an advantage of doing many tests in a single tunnel. The U12n.11 drift started to the right in a northerly direction off the junction of the U12n.08 and U12n.10 drifts (Figures 69-70). Mining for the U12n.11 line-of-sight drift for Miners Iron started in June 1976 to support the Diablo Hawk test. The drift was mined 299 ft (91 m) and used to house the ROSES units. Following completion of the Diablo Hawk test, the line-of-sight drift was re-started in April 1979 and was completed in September 1979 (Brady et al. 1989:198). Structural support for the first 299 ft (91 m) of the line-of-sight drift originally put in for this section consisted of steel sets and wood lagging. Rock bolts for extra support were put in where needed for the Diablo Hawk test. In contrast, the structural support for the rest of the drift, when mined, consisted of rock bolts, wire mesh, and shotcrete. This was the first time an Alpine miner was used to mine a test bed in the U12n Tunnel. The line-of-sight drift measured 1,304 ft (398 m) long and decreased incrementally in size from 16 ft (4.9 m) wide and high at the beginning to 8.5 ft (2.6 m) wide and 8 ft (2.4 m) high at the zero room (Hollins 1981:2). The working point was established 4 ft (1.2 m) from the end of the drift. The bypass drift was 100 ft (30.5 m) apart and parallel to the line-of-sight drift. It angled back and converged with the line-of-sight drift about 226 ft (69 m) short of the working point. Most of the bypass drift measured 13 ft (4 m) wide and high and changed to 8 ft (2.4 m) wide and 10.75 ft (3.3 m) high toward the end that allowed just enough clearance for the modified auxiliary closure to pass through.

Installation of the line-of-site pipe began in November 1979 and was finished in September 1980 (Brady et al. 1989:198). The pipe measured 1,145 ft (349 m) long. It contained a muffler, two modified auxiliary closures, a tunnel-and-pipe-seal, a bellows decoupler, three test chambers, and stub pipes behind the test chambers (Hollins 1981:1). Keyways to anchor the modified auxiliary closures and the tunnel-and-pipe-seal into the surrounding rock were excavated with an Alpine miner, the first such occurrence in the tunnels, rather than the drill and blast technique. This

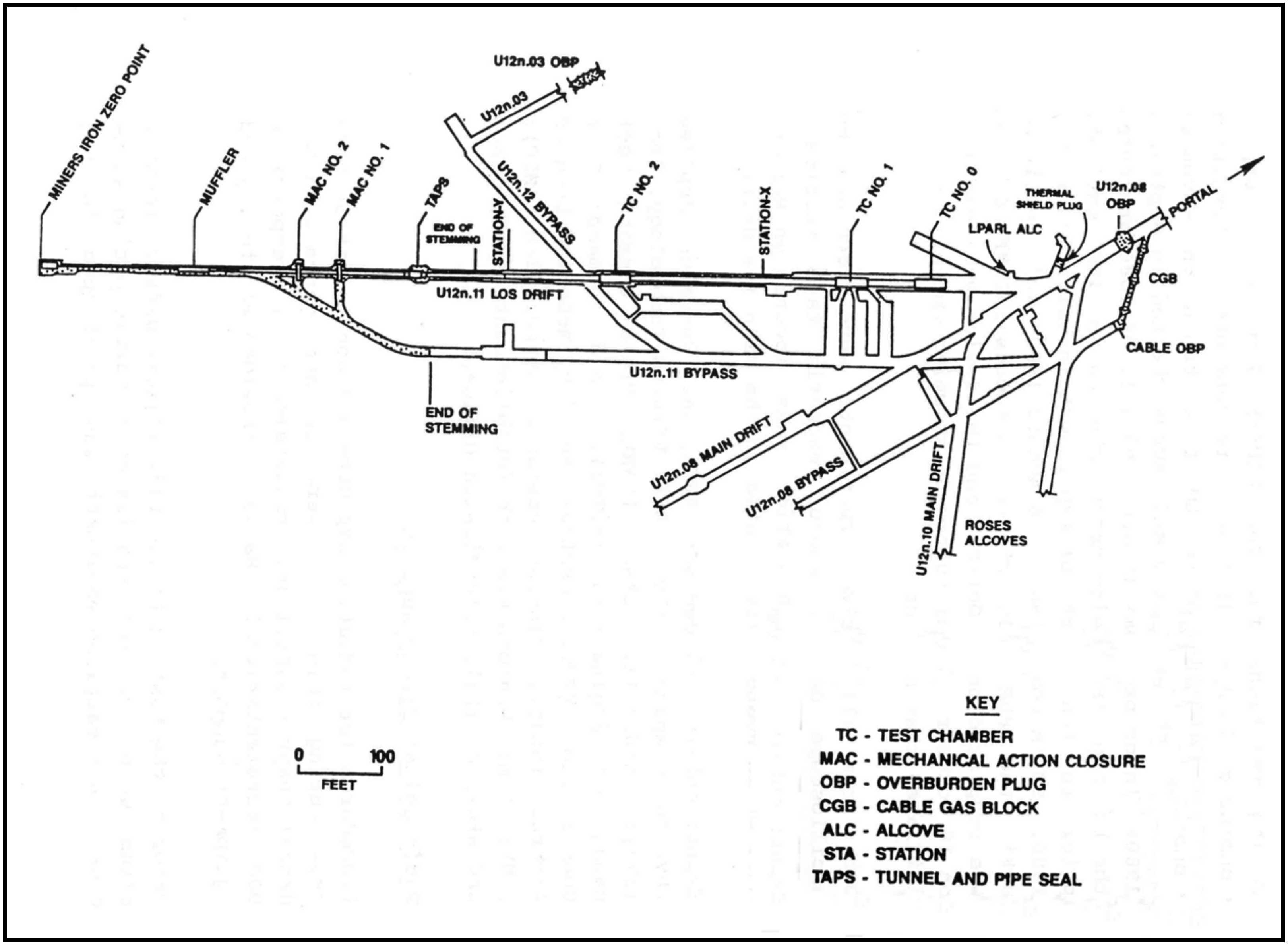
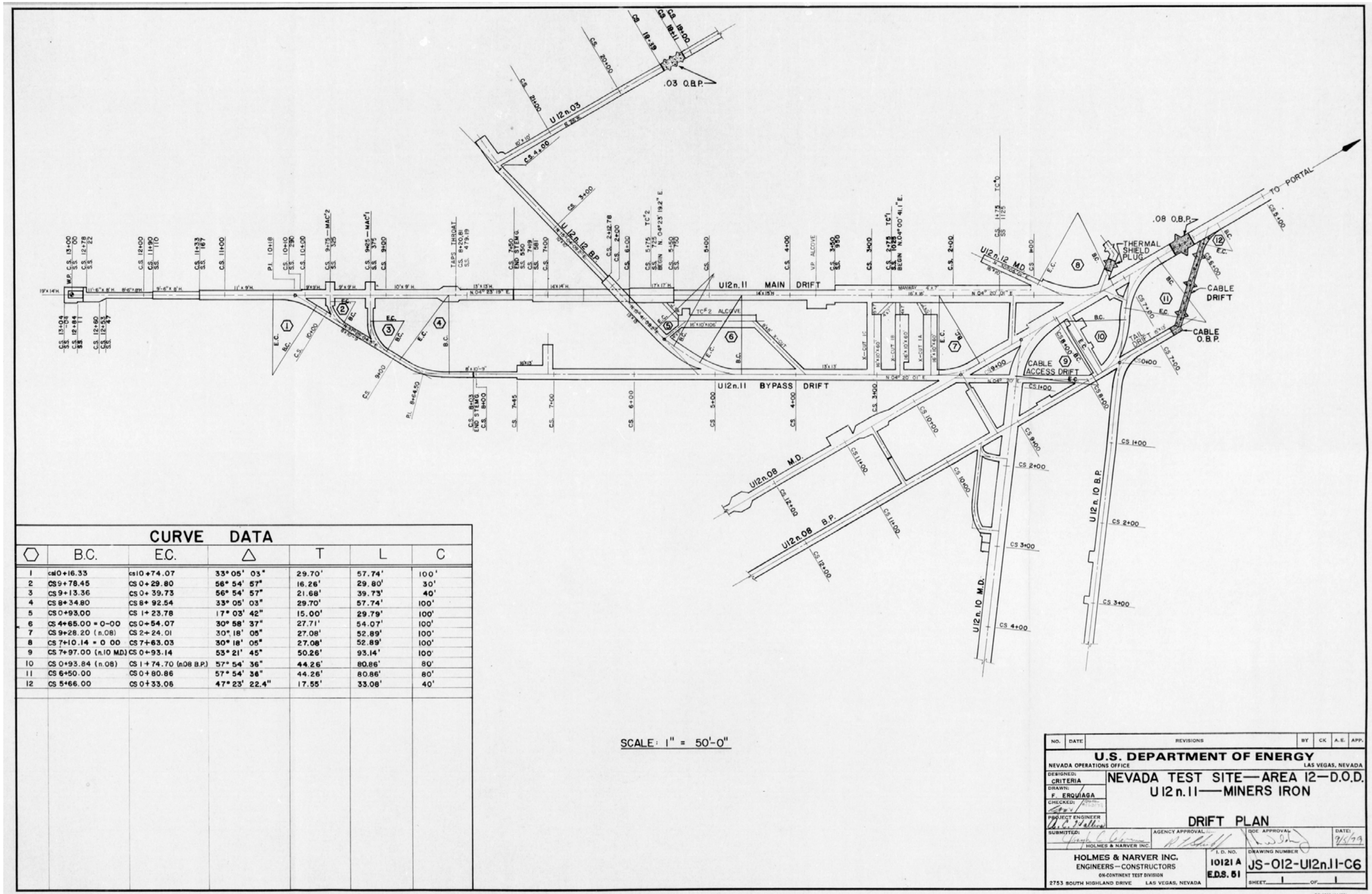


Figure 69. Plan of the U12n.11 drift for the Miners Iron test (Brady et al. 1989:197).



CURVE DATA

⬡	B.C.	E.C.	△	T	L	C
1	cs10+16.33	cs10+74.07	33° 05' 03"	29.70'	57.74'	100'
2	CS9+78.45	CS 0+29.80	56° 54' 57"	16.26'	29.80'	30'
3	CS 9+13.36	CS 0+39.73	56° 54' 57"	21.68'	39.73'	40'
4	CS 8+34.80	CS 8+92.54	33° 05' 03"	29.70'	57.74'	100'
5	CS 0+93.00	CS 1+23.78	17° 03' 42"	15.00'	29.79'	100'
6	CS 4+65.00 = 0-00	CS 0+54.07	30° 58' 37"	27.71'	54.07'	100'
7	CS 9+28.20 (n.08)	CS 2+24.01	30° 18' 05"	27.08'	52.89'	100'
8	CS 7+10.14 = 0 00	CS 7+63.03	30° 18' 05"	27.08'	52.89'	100'
9	CS 7+97.00 (n.10 M.D.)	CS 0+93.14	53° 21' 45"	50.26'	93.14'	100'
10	CS 0+93.84 (n.08)	CS 1+74.70 (n08 B.P.)	57° 54' 36"	44.26'	80.86'	80'
11	CS 6+50.00	CS 0+80.86	57° 54' 36"	44.26'	80.86'	80'
12	CS 5+66.00	CS 0+33.06	47° 23' 22.4"	17.55'	33.08'	40'

Figure 70. Construction plan of the U12n.11 drift for the Miners Iron test, 1979 (drawing JS-012-U12n.11-C6, on file at Archives and Records Center, Mercury, Nevada).

procedure reduced mining costs and made it easier to pressurize and test the closure keyways later because of the absence of blasting fractures in the surrounding rock. Two short crosscuts were mined between the bypass drift and the modified auxiliary closures in the line-of-sight drift. The metal A-box at the end of the line-of-sight drift was constructed in sections because of the small size of the line-of-sight drift at this point and the lack of a bypass drift to the working point. The A-box measured 9 ft (2.7 m) wide and high and 19 ft (5.8 m) long.

Three experimenter's alcoves were mined between the line-of-sight and bypass drifts at the portal end of the U12n.11 drift complex and opposite the first test chamber (Hollins 1981:2). They measured 60 ft (18 m) long, 16 ft (4.9 m) wide, and 10 ft (3 m) high. A fourth experimenter's alcove was mined parallel and between the line-of-sight and bypass drifts and near the second test chamber. This alcove measured 106 ft (32 m) long, 16 ft wide, and 10 ft high and was connected to both drifts by crosscuts.

A 400 hp Buffalo blower was moved from the air compressor pad at the portal to the ventilation-chiller pad on top of the mesa because of changes to the internal tunnel ventilation system (Hollins 1981:9). A 400 hp Sutorbilt blower was left at the portal for ventilation during tunnel reentries. Workers dismantled the existing multipurpose building at the portal and built a new two-story structure on the same footprint. The overhead crane assembly from the old building was reused in the new building. Workers also constructed a new building in the portal area to recharge batteries for newly-purchased electric-powered locomotives. A trailer park for additional offices was added down the hill from the portal. Because of project requirements, a new data building was constructed in the Area 12 camp located about 2 miles (3.2 km) east of the tunnel. This building was used to decontaminate certain experiments recovered after the test.

On the mesa, electrical power for the ventilation-chiller pad was upgraded in order to service additional equipment for the Miners Iron test (Hollins 1981:11). At the pad, the cooling system now included three 50 ton chillers, two 30 ton chillers, one cooling tower for backup, two 20 hp circulating pumps, and one 3 hp booster pump. Two 4-inch vertical pipes for circulating water connected the cooling system with a heat exchanger in the tunnel interior 1,300 ft (396 m) below (Hollins 1981:14). From the heat exchanger, cooled water moved to a storage tank and then to a pump skid that fed the underground tunnel distribution system composed of 3.5 ton, 5 ton, and 15 ton chillers in various alcoves (Hollins 1981:15). The system could circulate 350 to 400 gallons per minute and provide 200 tons of cooling. For ventilation of the U12n.11 drift complex, fresh air was drawn from the portal, through the tunnel, to the ends of the various vent line branches in the drifts, and to a common 36-inch pipe through the thermal shield plug on the working point side of the U12n.08 overburden plug. Two Buffalo blowers at the mesa pad then drew the air approximately 1,300 ft (396 m) up a 30-inch vertical pipe to the surface. Tunnel air on the portal side of the U12n.08 overburden plug ventilated through a common vent line to the portal.

Stemming of the U12n.11 drift took place in two stages. The first stage, pre-stemming, included 560 ft (171m) of the line-of-sight drift, leaving a 290 ft long cartway on the left side from the bypass intersection to the working point for device delivery, the bypass drift invert, and the zero room invert. After placement of the device, the second stage, button-up stemming, included the cartway in the line-of-sight drift, the crosscuts for the modified auxiliary closures, and the bypass drift.

On October 15, 1980 the mandatory full participation dry run proved successful and the nuclear device was emplaced the next day. (Brady et al. 1989:198). In the early morning of October 31, just after midnight, all excess personnel exited the tunnel area, leaving only the arming party, the final button-up team, the microwave timing party, and security to complete the final tasks before detonation. The Miners Iron nuclear device was detonated at 10:00 in the morning on October 31, 1980 (Brady et al. 1989:205). The cavity collapsed 1 hour and 46 minutes later (Townsend et al. 2007).

Except for two units in the line-of-sight drift, all remote area monitoring system units read background radiation levels immediately after detonation (Brady et al. 1989:205). The two units in the line-of-sight drift read in excess of 500 R/h just after detonation, but decreased to the low single digits by late evening. When all the units were secured on November 3, these two units were reading 11 and 9 mR/h, respectively.

Initial reentry teams were dispatched to the mesa and portal areas about an hour after detonation and completed their surveys within an hour. No radiation levels above background were detected. Remote gas sampling taken within the tunnel detected no above background radiation levels or toxic and explosive gases on the working point side of the overburden plug. Elevated levels of radiation and toxic and explosive gases were detected in the two test chambers closest to the working point. Workers disconnected cables at the cable splice shack on the mesa. In the evening, agency personnel conducted data recovery on the mesa and at the portal.

The next day, or D+1, the tunnel reentry personnel arrived at the portal and the reentry teams began donning their personal protective equipment, the work team lined up the equipment that would be used underground, the industrial hygiene and radsafe technicians set up their equipment and provided support. The reentry control team reviewed air quality conditions on the working point side of the gas seal door, hasty plug, U12n.08 overburden plug, and the Miners Iron line-of-sight drift. Remote area monitoring system units readings at the gas seal door and hasty plug were normal. Radiation levels at all other locations were elevated. This information was compared to similar readings from the remote area monitoring system monitor room at control point. Tunnel reentry began after a review of the data, a weather briefing, and receiving permission required from the DOE test controller to proceed. Following a health and safety briefing, the first reentry team went underground to the portal side of the gas seal door. They collected air quality measurements from the working point side of the plug and with the reentry controller's permission, opened the small man door and found some water on the working point side. The first team went through the opening and walked to the portal side of the hasty plug. After collecting air quality measurements on the working point side and getting permission to proceed, the team opened the tube turn doors on the vent tube and crawl tube, established ventilation through the plug, and crawled through. While the first reentry team was on their way to the hasty plug, a work team proceeded to the gas seal door. At the gas seal door, they opened the large trainway door, reinstalled the rail, and started pumping the water into the tunnel drain line. The work team then returned to the portal as the first reentry team made its way to the portal side of the U12n.08 overburden plug where they took air quality measurements on the working point side and transmitted them to the reentry controller at the portal. They also noted some damage to the tunnel on the way to the overburden plug. After verifying air quality on the working point side of the plug and getting permission to proceed, the team opened the tube turn doors on the vent tube and crawl tube, established ventilation through the plug, and crawled through. They then proceeded to the line-of-sight drift, and noted damage in all areas. An elevated radiation level was found at the second test chamber, but ventilation could not be established because of damage to the vent line (Brady et al. 1989:207).

The next day, or D+2, remote gas sampling revealed elevated levels of radiation and toxic and explosive gases in the line-of-sight pipe. The reentry team returned to the line-of-sight drift to repair the vent line at the second test chamber. The mesa blower was then switched on to establish ventilation to the mesa. In the ROSES area, the U12n.10 line-of-sight drift, the team established ventilation and noted some damage, with all the ROSES units found to be tilted. Data recovery teams entered the tunnel in the early afternoon on D+2 for initial recovery efforts in the ROSES and stub pipe areas of the drift (Brady et al. 1989:208).

On November 3, or D+3, remote gas sampling at the portal within test chamber 1 of the line-of-sight pipe indicated a normal background radiation level, but detected the presence of toxic and explosive gases. Elevated radiation levels were detected between the second test chamber and the tunnel-and-pipe-seal closure. Workers installed ventilation flex lines to the test chamber and tunnel-and-pipe-seal to ventilate the gases. A scientific assessment team then visited the three test chambers and found elevated radiation levels at all three (Brady et al. 1989:209). Removal of the hasty plug and overburden plugs began on swing shift that evening. On November 4, or D+4, data recovery commenced at the test chambers. Workers bagged and removed the experiments as contaminated material. Recovery of the experiments was continuous through November 21, 1980, D+21, with some equipment and experiments removed later.

On December 9, 1980, workers drilled a hole to the working point side of the tunnel-and-pipe-seal, installed a valve in the hole, and attached a line for ventilation (Brady et al. 1989:210). After ventilating the working point side of the tunnel-and-pipe-seal for a week, They opened the tunnel-and-pipe-seal door on December 16 after radiation levels and toxic and explosive gases had subsided. A piece of cable was discovered lodged in the tunnel-and-pipe-seal door preventing it from sealing completely (Duff 1984:38). Reentry operations then progressed up the line-of-sight pipe to the first modified auxiliary closure. Although the doors of the modified auxiliary closure had closed properly, leakage apparently occurred from a crack in the door and from a small hole drilled in the door before the test (Duff 1984:39). Modified auxiliary closure 1 was not visited again until January 13, 1981 when workers started drilling holes to the working point side to ventilate the line-of-sight pipe behind it. At this time, workers also began removing portions of the line-of-sight pipe and the shield wall near the first test chamber. Purging of the air behind modified auxiliary closure 1 through the tunnel ventilation system was conducted on January 21 (Brady et al. 1989:211). On January 23, workers washed down the inside of the line-of-sight pipe around the second test chamber to remove contamination in order to dismantle and remove the pipe. Removal of the pipe to the modified auxiliary closure 1 continued until June 1981. Investigations involving the two modified auxiliary closures and the space between them were carried out intermittently into 1982. Milling of a hole through each modified auxiliary closure began in early August 1981. At modified auxiliary closure 1, workers milled a 60 cm (24 inches) diameter hole through the two overlapping 30 cm (12 inches) thick doors of the closure (Duff 1984:39). Modified auxiliary closure 2 was found to be in good shape except for a small hole eroded through bottom of the door. Workers also milled a 60 cm diameter hole through the two overlapping doors of modified auxiliary closure 2 (Duff 1984:46). In

1981, drillers cored a single hole from the U12n.15 bypass drift toward the U12n.11 working point to characterize the chimney (Townsend et al. 2007).

U12n.12 Drift - Mini Jade

The Mini Jade nuclear test was executed in an underground cavity on May 26, 1983 in the U12n.12 drift complex at a vertical depth of 1,243 ft (379 m) below the surface (Stinson et al. 1993:91). It was the thirteenth nuclear test in the tunnel. LANL supplied the nuclear device and the yield was less than 20 kilotons (DOE/NV 2000).

The location of the U12n.12 drift was in the northern part of the tunnel and between the U12n.03 and U12n.11 drifts. Mining of the U12n.12 drift began in October 1982 (Bennett 1991; Toole 1983:9), and started to the right off the U12n.11 line-of-sight drift (Figures 71-72). The relatively short U12n.12 drift did not have a line-of-sight pipe and consisted primarily of a main access drift and a hemispherical cavity (Stinson et al. 1993:91). The hemispherical cavity measured 36 ft (11 m) in radius and was mined from the top down with an AM-50 Alpine mining machine. Rockbolts of 16 ft (4.9 m), 20 ft (6.1 m), and 24 ft (7.3 m) lengths, woven wire mesh, and shotcrete 3 inches (7.6 cm) thick supported the ceiling. Miners also constructed a side drift off to the right of the main drift, a cable subdrift from the U12n.11 main drift underneath the hemispherical cavity, and a drill alcove from the U12n.11 main drift toward the cavity. The miners finished this work in December 1982.

The U12n.12 main access drift measured 397 ft (121 m) in length, 16 ft (4.9 m) wide and 10 ft (3 m) high at the start, and then decreased to 10 ft wide and high about halfway where a ramp to the cavity started. The ramp was originally at an upward angle to support mining of the upper portion of the cavity. As the cavity was excavated downward, so was the ramp to allow removal of muck from the cavity excavation. The side drift measured 153 ft (47 m) long and 8.5 ft (2.6 m) wide and high and was mined at an upward angle. The cable subdrift measured 224 ft (68 m) long, 10 ft wide, and 9 ft (2.7 m) high and extended at a downward angle toward and under the cavity where the back, or roof, of the subdrift was 36 ft (11 m) below the invert, or floor, of the cavity. The drill alcove measured 58 ft (17.7 m) long, 10 ft wide and high, and flared out at the end. Two 4 ft (1.2 m) wide and 7 ft (2.1 m) high dogruns or walkways connected the U12n.12 main access drift with the U12n.11 main drift. Alcoves already in place between the U12n.11 main and bypass drifts served as the experimenter alcoves for recording the test, with fiber optic links to the portal recording station, and then by microwave signal to the recording stations at control point (Toole 1983:51). A new microwave system was also used, with five microwave dishes located behind the portal recording station relaying signals back and forth from the control point by way of a passive reflector located on top of the mesa. The U12n.10 main drift contained the ROSES units.

In January 1983, miners started removing the invert or floor of the hemispherical cavity. First, they excavated the invert 3.3 ft (1 m) below what would become the finished elevation to provide sufficient depth for gauges, other instruments, and cables to be captured in grout below the nuclear device (Stinson et al. 1993:93; Toole 1983:15). When the test bed was ready, only the tip or active portion of each gauge or instrument was exposed. The rest of the gauge and all the cables were captured in grout below the final invert elevation. A dense cluster of gauges and instruments were positioned directly below the working point (Toole 1983:25). A 3.3 ft (1 m) diameter by 3.3 ft high fiberglass container bucket was placed on the invert in the center of the cavity. The bucket provided

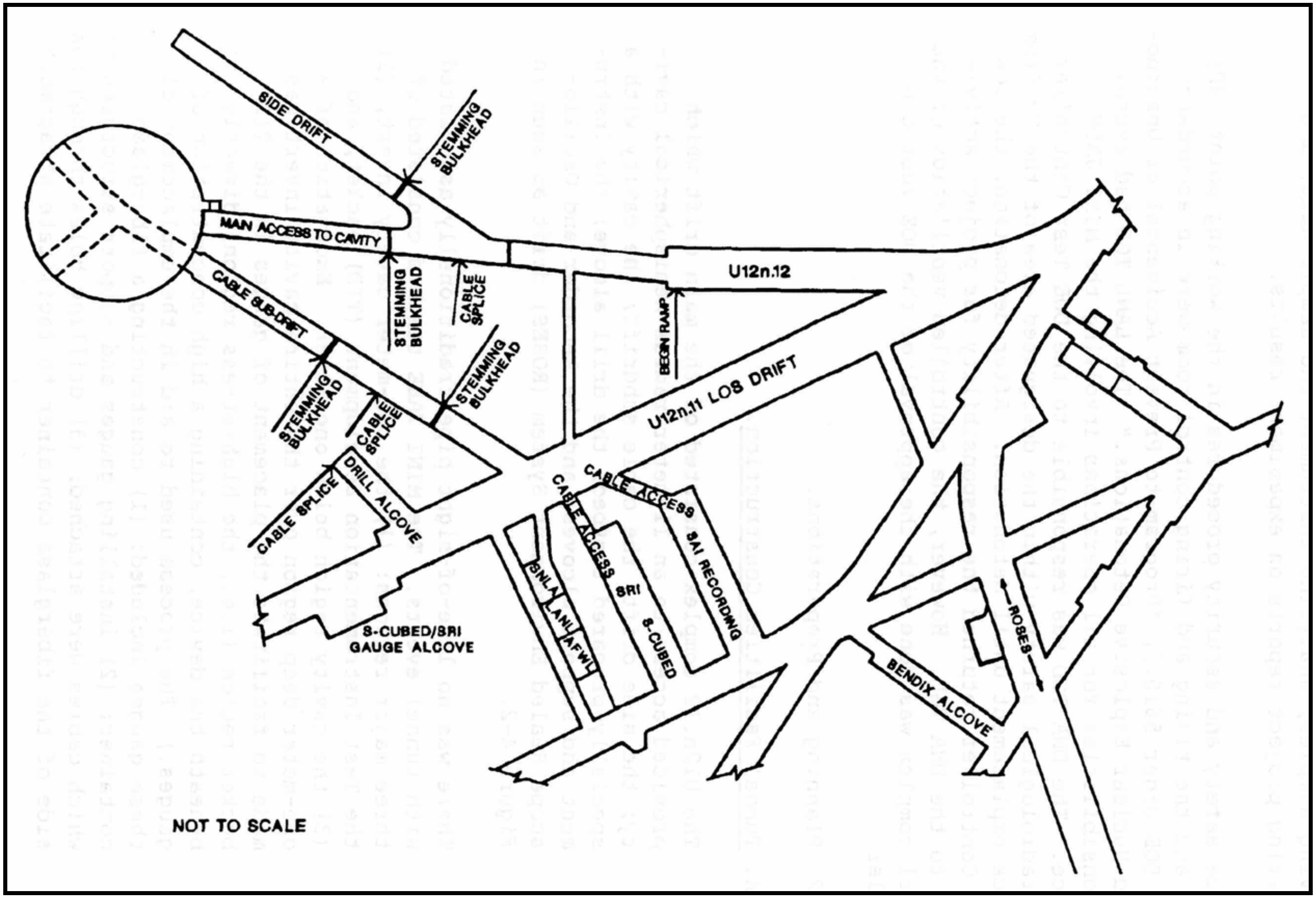


Figure 71. Plan of the U12n.12 drift for the Mini Jade test (Stinson et al. 1993:94).

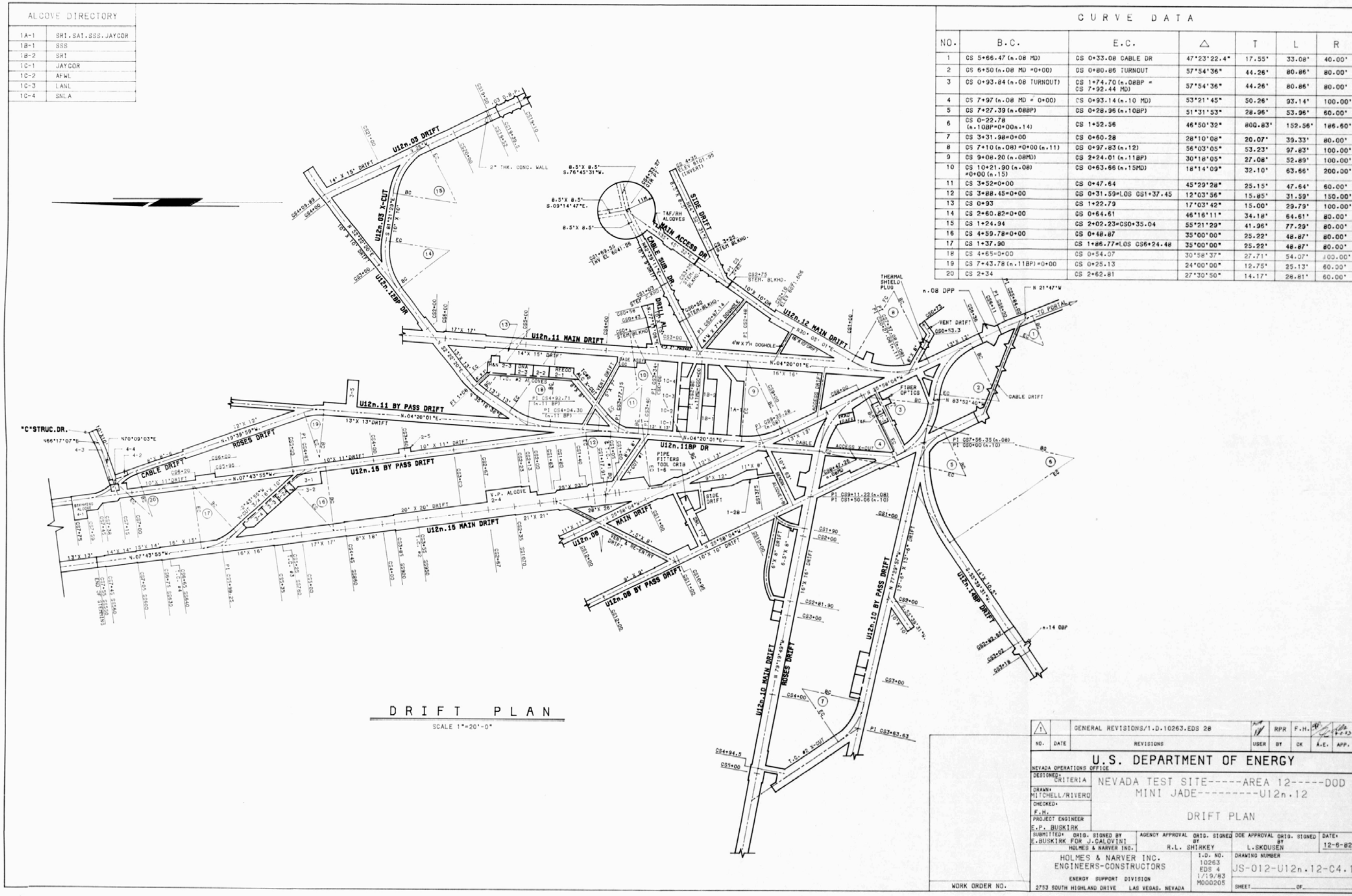


Figure 72. Construction plan of the U12n.12 drift for the Mini Jade test, 1982 (drawing JS-012-U12n.12-C4.1, on file at Archives and Records Center, Mercury, Nevada).

temporary protection of the numerous gauges and allowed cables to be attached to the gauges through small holes drilled in the side of the bucket. Finally, the bucket, used as a form, was filled with grout, sealing the critically aligned gauges and instruments in place. The fiberglass bucket was carefully removed when the grout hardened. An array of 42 additional gauges and instruments were positioned on the invert in the area surrounding the bucket. Holes were drilled through the tuff substrate invert below the cavity into the underlying cable subdrift (Stinson et al. 1993:95). Cables carrying signals from gauges and instruments in the cavity were routed down through the holes into the cable subdrift below, out the end of the cable subdrift, and across the U12n.11 line-of-sight drift to the recording alcoves. An additional 38 cable holes were drilled from the side drift into the cavity. These cable holes supported gauges that were mounted in the wall of the cavity. After placement, the gauges were grouted in the hole. A total of 20 additional holes, 4 inches (10 cm) in diameter and 129 ft (39 m) in depth, were drilled from the drill alcove to place gauges below the cavity. This work was finished by March 1983 and all the holes were pressure-grouted.

The side drift was completely pre-stemmed with grout as was most of the subdrift. The full diameter of the cavity was filled with grout 3.3 ft deep to capture the pre-grouted bucket, the array of 42 gauges and instruments surrounding the bucket, and all the cables. A 50 ft (15 m) long containment plug was placed in the U12n.12 access drift. The plug was designed with a 3 ft (91 cm) wide, 6 ft (1.8 m) high, 50 ft long steel-lined walkway through the middle to facilitate device insertion.

A new permanent plug, designed to replace the hasty plug, was constructed in the U12n main drift. The new gas seal plug was designed and constructed with a steel-lined trainway through it to facilitate efficient button-up stemming and reentry mining operations. The gas seal plug trainway was stemmed after device insertion. All experiments were installed by May 1983.

A successful mandatory full power dry run was completed May 19 and the nuclear device was delivered and installed the next day by LANL device engineers and technicians. Button-up stemming operations started soon after device insertion. Grout for the U12n.12 containment plug walkway, the U12n.08 drift protection plug trainway, formerly the overburden plug, and the U12n main drift gas seal plug trainway was placed during button-up stemming operations. Vessel II containment plugs for the Mini Jade test were the U12n.03 drift protection plug, the U12n.08 main drift protection plug, the U12n.08 cable drift protection plug, the U12n.14 bypass drift protection plug, and the U12n.08 vent drift thermal shield plug. Vessel III containment included the U12n main drift gas seal plug and the runaround gas seal plug.

In the early morning of May 26, 1983, all excess personnel had left the test area and permission was granted to arm the device for the Mini Jade test (Stinson et al. 1993:104). The button-up team, including the device engineers and security personnel, completed their work by 6:15 and by 6:30 all personnel had left the area. The Mini Jade device was detonated at 7:30 in the morning. The hemispherical cavity did not collapse and a chimney did not form. Radiation readings at the remote area monitoring system monitor room at the control point began immediately after detonation and all the units read background radiation levels (Stinson et al. 1993:105). Shortly thereafter, however, all the units on the working point side of the U12n.08 drift protection plug began to read high levels of radiation. By May 31, or D+5, all but two of the units closest to the working point read background radiation levels. These two units were approaching safe levels as well.

Reentry teams began their initial surveys of the portal and mesa about an hour after detonation. No elevated radiation levels were detected. Tunnel reentry began May 27, or D+1, by getting the latest radiation readings from the remote area monitoring system monitor room at control point, the weather forecast, and permission to reenter the tunnel from the DOE test controller. Reentry personnel arrived at the portal and the reentry teams donned their personal protective equipment, the work team lined up the equipment that would be used underground, and the industrial hygiene and radsafe technicians set up their equipment and otherwise helped get the reentry teams ready. The reentry control team reviewed air quality conditions on the working point side of the gas seal door, the gas seal plug, the U12n.08 drift protection plug, and the Mini Jade drifts. Readings at the gas seal door and gas seal plug were normal. Radiation levels on the working point side of the U12n.08 drift protection plug were elevated. Following a health and safety briefing, the first reentry team went underground to the portal side of the gas seal door. They collected air quality measurements from the working point side of the plug and with the reentry controller's permission, opened the man door. The team went through the opening and proceeded to the portal side of the gas seal plug. After collecting air quality measurements on the working point side and getting permission to proceed, the team opened the tube turn doors on the vent tube and crawl tube, established ventilation through the plug, and crawled through. While the first reentry team was on their way to the gas seal plug, a work team proceeded to the gas seal door where they opened the large trainway door and reinstalled the rail line. The work team then returned to the portal as the first reentry team made its way to the U12n.08 overburden plug where they took air quality measurements on the working point side of the U12n.08 drift protection plug and elevated levels of radiation and toxic and explosive gasses were confirmed. The tunnel was secured until May 31, or D+5, when reentry operations resumed. With permission from the DOE test controller, the reentry team proceeded to the U12n.08 drift protection plug again. Readings were taken and data relayed to the reentry controller at the portal. After receiving permission to proceed, the team opened the containment doors on the vent tube and crawl tube, established ventilation through the plug, and crawled through. They then proceeded to the thermal shield plug at the bottom of the U12n.08 vent hole. Ventilation was established in the test area working point side of the U12n.08 drift protection plug, including the Mini Jade test drift and to the mesa (Stinson et al. 1993:107). The reentry teams completed their work by early afternoon and the scientific and data recovery teams began about an hour later. They also completed their work on this day.

Reentry mining through the gas seal plug trainway started on May 31, 1983 and finished on June 1. Reentry mining through the U12n.08 drift protection plug trainway and rehabilitation of the U12n.12 main and subdrifts was completed by June 3. All work areas on the working point side of the U12n.08 drift protection plug, including drifts adjacent to the U12n.12 drift, were sprayed with a sodium silicate sealant to control the resuspension of contaminated material. The working point and drift areas of the upcoming Tomme/Midnight Zephyr test also had to be cleaned and sprayed. Reentry mining for the U12n.12 drift stopped temporarily in mid June to focus on the Tomme/Midnight Zephyr test under construction in the U12n.18 drift.

Reentry mining resumed in the U12n.12 drift on October 15, 1983, three weeks after the Tomme/Midnight Zephyr test. The objective was to remove the stemming material from the U12n.08 drift protection plug trainway and bulkheads in the cable subdrift and the drill alcove. High radiation levels and toxic and explosive gases were detected in the pre-mining drill holes. A reentry hole was drilled from the right rib of the U12n.11 line-of-sight drift into the U12n.12 cavity to ventilate and release the gases contained there so work could continue (Stinson et al. 1993:108). The drill hole also allowed probing of the crater created in the floor of the cavity. A small opening was finally made through the last bulkhead of the drift protection plug walkway into the cavity on November 28. An air sample taken from inside the cavity revealed a high radiation level. The small hole was enlarged to 1 ft (30.5 cm) by 2 ft (61 cm) for further sampling and photography. This work continued until December 13, 1983. No post test drilling was conducted from the mesa into the cavity.

U12n.13 Drift

Like the other tunnels at the NNSS, there was no U12n.13 drift because of miner's superstition involving the number 13.

U12n.14 Drift - Pre-Mill Yard and LLNL Rock Bolt Test

The Pre-Mill Yard test at the NNSS was one of nine high explosive tests conducted for the Mill Yard nuclear test (Hendrickson 1986:5-6). The other eight Pre-Mill Yard high explosive tests were conducted at the Yuma, Arizona test site. Overall objectives of the tests were to evaluate gauge support systems, soil compaction methods, and cable routing schemes for the Mill Yard nuclear test (Hendrickson 1986:74). Objectives of the Pre-Mill Yard test at the NNSS were to evaluate the effects of reconstituted soil and the effects of cavity back pressure on a forming crater. In addition, during the test at the NNSS, the initial design of a self-sealing plug was tested.

The Pre-Mill Yard test, the second high explosive test in U12n Tunnel, was conducted in a hemispherical cavity mined at the end of a drift originating from an existing drill alcove (Figures 73-75). The alcove was mined in a southwest direction off the left rib of the U12n.10 bypass drift and was 12 ft (3.6 m) wide by 10 ft (3.0 m) high and 43 ft (13.1 m) long. An exploratory drill hole to support the planned U12n. 14 test drift, starting at the end of the alcove, was 3 inches (7.6 cm) in diameter (7.6 cm) and 2,094 ft (638 m) long. The U12n.14 test drift was not mined, however, as its working point would have interfered with the location of the proposed U12n extension drift. The Pre-Mill Yard drift turned 20 degrees to the right at 33.19 ft into the drill alcove and was 9 ft (2.7 m) wide and high and 34.81 ft (10.6 m) long. A 9 ft (2.7 m) radius hemispherical cavity was mined at the end of the Pre-Mill Yard drift. The test bed consisted of a 14 ft (4.3 m) diameter depression in the cavity floor 6.5 ft (2 m) in depth and filled with sand from Yuma, Arizona. The explosive for the Pre-Mill Yard test consisted of 300 pounds (134 kilograms) of nitromethane (Heuze et al. 1993:2). The test was successfully conducted on October 27, 1984 (Hendrickson 1986:74). Both the cavity and the self-sealing plug maintained pressure until venting began two days after detonation.

LLNL fielded an add-on rock bolt experiment that was designed to look at the explosive detonation produced in the Pre-Mill Yard cavity. The experiment was located in a small alcove off the left rib of the U12n.10 bypass drift and oriented in a southeast direction toward the Pre-Mill Yard working point. The alcove was trapezium in form. Its left side was 10.5 ft (3.2 m) long and the right side was 15 ft (4.6 m) long. The flat face of the alcove was 13 ft (4.0 m) wide and perpendicular to the alcove center line. The alcove face was 29.33 ft (8.9 m) from the working point. The configuration of the experiment consisted of a series of rock bolts drilled into the face of the alcove and pointed toward the Pre-Mill Yard cavity. Each bolt had different diameters, lengths, and anchorages.

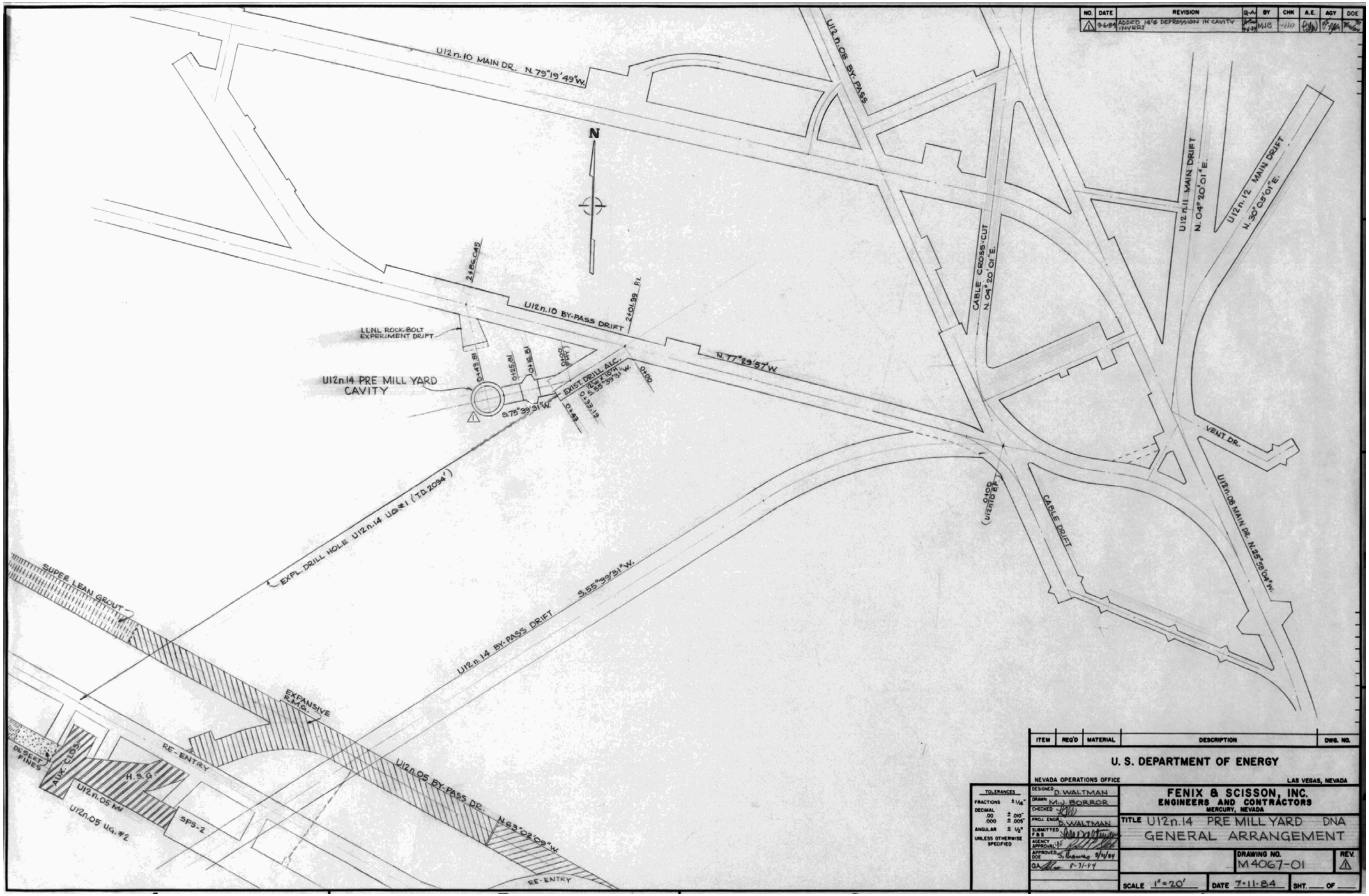


Figure 73. Plan of the Pre-Mill Yard test and the proposed U12n.14 drift, 1984 (drawing M 4067-01, on file at Archives and Records Center, Mercury).

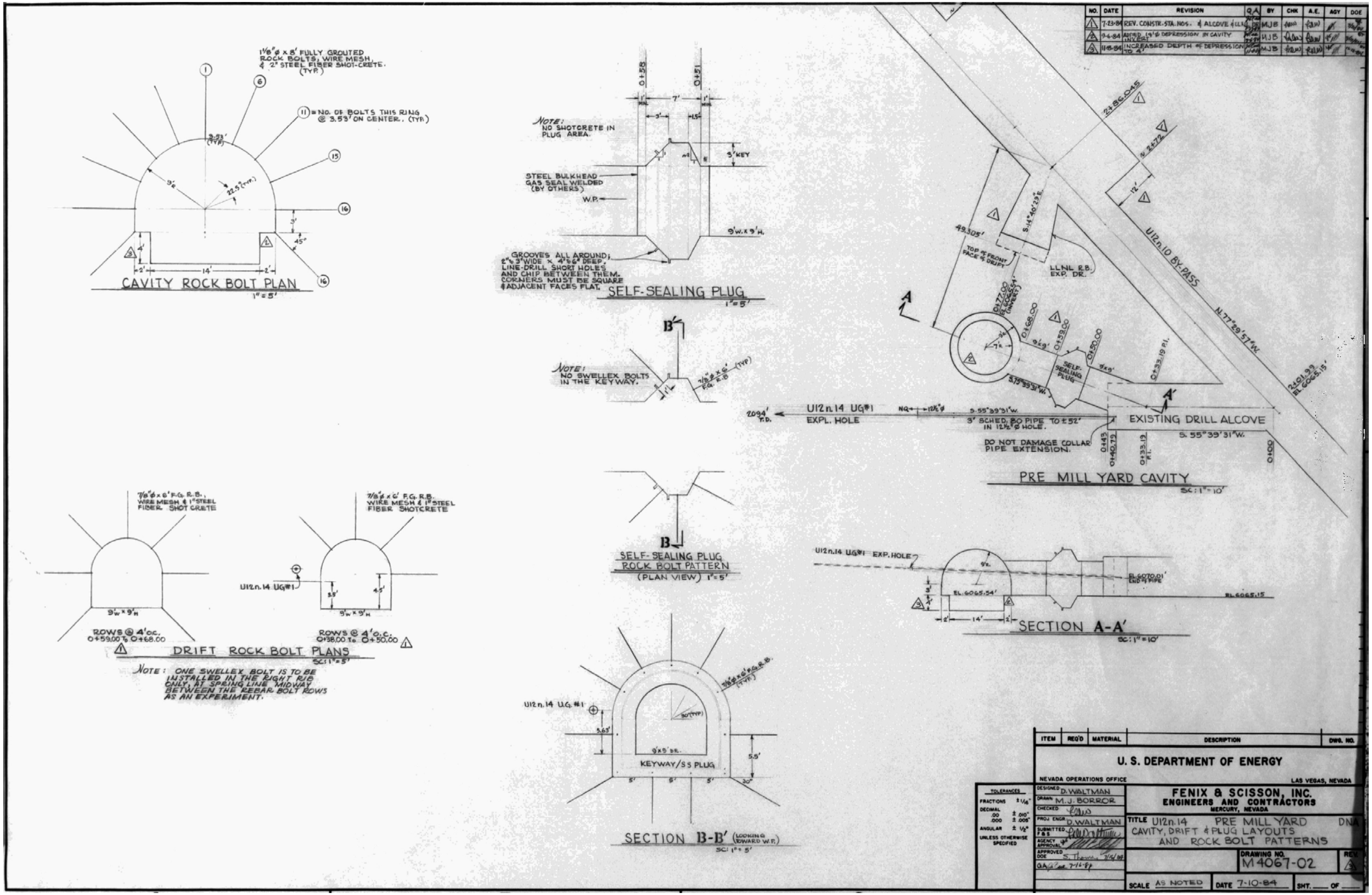


Figure 74. Plan and sections of the U12n.14 drift for the Pre-Mill Yard high explosive test, 1984 (drawing M 4067-02, on file at Archives and Records Center, Mercury).

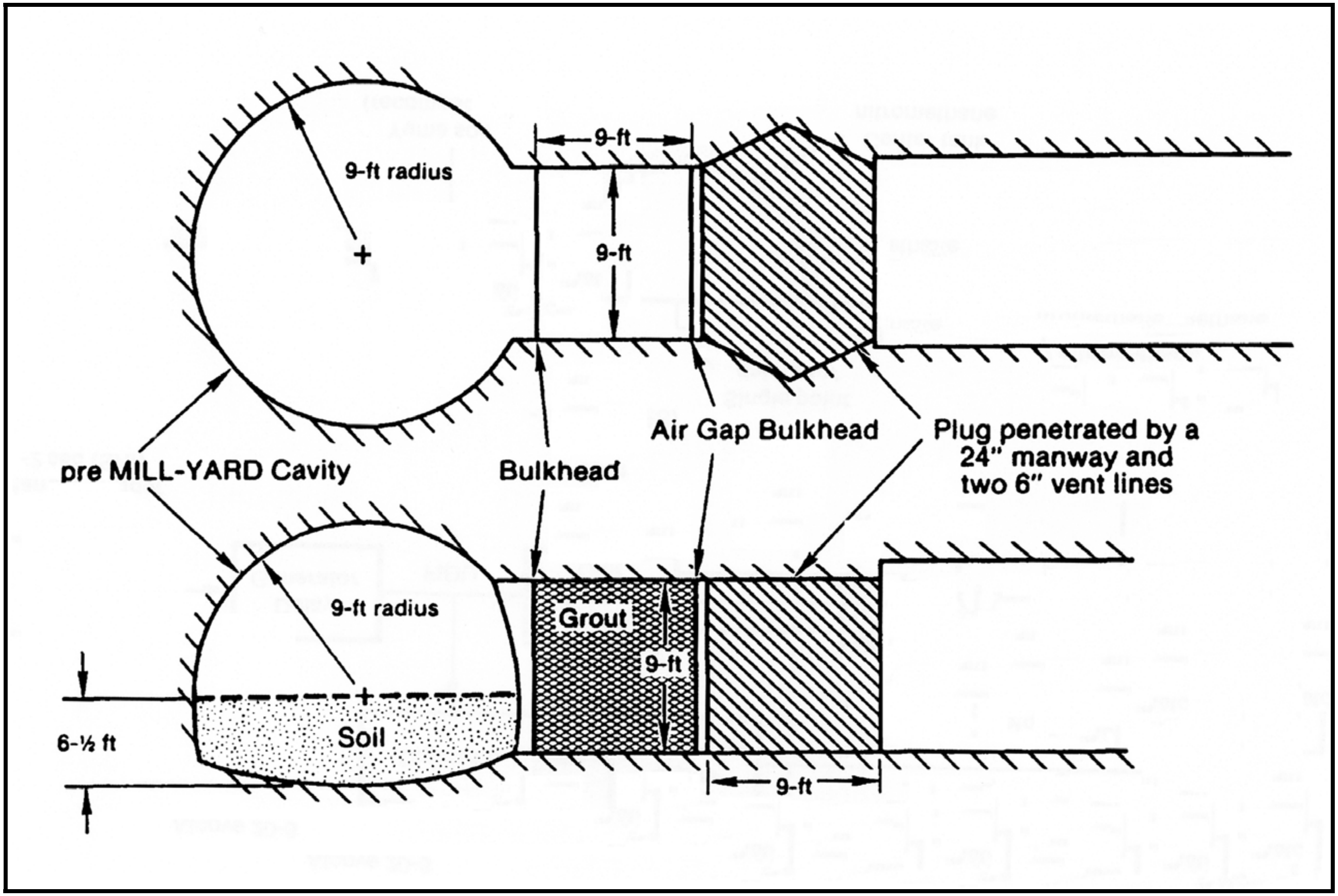


Figure 75. Plan and profile of the Pre-Mill Yard high explosive test in the U12n.14 drift (Hendrickson 1986:7).

U12n.15 and U12n.15a Drifts - Huron Landing and Diamond Ace

The Huron Landing and the Diamond Ace nuclear devices, located 40 ft (12 m) apart in the U12n.15 and U12n.15a drifts, respectively, were detonated within two microseconds of one another on September 23, 1982 (Stinson et al. 1993:69, 82). The Diamond Ace test was a late time add on to the Huron Landing test. This was the first time two nuclear devices were detonated at the same time in the same drift complex. Although the results were inconclusive, the double detonations were an attempt to differentiate seismic signals between them. Each test was less than 20 kilotons in yield (DOE/NV 2000). Vertical depth of the Huron Landing device was 1,339 ft (408 m) below the surface, while the Diamond Ace device was at 1,335 ft (407 m) below the surface. LANL provided the device for the Huron Landing test (Stinson et al. 1993:69). LLNL provided the device for the Diamond Ace test that also had objectives of nuclear source development and to evaluate the concept and design of a low-yield test bed.

The U12n.15 drift complex started in a northerly direction from the junction of the U12n.08 and U12n.11 drifts (Figures 76-77). Mining of the U12n.15 drift complex began in February 1981. The U12n.15 complex consisted of two line-of-sight drifts, one for each test, two zero rooms, the Huron Landing bypass drift, four crosscuts between the bypass drift and the Huron Landing line-of-sight drift, two crosscuts between the Huron Landing bypass drift and the Diamond Ace line-of-sight drift, three structures drifts to the right of the bypass drift, and one combination cable and ROSES drift between the bypass drift and the U12n.11 bypass drift. The Huron Landing line-of-sight drift, which started off the right rib of the U12n.08 line-of-sight drift, was 1,309 ft (399 m) long. At the start, the drift measured 28 ft (8.5 m) wide and 26 ft (7.9 m) high, and then incrementally decreased in size over about a 1,000 ft (305 m) span to where it began to taper to a final size of 6 ft (1.8 m) wide and 7 ft (2.1 m) high at the zero room. The working point was established 4 ft (1.2 m) from the end of the line-of-sight drift and near the rear of the zero room. The A-box consisted of a steel box fabricated by iron workers at the Area 12 camp and assembled underground (see Figure 3). It measured 19 ft (5.8 m) long and 9 ft (2.7 m) wide and high. A reaction history experiment was attached to the right side of the A-box. The U12n.15 bypass drift, started off left rib of the U12n.11 bypass drift, and paralleled the Huron Landing line-of-sight drift except at the end where it angled back to the working point. The bypass drift measured 10 ft (3 m) wide and 11 ft (3.4 m) high for most of its length and decreased to 8.5 ft (2.6 m) wide and 9 ft high toward the end. An access drift for the U12n.15a Diamond Ace line-of-sight drift was mined to the right off the bypass drift at the point where the bypass drift began to angle left and back to the working point. The Diamond Ace line-of-sight drift, only 143 ft (43.5 m) long, paralleled the angled portion of the bypass drift. Three structures drifts, approximately 95 ft (29 m) long and labeled A, B, and C, were mined at 90 degrees to the Huron Landing working point off the right rib of the bypass drift (Stinson et al. 1993:74). The structures experiments were late time add ons to the Huron Landing test with mining and construction occurring subsequent to completion of the primary U12n.15 complex drifts.

The line-of-site pipe for Huron Landing measured 1,230 ft (375 m) in length, with diameters of 8 inches (20 cm) at the working point and 19.3 ft (5.9 m) at test chamber 1 at the portal end (Stinson et al. 1993:71). The Huron Landing line-of-sight pipe was the largest ever constructed at the U12n Tunnel. The larger diameter pipe sections were too large to pass through the tunnel's main drift. Consequently, nearly half of the pipe had to be transported underground in quarter and half round sections, mated together, and then welded in a large assembly bay constructed specifically for that

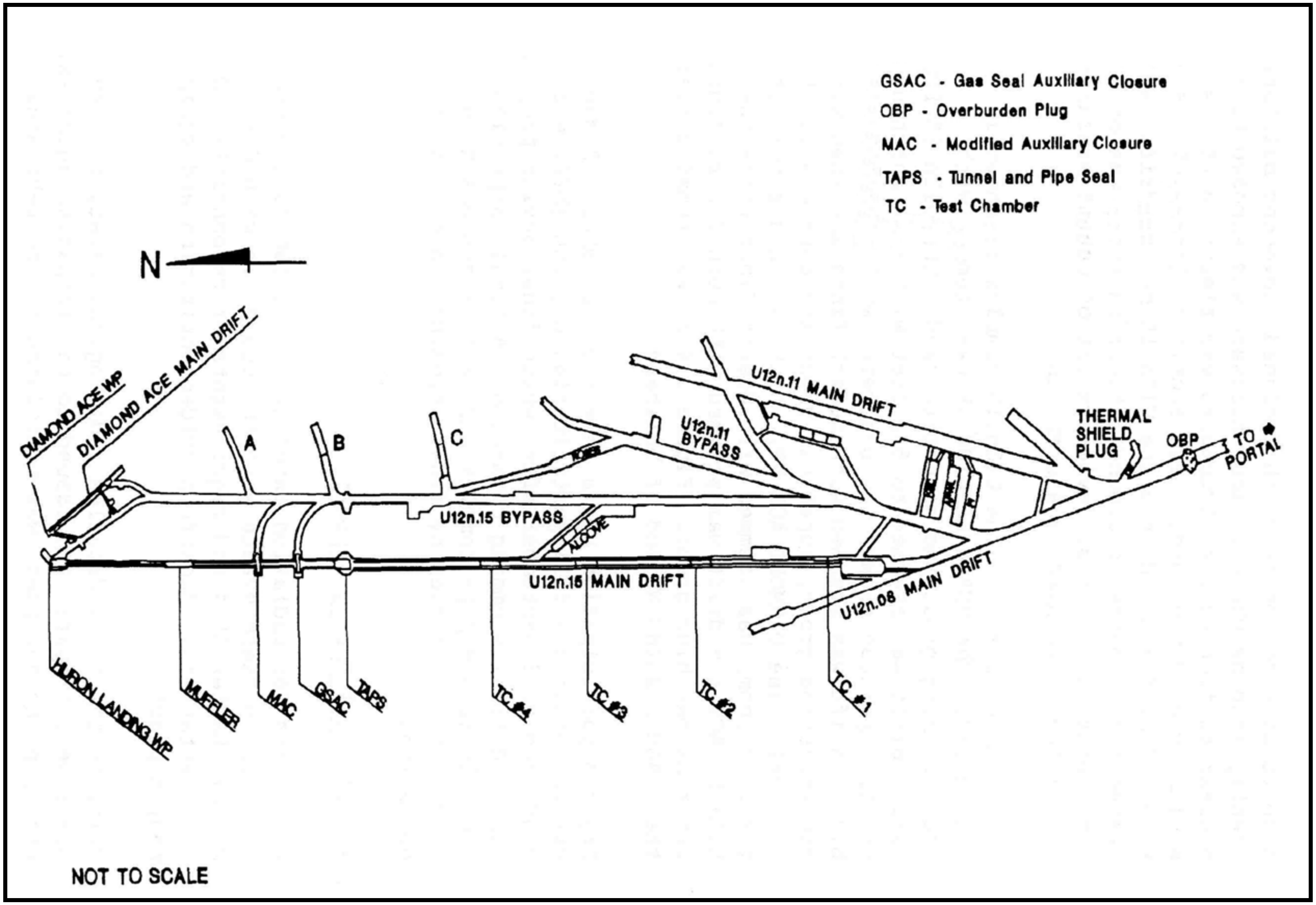


Figure 76. Plan of the U12n.15 drift for the Huron Landing and Diamond Ace tests (Stinson et al. 1993:73).

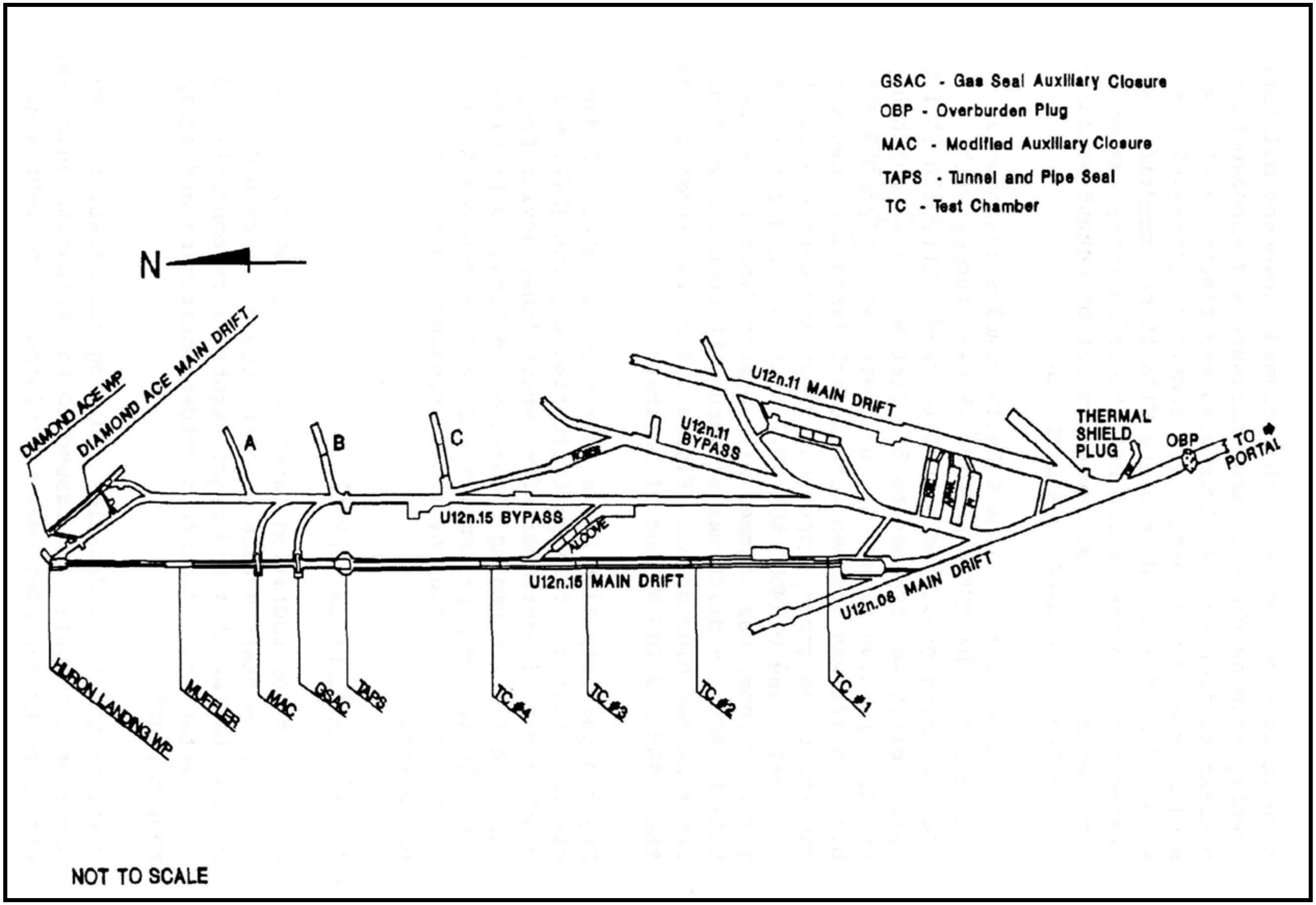
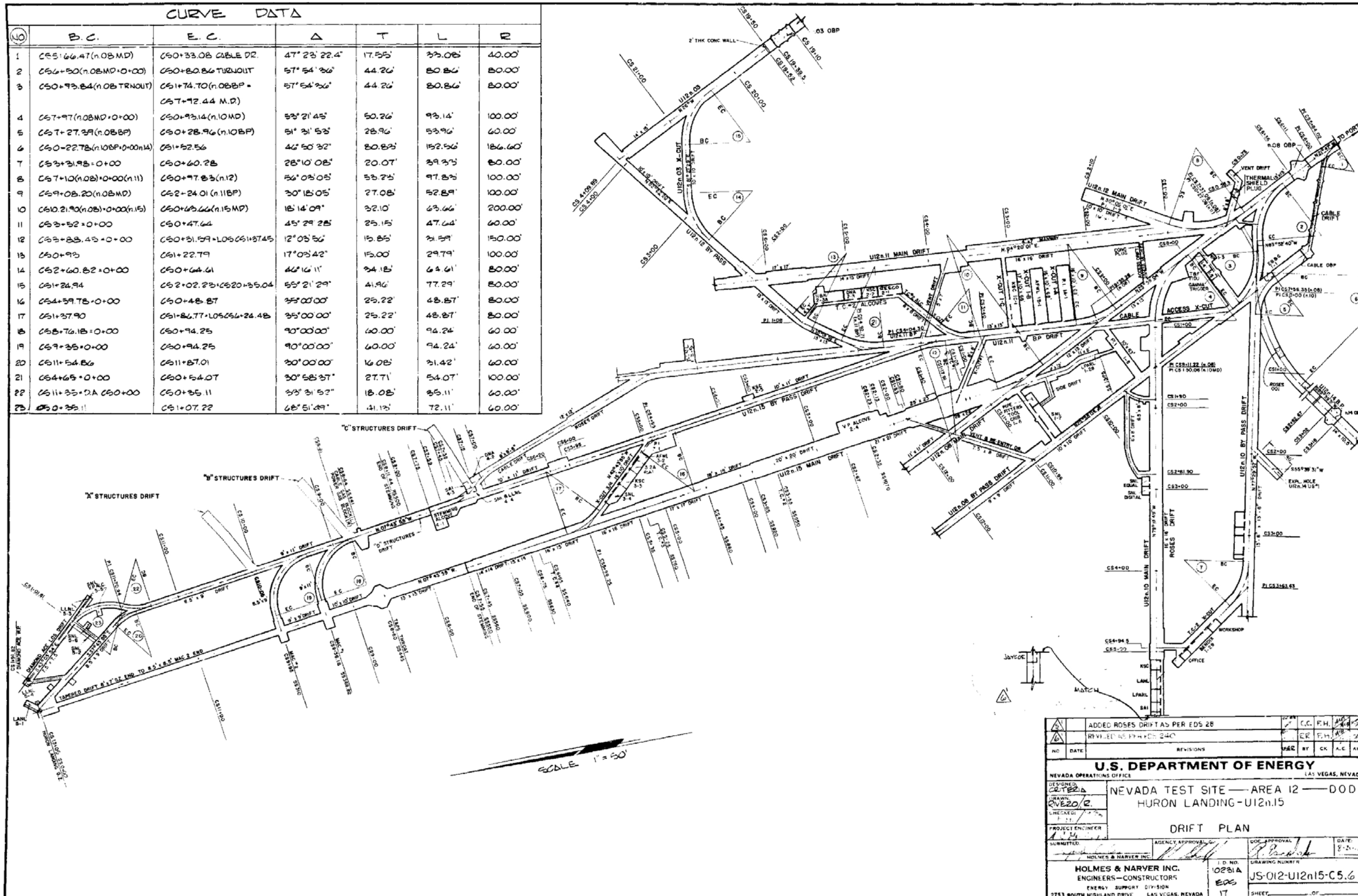


Figure 76. Plan of the U12n.15 drift for the Huron Landing and Diamond Ace tests (Stinson et al. 1993:73).



CURVE DATA

NO	B.C.	E.C.	Δ	T	L	R
1	CS5+66.47(n.08MD)	CS0+33.08 CABLE DR.	47° 23' 22.4"	17.55'	33.08'	40.00'
2	CS6+50(n.08MD=0+00)	CS0+80.86 TURNOUT	57° 54' 36"	44.26'	80.86'	80.00'
3	CS0+93.84(n.08 TRNOUT)	CS1+74.70(n.08BP = CS7+92.44 M.D.)	57° 54' 36"	44.26'	80.86'	80.00'
4	CS7+97(n.08MD=0+00)	CS0+93.14(n.10MD)	53° 21' 45"	50.26'	93.14'	100.00'
5	CS7+27.39(n.08BP)	CS0+28.96(n.10BP)	51° 31' 53"	28.96'	53.96'	60.00'
6	CS0-22.78(n.10BP=0+00n.14)	CS1+52.56	46° 50' 32"	80.83'	152.56'	186.60'
7	CS3+31.98=0+00	CS0+60.28	28° 10' 08"	20.07'	39.33'	80.00'
8	CS7+10(n.08)=0+00(n.11)	CS0+97.83(n.12)	56° 03' 05"	53.23'	97.83'	100.00'
9	CS9+08.20(n.08MD)	CS2+24.01(n.11BP)	30° 18' 05"	27.08'	52.89'	100.00'
10	CS10.21.90(n.08)=0+00(n.15)	CS0+63.66(n.15MD)	18° 14' 09"	32.10'	63.66'	200.00'
11	CS3+52=0+00	CS0+47.64	45° 29' 28"	25.15'	47.64'	60.00'
12	CS3+88.45=0+00	CS0+31.59=LOS CS1+37.45	12° 03' 56"	15.85'	31.59'	150.00'
13	CS0+93	CS1+22.79	17° 03' 42"	15.00'	29.79'	100.00'
14	CS2+60.82=0+00	CS0+64.61	46° 16' 11"	34.18'	64.61'	80.00'
15	CS1+24.94	CS2+02.23=CS20+35.04	55° 21' 29"	41.96'	77.29'	80.00'
16	CS4+59.78=0+00	CS0+48.87	35° 00' 00"	25.22'	48.87'	80.00'
17	CS1+37.90	CS1+86.77=LOS CS6+24.48	35° 00' 00"	25.22'	48.87'	80.00'
18	CS8+76.18=0+00	CS0+94.25	90° 00' 00"	60.00'	94.24'	60.00'
19	CS9+35=0+00	CS0+94.25	90° 00' 00"	60.00'	94.24'	60.00'
20	CS11+54.86	CS11+87.01	30° 00' 00"	16.08'	31.42'	60.00'
21	CS4+65=0+00	CS0+54.07	30° 58' 37"	27.71'	54.07'	100.00'
22	CS11+35=D.A CS0+00	CS0+35.11	33° 31' 53"	18.08'	35.11'	60.00'
23	CS0+35.11	CS1+07.22	68° 51' 49"	41.13'	72.11'	60.00'

Figure 77. Construction plan of the U12n.15 drift for the Huron Landing and Diamond Ace tests, 1981 (drawing JS-012-U12n.15-C5.6, on file at Archives and Records Center, Mercury, Nevada).

purpose. Workers began to install the Huron Landing pipe in October 1981 and finished in May 1982. The pipe contained a muffler, a modified auxiliary closure, a gas seal auxiliary closure, a tunnel-and-pipe-seal, bellows decoupler, and four test chambers. Test chamber 1 had seven stub pipes extending from the portal end. The vacuum pumps and the tunnel-and-pipe-seal were recovered from the Miners Iron test in the nearby U12n.11 drift. Workers installed the Diamond Ace line-of-sight pipe from March to June 1982. The Diamond Ace line-of-sight pipe measured 112 ft (34 m) long and did not contain any containment closures. Installation of the Huron Landing experiments began in April 1982 and finished in August. Stemming with grout and concrete extended out to 550 ft (168 m) for the Huron Landing line-of-sight drift and to 500 ft (152 m) with desert sands, grout, and concrete for the bypass drift (Stinson et al. 1993:74). Stemming for the Diamond Ace drift consisted of desert sands and grout for the entire length of the pipe. A void was left at the back of the zero room for the Diamond Ace test, while grout and magnetite sand filled the Huron Landing zero room.

Final preparations for the tests began at midnight on September 22 when all personnel, except those needed to arm the two devices, button-up the tunnel, and provide security, left the tunnel and forward muster areas (Stinson et al. 1993:77). Permission to arm the devices was given at 4:30 in the morning and by 8:00 button-up was completed and all personnel were out of the area and back at control point. Both nuclear devices were detonated at 9:00 on the morning of September 23, 1982.

The first reentry teams were dispatched to the portal and mesa areas at 10:45 in the morning and completed the initial surveys by 11:40 (Stinson et al. 1993:83). The teams did not detect any radiation levels above background (Stinson et al. 1993:84). Recovery of data from the portal and mesa areas then commenced and was completed by 4:30 in the afternoon. About one hour after detonation, radioactive gas seeped into containment vessel 1, between the end of stemming and the U12n.08 overburden plug (Stinson et al. 1993:69).

Reentry into the tunnel began the morning of the following day, or D+1 (Stinson et al. 1993:84). Reentry personnel arrived at the portal and the reentry teams began donning their personal protective equipment, the work team lined up the equipment that would be used underground, and the industrial hygiene and radsafe technicians set up their equipment and otherwise helped get the reentry teams ready to enter the tunnel. The reentry control team reviewed air quality conditions on the working point side of the gas seal door, the hasty plug, the U12n.08 overburden plug, and the Huron Landing drifts. Readings at the gas seal door and hasty plug were normal. Radiation levels at all other locations underground were elevated. Tunnel reentry began after a review of the data, a weather briefing, and receiving permission required from the DOE test controller to proceed. Following a health and safety briefing, the first reentry team went underground to the portal side of the gas seal door. They collected air quality measurements from the working point side of the door and with the reentry controller's permission, established ventilation to the portal side of the hasty plug, and opened the small man door and found some water on the working point side. The first team went through the opening and proceeded to the portal side of the hasty plug. After collecting air quality measurements on the working point side and getting permission to proceed, the team opened the tube turn doors on the vent tube and crawl tube, established ventilation through the plug, and crawled through. While the first reentry team was on their way to the hasty plug, a work team proceeded to the gas seal door. At the gas seal door, they opened the large trainway door, reinstalled the rail line, and started pumping the accumulated water into the tunnel drain line. The work team then returned to the portal as the first reentry team made its way to the portal side of the U12n.08 overburden plug where they took air quality measurements on the working point side and relayed them to the reentry controller at the portal. They also noted some damage to the tunnel on the way to the overburden plug. After verifying air quality on the working point side of the plug and getting permission to proceed, the team opened the tube turn doors on the vent tube and crawl tube, established ventilation through the plug, and crawled through. They then proceeded to the thermal shield plug at the bottom of the U12n.08 vent hole, opened the containment door, and reestablished the mesa ventilation system by connecting and securing the vent line slip joint. The reentry team departed the thermal shield plug and proceeded up the U12n.08 drift to the intersection with the U12n.15 line-of-sight drift. They walked the line-of-sight drift assessing damage and noting elevated levels of radiation, toxic and explosive gasses outside the line-of-sight pipe. The team inspected the flexible vent lines attached to a valve at the top of each test chamber and found them still attached. They opened the valves by climbing up the side of the test chamber on a pre-positioned ladder and pulled a rope attached to the valve handle. The team then unbolted and slightly opened the test chamber doors which allowed air to be circulated through the test chambers and out the tunnel through the ventilation system. This controlled release was approved by the DOE test controller and would last about eight hours. The first team then departed the tunnel and work for D+1 was completed.

On September 25, D+2, the reentry personnel assembled at the portal and repeated all the preparatory work required to start again. A reentry team departed the portal and proceeded to the U12n.15 bypass drift and examined the end of stemming where they found considerable damage. Slightly elevated levels of radiation were found on the equipment in the bypass drift and in the experimenter's alcoves. The team went to the line-of-sight drift where they entered test chamber 4 and then proceeded up the line-of-sight pipe to the tunnel-and-pipe-seal door. Again, the radiation levels were slightly elevated. The team then departed the line-of-sight pipe and drift and headed back to the portal. A scientific assessment team then went into the tunnel to assess the condition of experiments within the line-of-sight pipe. Experiment recovery then started along with cleanup of the drifts and removal of reusable equipment from the tunnel. Experiment recovery was completed by October 7. There was no reentry planned or associated with the Diamond Ace line-of-sight drift as it was designed to be consumed by the Huron Landing detonation. Test data and recording equipment from both the Diamond Ace and Huron Landing tests were recovered.

Post test reentry mining of the hasty plug began on September 25, or D+2, and was finished in two days. Work then started on removing the overburden plug (Stinson et al. 1993:87). Most of the overburden plug was removed by early October. Reentry, repair, and recovery operations then expanded to the test chambers, the line-of-site drift, the bypass drift, and the C structure drift. This work was finished by the end of mid October 1982. Reentry mining resumed again in late October 1982 to investigate the A and B structures drifts, the modified auxiliary closure and the gas seal auxiliary closure crosscut drifts, and intermittently in the line-of-site drift. The reentry mining reached a point just inside the Huron Landing cavity wall by the spring of 1983.

Post test drilling of five vertical holes from the mesa began on October 3, 1982 and was finished by October 7 (Bennett 1991; Stinson et al. 1993:88). The drill holes were postshots 1A, 1AA, 1AB, 1AC, and 1AD. All were in the same primary postshot 1A drill hole, but at different angles and depths. The first 11 ft (3.4 m) of the drill hole was 6 ft (1.8 m) in diameter, then decreased to a diameter of 15 inches (38 cm) to a depth of 128 ft (39 m) below surface, and then to a final diameter of 9 7/8 inches (25 cm), the remaining depth for each of the five drill holes (Bennett 1991). Postshot 1AC reached the greatest depth at 1,631 ft (497 m). Casing was put in the first 80 ft (24 m) of the drill hole. A total of 60 core samples were obtained from the first four drill holes and deemed a sufficient number of samples; no samples were needed from the fifth drill hole (Stinson et al. 1993:88). The hole was plugged with concrete from a depth of 8 ft (2.4 m) to 682 ft (208 m) below surface and an extension pipe and steel plate were added at the top. A core hole and a probe hole were also drilled from the tunnel interior into the chimney in order to characterize it (Townsend et al. 2007).

U12n.16 Drift

No test was conducted in the U12n.16 drift when it and the U12n.14 drift were determined they would impact the newly planned U12n extension drift. Instead of being developed into a test drift, the U12n.16 drift became a short passageway between the U12n.06 and U12n.17 drifts. The U12n.17 bypass drift and a users alcove were later mined off to the left of the U12n.16 drift for the Misty Rain test.

U12n.17 Drift - Misty Rain

Misty Rain was the fifteenth nuclear test in U12n Tunnel. It was conducted on April 6, 1985 in the U12n.17 drift at a vertical depth of 1,273 ft (388 m) below the surface (Stinson et al. 1993:155). LLNL supplied the nuclear device and it had a yield of less than 20 kilotons (DOE/NV 2000). The test focused on the survivability of satellites and evaluated the response of electronics in a nuclear environment (DTRA 2002:389). The Misty Rain test was the first test to use the new, larger extension drift. The 18.5 ft diameter extension drift allowed the Source-Generated Electromagnetic Pulse Test Analysis and Research Satellite (a.k.a. STARSAT) to be tested as a complete unit in the underground nuclear environment.

Mining of the U12n.17 drift started on March 7, 1983 (Bennett 1991), and finished in December 1983. The U12n.17 drift turned left off the U12n extension drift at 3014 ft (919 m) from the portal, crossed the U12n.16 drift, and coursed between the U12n.02 and U12n.06 drifts (Figures 78-79). All excavations were mined with an Alpine miner. Main components of the U12n.17 drift consisted of a line-of-sight drift, a bypass drift, two crosscuts, a zero room, experiment and instrumentation alcoves, and a vacuum pumping and monitoring station (Stinson et al. 1993:157). The working point was 4,820 ft (1,469 m) from the portal. The U12n.17 line-of-sight drift measured 1,426 ft (435 m) long and tapered from 19 ft (5.8 m) wide and high at the start to 8 ft (2.4 m) wide and high at the zero room. The zero room measured 44 ft (13.4 m) long, 18 ft (5.5 m) wide, and 16 ft (4.9 m) high. A sump pit 7ft (2.1 m) deep and 2.5 ft (76 cm) in diameter was put in the zero room for removing water to the U12n.06 drift by way of a single pipeline. No groundwater problems were encountered during construction of the drift. Installation of the line-of-sight pipe took place from February 1984 to December 1984. Closures in the pipe included a muffler, a modified auxiliary closure, a gas seal auxiliary closure, and a tunnel-and-pipe-seal. The opening in the modified auxiliary closure was 62 inches (157.5 cm) in diameter. For the gas seal auxiliary closure, the opening was 72 inches (182.9 cm) in diameter. The tunnel-and-pipe-seal closure was 36 ft (11 m) long and designed to withstand 1,000 degrees Fahrenheit and 1,000 psi gas pressure for two hours. Only one test chamber was employed for the test and seven stub pipes were attached to the portal end of the chamber. The total

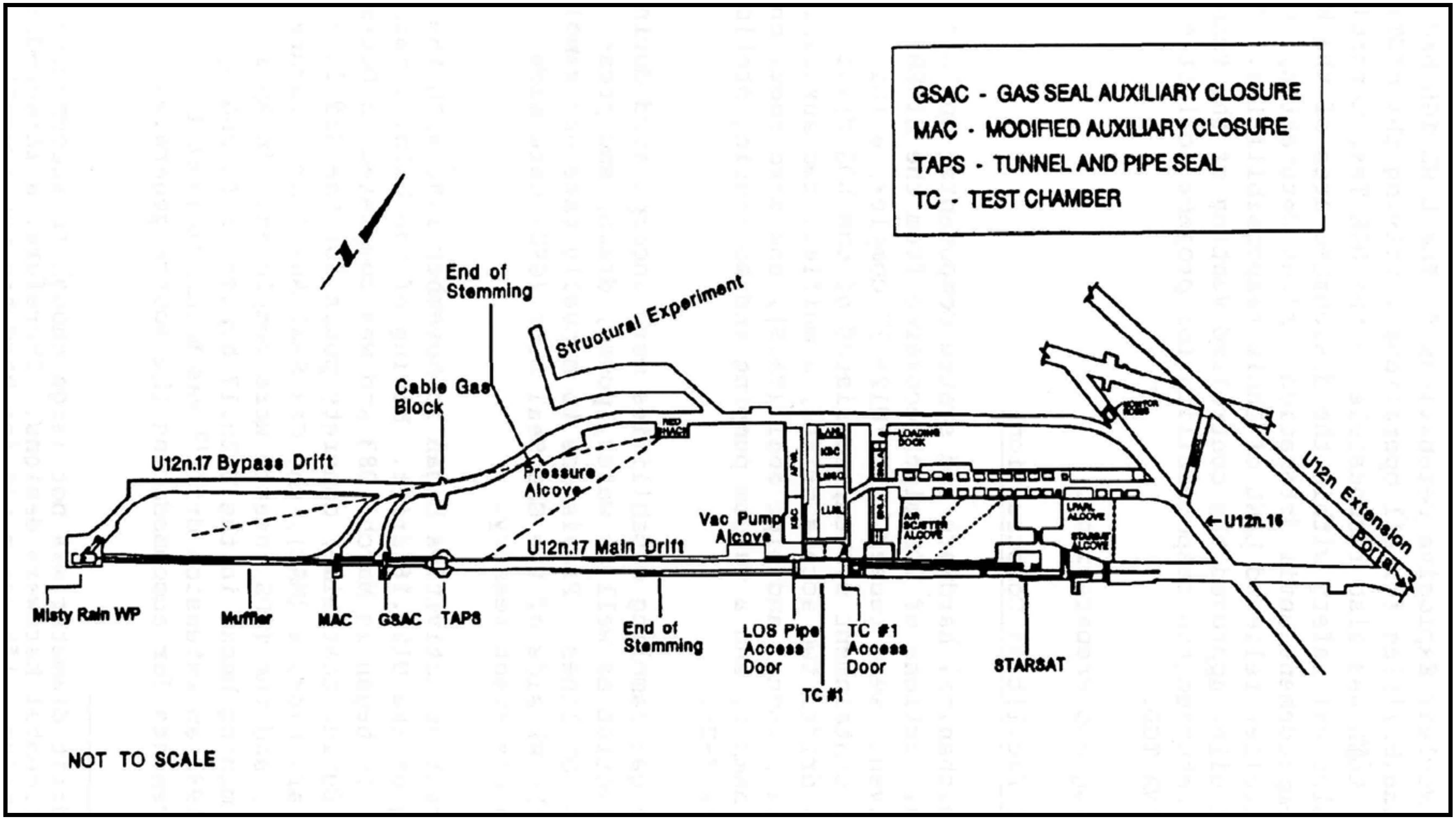


Figure 78. Plan of the U12n.17 drift for the Misty Rain test (Stinson et al. 1993:158).

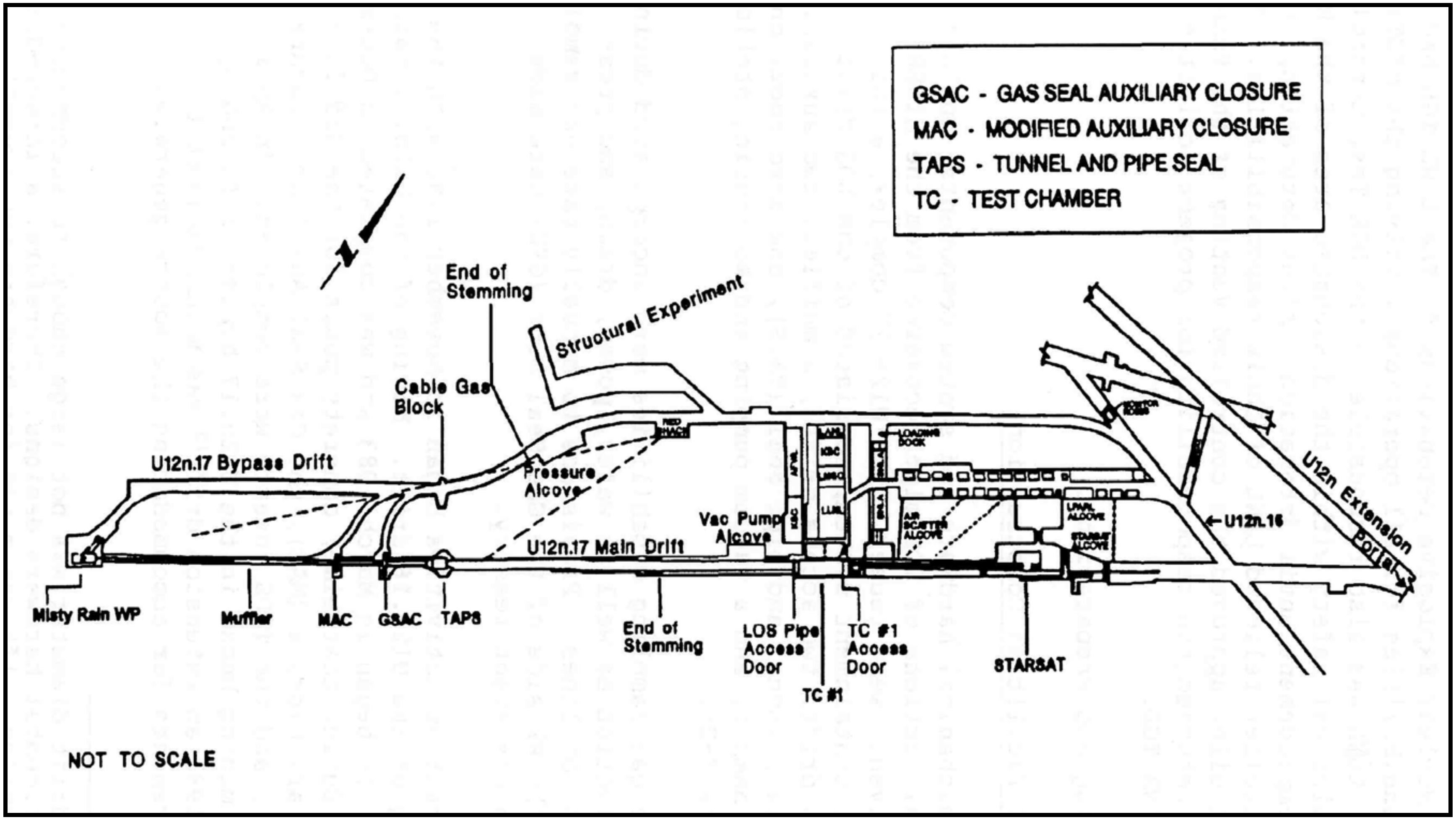
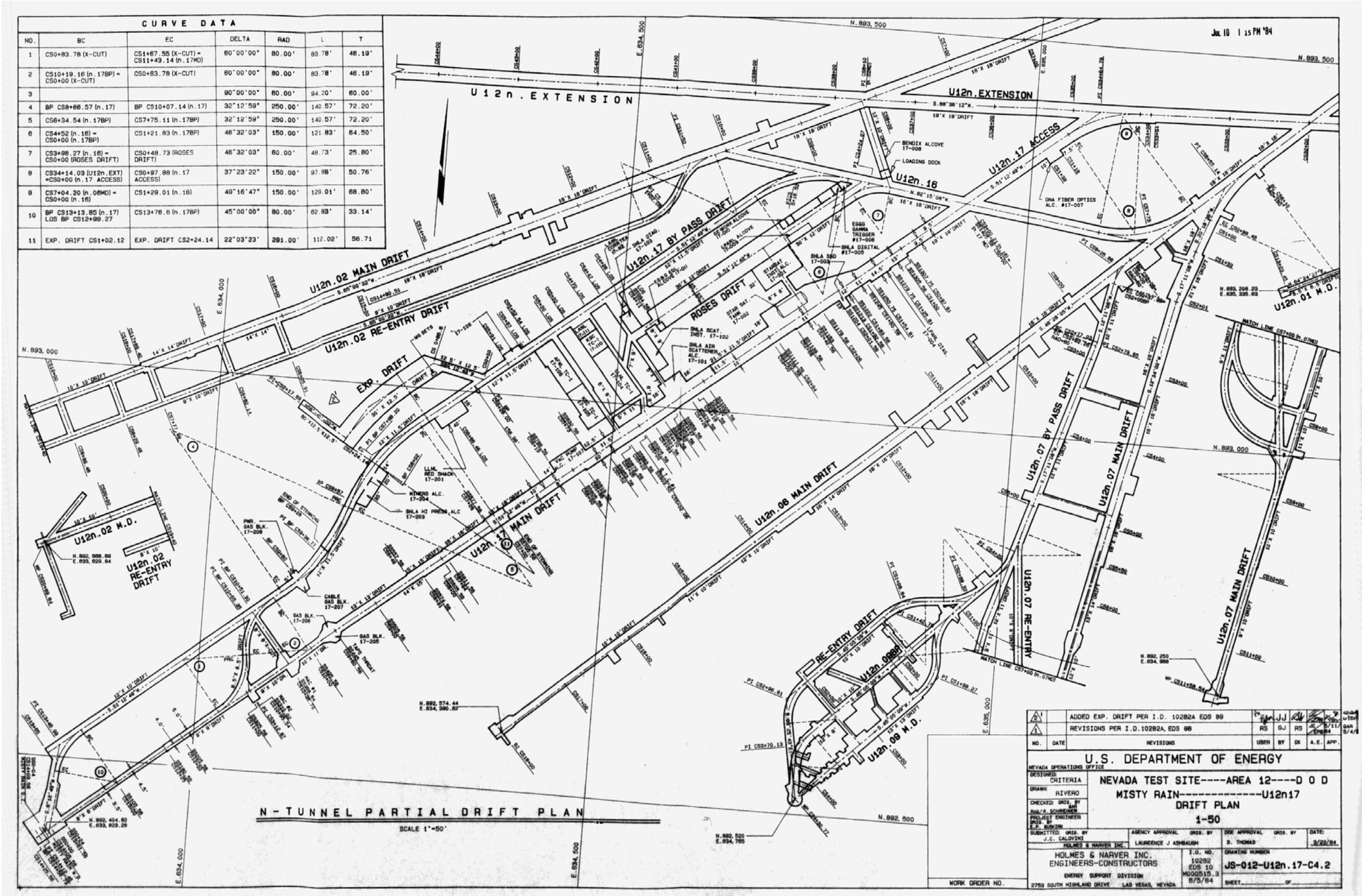


Figure 78. Plan of the U12n.17 drift for the Misty Rain test (Stinson et al. 1993:158).



NO.	BC	EC	DELTA	RAD	L	T
1	CS0+83.78 (X-CUT)	CS1+67.55 (X-CUT) = CS11+43.14 (n.17MD)	60°00'00"	80.00'	83.78'	46.19'
2	CS10+19.16 (n.17BP) = CS0+00 (X-CUT)	CS0+83.78 (X-CUT)	60°00'00"	80.00'	83.78'	46.19'
3			90°00'00"	60.00'	94.20'	60.00'
4	BP CS8+66.57 (n.17)	BP CS10+07.14 (n.17)	32°12'59"	250.00'	140.57'	72.20'
5	CS6+34.54 (n.17BP)	CS7+75.11 (n.17BP)	32°12'59"	250.00'	140.57'	72.20'
6	CS4+52 (n.16) = CS0+00 (n.17BP)	CS1+21.83 (n.17BP)	46°32'03"	150.00'	121.83'	64.50'
7	CS3+98.27 (n.16) = CS0+00 (ROSES DRIFT)	CS0+48.73 (ROSES DRIFT)	46°32'03"	60.00'	48.73'	25.80'
8	CS34+14.03 (U12n.EXT) =CS0+00 (n.17 ACCESS)	CS0+97.88 (n.17 ACCESS)	37°23'22"	150.00'	97.88'	50.76'
9	CS7+04.20 (n.08MD) = CS0+00 (n.16)	CS1+29.01 (n.16)	49°16'47"	150.00'	129.01'	68.80'
10	BP CS13+13.85 (n.17) LOS BP CS12+99.27	CS13+76.6 (n.17BP)	45°00'00"	80.00'	62.83'	33.14'
11	EXP. DRIFT CS1+02.12	EXP. DRIFT CS2+24.14	22°03'23"	291.00'	112.02'	56.71

Figure 79. Construction plan of the U12n.17 drift for the Misty Rain test, 1984 (drawing JS-012-U12n.17-C4.2, on file at Archives and Records Center, Mercury, Nevada).

length of the pipe with test chamber was 934 ft (285 m). Sections of the line-of-sight pipe from the Miners Iron test in the U12n.11 drift were reused in this test.

Mining of the bypass drift began in April 1983 and started off the left rib of the U12n.16 drift. It was 12 ft (3.7 m) wide and 11.5 ft (3.5 m) high. After completion, a 200 ft (61 m) structures experiment drift was added off the bypass drift in May 1984 for a tunnel hardening experiment (Stinson et al. 1993:159). The alcove for the STARSAT chamber was adjacent to the line-of-sight drift and measured 68 ft (20.7 m) long, 39.5 ft (12.0 m) wide, and 23 ft (7 m) high. The STARSAT instrumentation alcove was mined off the left rib of the ROSES drift and measured 56 ft (17.1 m) long, 32 ft (9.8 m) wide, and 12 ft (3.7 m) high. A scatterer alcove was mined off the right rib of the line-of-sight drift and it measured 34 ft (10.4 m) long, 16 ft (4.9 m) wide, and 20 ft (6.1 m) high. The ROSES drift and instrumentation alcoves were constructed between November 1983 and March 1984 and located between the line-of-sight and bypass drifts. The ROSES drift was 305 ft (93 m) long, 30 ft (9.1 m) wide, and 12 ft (3.7 m) high. The ROSES units were installed in January 1985. Installation of experiments began in November 1984 and was completed by February 1985.

Two 150-ton cooling towers, one 1,800 gallon storage tank, and pumps were located above the portal to circulate water to a 16,000 gallon storage tank underground in the U12n.07 drift. From the underground storage tank, the water was distributed by a 6-inch supply line to different size chillers in the recording alcoves and to the vacuum pump alcove. Underground electrical power was supplied by substation 12-5 located at the portal.

Stemming of the line-of-sight drift outward to 705 ft (215 m) from the working point was conducted in July 1984. Stemming of the bypass drift occurred after installation of the nuclear device. Sandbags containing desert sand and weighing 25 pounds each were placed near the working point followed by stemming of the bypass drift with various grout mixtures out to 500 ft (152 m). All mechanical and electrical penetrations into the stemmed areas were gas blocked to prevent seepage of radioactive gases. A new gas seal plug, with containment design criteria similar to the plugs in the U12n main drift and U12n main runaround drift was constructed in the new U12n extension drift. It was 10 ft (3 m) in length, constructed without a trainway and mined out after the Misty Rain test execution. Misty Rain was the first event that could pose a containment threat to the new U12n extension drift. The U12n main drift gas seal plug trainway was the last area stemmed prior to Misty Rain readiness.

In the final preparations for the test, all excess personnel had exited the test area by midnight on April 5, 1985, leaving only the arming party, button-up crews, and security (Stinson et al. 1993:171). Permission to arm the device was given a few hours later and button-up was completed by 8:00 on the morning of April 6. Detonation of the device was planned for 9:00, but adverse weather conditions postponed it for six hours. The Misty Rain nuclear device was detonated at 3:15 in the afternoon of April 6, 1985. The collapse of the cavity occurred on April 7, 10 hours and 19 minutes after detonation (Townsend et al. 2007). Radioactive readouts from remote area monitoring system units began in the monitor room at the Area 6 control point immediately after detonation. All remote area monitoring system units located in the tunnel on the working point side of the drift protection plugs, and still operating after the detonation, had radiation readings above normal background levels (Stinson et al. 1993:172). The highest reading of 1,000 R/h at 11 minutes after detonation came from unit 15 in the line-of-sight drift. All other units outside the drift protection plugs, at the portal, and on the mesa read normal background levels. By April 12, unit 15 had a reading of 0.9 R/h and all the other units were at normal background levels.

Initial reentry to the portal and mesa areas started about two hours after detonation. The initial reentry teams completed their work in about 30 minutes, with no radiation levels above normal background detected. Remote gas sampling inside the tunnel then commenced to the working point side of the gas seal door, the gas seal plugs, the drift protection plugs, at the end of stemming in the bypass drift, in the line-of-sight drift, both inside and outside the pipe, and at the tunnel-and-pipe-seal. High levels of toxic and explosive gases and low levels of oxygen were found on the working point side of the U12n extension drift protection plug and at the line-of-sight pipe.

There were no tunnel reentry activities on April 7, D+1. Tunnel reentry began in the early afternoon of April 8, D+2. The reentry controller and his health physicist met at control point and reviewed the current radiation readings in the remote area monitoring system room, the weather predictions, and received permission from the DOE test controller to proceed with manned reentry. The construction crews and reentry support personnel arrived at the portal and the reentry teams dressed out in protective equipment. Radsafe and industrial hygiene technicians set up their equipment, and after a health and safety brief the work team went underground to inspect the gas seal door. At the portal side of the door the team took readings on the working point side and relayed the information to the reentry controller at the portal. The team received permission to proceed and they opened the small personnel door and checked for water on the working point side; none was found. The work team then returned to the portal and the first reentry team entered the tunnel, crawled through the small door at the gas seal door and proceeded to the gas seal plug in the bypass runaround. They checked the air quality conditions on the working point side and, after receiving permission, opened the tube turn containment doors on the vent tube and crawl tube and connected a slip joint on the vent line to the vent tube to establish ventilation to the portal side of the drift protection plugs. The team then returned to the portal and the D+2 work day was finished.

On April 9, D+3, the reentry teams and support personnel arrived at the portal and proceeded with the preparation work. Permission to proceed with reentry was received from the DOE test controller and the reentry team was briefed on tunnel health and safety conditions. The team entered the tunnel and traveled to the U12n.08 thermal shield plug. They opened the thermal shield plug containment door, crawled through, opened the containment door on the vent pipe, and requested the fans on the mesa be turned on. The team then returned to the portal. On April 10, D+4, portal operations were repeated and the reentry team proceeded to the U12n.06 drift and then to the Misty Rain drift complex. At the first shield wall in the U12n.17 line-of-sight drift, the team sampled the working point side and found elevated levels of radiation, toxic and explosive gasses, and a low oxygen level. With permission, the team opened the T-bolt type containment door in the shield wall and reestablished ventilation to the Misty Rain line-of-sight drift before returning to the portal. During the same time, the work team had proceeded to the gas seal door, opened the trainway door, reestablished rail lines through the door, and reconnected the tunnel drain line. The work team then returned to the portal and work for D+4 was completed. The reentry team returned on April 12, D+6, to the shield wall and then traveled to the first test chamber. They opened the door to the test chamber and detected elevated levels of radiation and toxic and explosive gases inside. The reentry team did their assessment of the rest of the U12n.17 drifts. The structural experiment drift had extensive damage from the collapse of the back, or ceiling. Scientific assessment and data recovery teams entered the Misty Rain drifts on April 16 to assess conditions and begin recovering experiments (Stinson et al. 1993:174). Data recovery lasted until May 10, 1985.

Reentry mining of the gas seal plug in the extension drift began April 10, D+4, and was completed on D+9, April 15, 1985. On April 19, D+13, rehabilitation of the U12n.17 drift was initiated by mucking the inverts, painting the walls, rockbolting and hanging wire mesh, and placing pea gravel on the inverts of the drifts. Mining toward the line-of-sight closures was also conducted with the drill and blast technique. Probe holes in the working faces were drilled ahead of the mining to detect any presence of radiation. Between September 1985 and August 1986 hydraulic fracture holes were drilled in the heading and ribs of the U12n.17 drift to examine the geology. Mining operations terminated in the drift in December 1986 to allow continuation of the geological studies (Stinson et al. 1993:175).

No post test drilling was conducted from the mesa. An underground drilling area was setup in the bypass drift and drilling of two holes began on May 1, 1986. In the first hole, 13 core samples were taken from the experimental drift crosscut. In the second hole, 29 core samples were obtained from the cross section at the tunnel-and-pipe-seal. Radiation readings on all core samples were at normal background levels. This operation was completed in June, 1986.

U12n.18 Drift - Tomme/Midnight Zephyr

The Tomme nuclear test was sponsored and conducted by LLNL, the fourteenth nuclear test in the U12n Tunnel; Midnight Zephyr was an add-on experiment to Tomme and sponsored by DTRA (Stinson et al. 1993:111). The Tomme/Midnight Zephyr nuclear test was originally planned for the U12t Tunnel, but was shifted to the U12n Tunnel because of scheduling conflicts. The purpose of the Midnight Zephyr experiment was to evaluate the stemming and containment design of a low yield test bed using a shorter horizontal line-of-sight pipe. A shorter line-of-sight pipe would reduce costs and provide greater flexibility. The Midnight Zephyr experiment marked the first time DTRA completely recorded a test with underground equipment (DTRA 2002:388). No instrumentation trailers on the mesa were used by DTRA. The Tomme/Midnight Zephyr test was executed on September 21, 1983 in the U12n.18 drift at a vertical depth of 1,325 ft (404 m) below the surface. It had a yield of less than 20 kilotons (DOE/NV 2000).

On January 18, 1983, mining of the U12n.18 drift began in a northward direction from the right rib of the U12n.10 main drift (Bennett 1991; Figures 80-81). When finished, the U12n.18 drift for the Tomme test consisted of the main drift being mined 235 ft (72 m) to the point of intersection where the Tomme access crosscut angled left and continued for 155 ft (47 m) to the Tomme line-of sight drift. Mining for the Tomme line-of sight drift turned right and continued for another 105 ft (32 m) to the working point. A small 25 ft (7.6m) tail drift at the back of the line-of sight drift completed the Tomme drifts. Mining for the Midnight Zephyr experiment started at the point of intersection of the Tomme access crosscut and continued in a northerly direction until it intersected the common working point. Both the Tomme drift and the Midnight Zephyr drift contained a line-of-sight pipe aligned to a common working point. A crosscut was mined between the Tomme access crosscut and the Midnight Zephyr drift to contain a side pipe for Sandia National Laboratories (Stinson et al. 1993:113). Alcoves were also mined. There was no bypass drift. A facility drift protection plug was

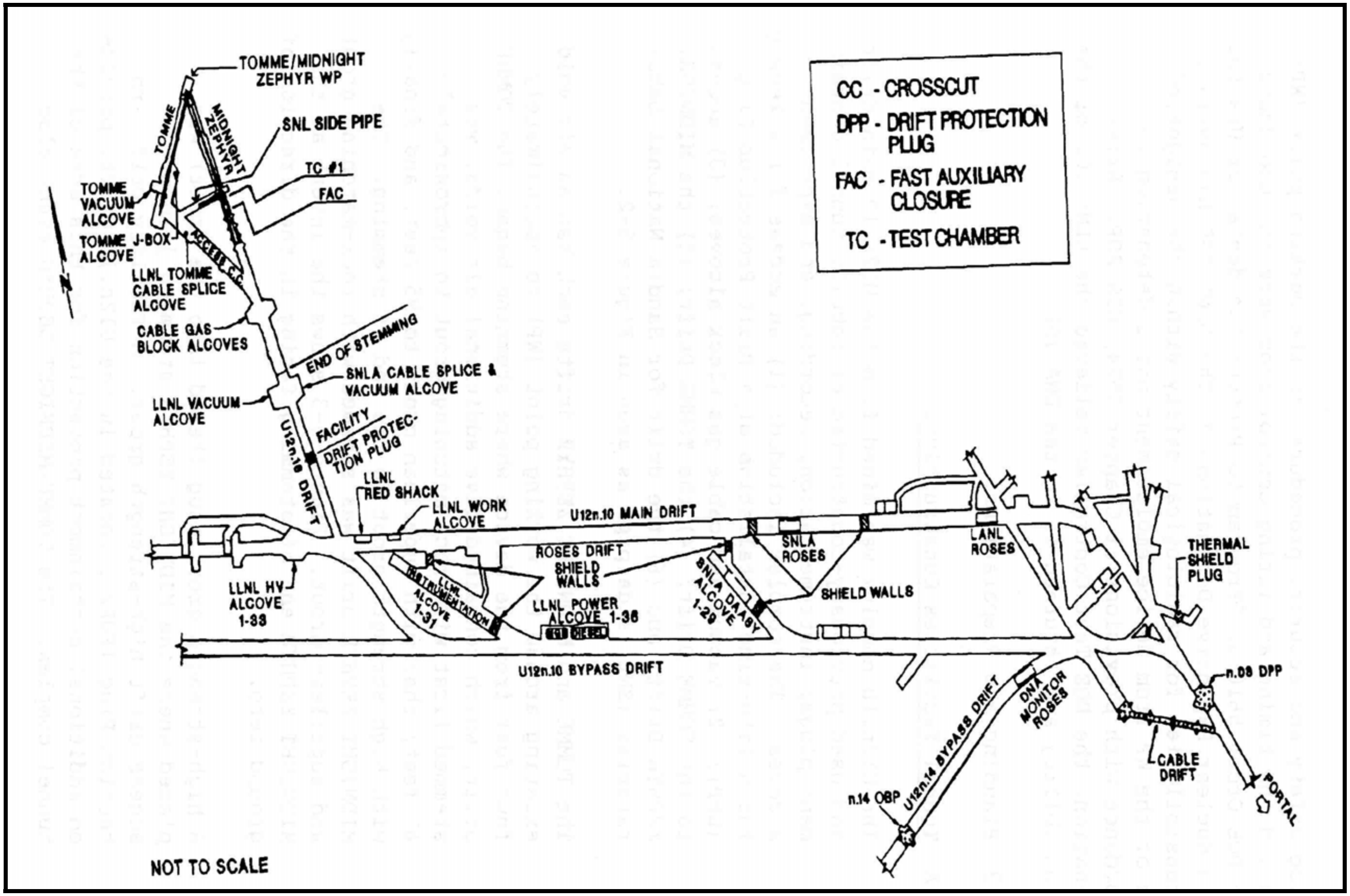
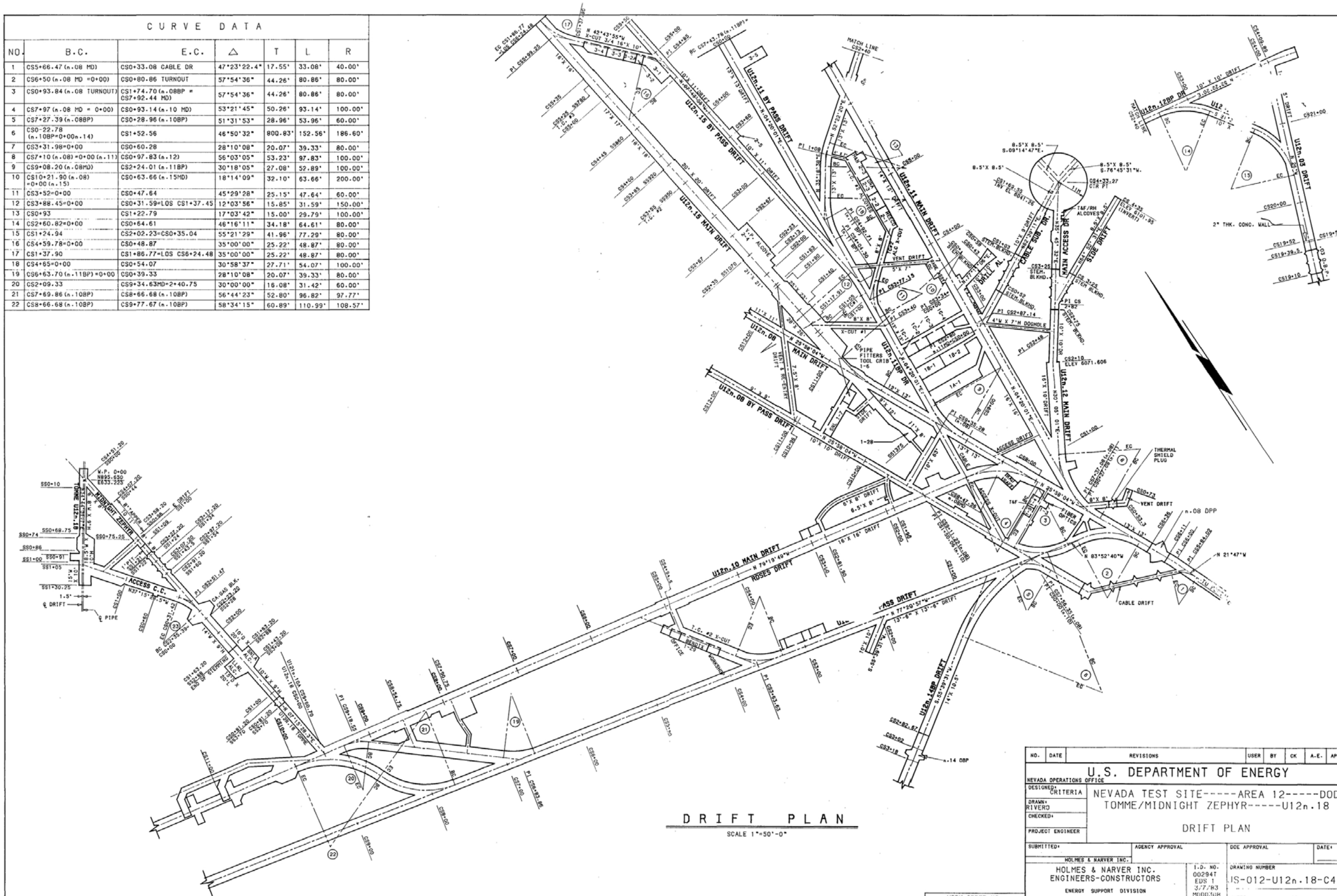


Figure 80. Plan of the U12n.18 drift for the Tomme/Midnight Zephyr test (Stinson et al. 1993:114).



CURVE DATA

NO.	B.C.	E.C.	△	T	L	R
1	CS5+66.47 (n.08 MD)	CS0+33.08 CABLE DR	47°23'22.4"	17.55'	33.08'	40.00'
2	CS6+50 (n.08 MD =0+00)	CS0+80.86 TURNOUT	57°54'36"	44.26'	80.86'	80.00'
3	CS0+93.84 (n.08 TURNOUT)	CS1+74.70 (n.08BP = CS7+92.44 MD)	57°54'36"	44.26'	80.86'	80.00'
4	CS7+97 (n.08 MD = 0+00)	CS0+93.14 (n.10 MD)	53°21'45"	50.26'	93.14'	100.00'
5	CS7+27.39 (n.08BP)	CS0+28.96 (n.10BP)	51°31'53"	28.96'	53.96'	60.00'
6	CS0-22.78 (n.10BP=0+00n.14)	CS1+52.56	46°50'32"	800.83'	152.56'	186.60'
7	CS3+31.98=0+00	CS0+60.28	28°10'08"	20.07'	39.33'	80.00'
8	CS7+10 (n.08) =0+00 (n.11)	CS0+97.83 (n.12)	56°03'05"	53.23'	97.83'	100.00'
9	CS9+08.20 (n.08MD)	CS2+24.01 (n.11BP)	30°18'05"	27.08'	52.89'	100.00'
10	CS10+21.90 (n.08) =0+00 (n.15)	CS0+63.66 (n.15MD)	18°14'09"	32.10'	63.66'	200.00'
11	CS3+52=0+00	CS0+47.64	45°29'28"	25.15'	47.64'	60.00'
12	CS3+88.45=0+00	CS0+31.59=LOS CS1+37.45	12°03'56"	15.85'	31.59'	150.00'
13	CS0+93	CS1+22.79	17°03'42"	15.00'	29.79'	100.00'
14	CS2+60.82=0+00	CS0+64.61	46°16'11"	34.18'	64.61'	80.00'
15	CS1+24.94	CS2+02.23=CS0+35.04	55°21'29"	41.96'	77.29'	80.00'
16	CS4+59.78=0+00	CS0+48.87	35°00'00"	25.22'	48.87'	80.00'
17	CS1+37.90	CS1+86.77=LOS CS6+24.48	35°00'00"	25.22'	48.87'	80.00'
18	CS4+65=0+00	CS0+54.07	30°58'37"	27.71'	54.07'	100.00'
19	CS6+63.70 (n.11BP) =0+00	CS0+39.33	28°10'08"	20.07'	39.33'	80.00'
20	CS2+09.33	CS9+34.63MD=2+40.75	30°00'00"	16.08'	31.42'	60.00'
21	CS7+69.86 (n.10BP)	CS8+66.68 (n.10BP)	56°44'23"	52.80'	96.82'	97.77'
22	CS8+66.68 (n.10BP)	CS9+77.67 (n.10BP)	58°34'15"	60.89'	110.99'	108.57'

Figure 81. Construction plan of the U12n.18 drift for the Tomme/Midnight Zephyr test, 1983 (drawing JS-012-U12n.18-C4, on file at Archives and Records Center, Mercury, Nevada).

constructed between 81 (25 m) and 91 ft (28 m) from the start of the U12n.18 drift. Additional alcoves and the recording stations were located in the U12n.10 drift.

Installation of the line-of-sight pipes began in March and was completed by the end of August (Stinson et al. 1993:116). For the Midnight Zephyr portion of the test, the fast acting closure was installed pre-closed and there were no experiments in the pipe (Townsend et al. 2007). Gauges were installed, however, to evaluate the new stemming and containment design concept. In May, the U12n.18 drift was contaminated with radioactive material from the Mini Jade test and had to be painted and sprayed with sealant to reduce particulate resuspension (Stinson et al. 1993:116). This procedure was not completely successful and the workers had to wear anti-contamination clothing as a precaution to finish the remaining work. Both the Tomme and Midnight Zephyr drifts were stemmed with grout (Stinson et al. 1993:113).

The final dry run for the test was conducted on September 20, 1983 and final button-up activities began that evening (Stinson et al. 1993:117). In the early morning of the next day, permission was granted to arm the nuclear device and by 6:30 the button-up was complete (Stinson et al. 1993:124). The nuclear device was detonated at 8:00 on the morning of September 21, 1983 (Stinson et al. 1993:125). The cavity collapsed 35 minutes after detonation. All underground remote area monitoring system units read normal background radiation levels at the control point monitoring room except for the three closest to the detonation. Two of the units reading above background were on the working point and portal side of the U12n.18 facility drift protection plug. The third unit was at the intersection of U12n.18 and the U12n.10 line-of-site drift. The elevated radiation readings indicated some seepage occurred at the end of stemming in the U12n.18 main drift and then through the U12n.18 facility drift protection plug.

Initial reentry surveys began three hours after detonation. No elevated radiation levels were detected. Samples taken remotely from the tunnel interior did not show any evidence of radiation, toxic or explosive gases (Stinson et al. 1993:126). Tunnel reentry started on September 22, or D+1. No elevated radiation levels or toxic and explosive gases were detected. Mechanical closures at the gas seal door, the gas seal plug, and the U12n.08 drift protection plug were opened following sampling at each location. The reentry team then proceeded to the U12n.08 drift and opened the thermal shield plug and reconnected the vent line to establish ventilation to the mesa. The ventilation fans on the mesa were then turned on. The reentry team made their way through the U12n.10 bypass drift to the portal side of the U12n.18 facility drift protection plug. The oxygen level on the portal side of the facility drift protection plug was 20 percent. On the working point side of the plug, high levels of toxic and explosive gases were present (Stinson et al. 1993:127). The reentry team then opened the alcove protection plug at the LLNL instrumentation alcove and took smear samples in the alcove before returning to the portal in the late afternoon. The smear samples did not provide any evidence of elevated radiation levels. Data recovery teams then entered the tunnel at 5:20 in the afternoon and finished all their work by 7:00 pm.

Reentry mining began on the swing shift on September 22, or D+1, with mining out of the gas seal plug trainway, followed by the U12n.08 drift protection plug trainway. Cleanup in the U12n.10 drift was started September 27 and by September 28 had reached the portal side of the U12n.18 facility drift protection plug. On October 4, readings from the working point side of the plug showed no elevated radiation levels, but elevated levels of toxic and explosive gases and a below normal oxygen level were present. Ventilation was established to the plug. The containment door on the crawl tube in the facility drift protection plug was opened on October 14 and by November 9 no elevated radiation levels or toxic and explosive gases were detected. By mid January 1984, the Midnight Zephyr line-of-sight pipe was opened, air and water lines connected, and slightly contaminated water and slush inside the pipe were bailed into barrels (Stinson et al. 1993:128). All mining and cleanup was completed by the middle of March, 1984. No reentry work was done in the Tomme line-of-sight pipe or drift.

Post test drilling for the first of three holes began on September 23, or D+2, from the top of Rainier Mesa. All three were in the same hole but at alternate angles. The first drill hole, PS 1A, was 1,564 ft (477 m) deep and 16 core samples were obtained on September 24. The second drill hole, PS 1AA, and the taking of nine core samples were completed on September 25. The core samples were retrieved to a depth of 1,532 ft (467 m). The third drill hole, PS 1AAB, with eight core samples taken below 1,564 ft, was completed on September 26. The abandonment valve for the drill hole was closed on September 26, equipment was moved to the decontamination pad for cleanup, and drilling operations on the mesa finished on September 27, 1983.

One 350 ft (107 m) long reentry hole, RE 1, was drilled underground from an alcove in the U12n.10 drift toward the back corner of the instrumentation void in the Tomme drift. The drill hole was started October 12, 1983 and was completed on November 8, 1983. Air samples during the drilling showed no presence of toxic and explosive gases and radiation readings from core samples were at normal background levels.

U12n.19 Drift - Diamond Beech

The Diamond Beech nuclear test, the seventeenth in the U12n Tunnel, was conducted in the U12n.19 drift on October 9, 1985 the same day as the Mill Yard nuclear test (Schoengold 1999:82). Many of the requirements for the two tests overlapped, including construction, pretest activities, telemetry, security, button-up, and reentries. These dual efforts resulted in substantial economic savings (Schoengold 1999:90). Distance between the two working points was 1,460 ft (445 m). LLNL supplied the Diamond Beech nuclear device and placed it in the U12n.19 drift at a vertical depth of 1,325 ft (404 m) below the surface. The device had a yield of less than 20 kilotons (DOE/NV 2000). The purpose of the test was to continue with the investigation of the low yield test bed concept first tested in the earlier Midnight Zephyr experiment (DTRA 2002:389). Specific objectives included radiation output, proof-of-concept for the line-of-sight pipe stemming plan design, and containment information (Schoengold 1999:82).

The U12n.19 drift complex consisted primarily of a line-of-sight drift, a parallel bypass drift, crosscuts between them, and a zero room (Schoengold 1999:90). Some equipment and alcove space were reused from previous tests. The U12n.19 line-of-sight drift began at an angle to the left from the U12n.18 main drift, while the bypass drift started at an angle to the right from the U12n.10 main drift (Figures 82-83). Mining of the line-of-sight and bypass drifts began in August 1984 and was completed by October (Schoengold 1999:92). The line-of-sight drift measured 507 ft (155 m) long and 10 ft (3 m) wide and high at the beginning and 9 ft (2.7 m) wide and high at the end. The parallel bypass drift measured 539 ft (164 m) long and mirrored the width and height dimensions of the line-of-site drift. The bypass drift was slightly longer than the line-of-sight drift and did not angle toward

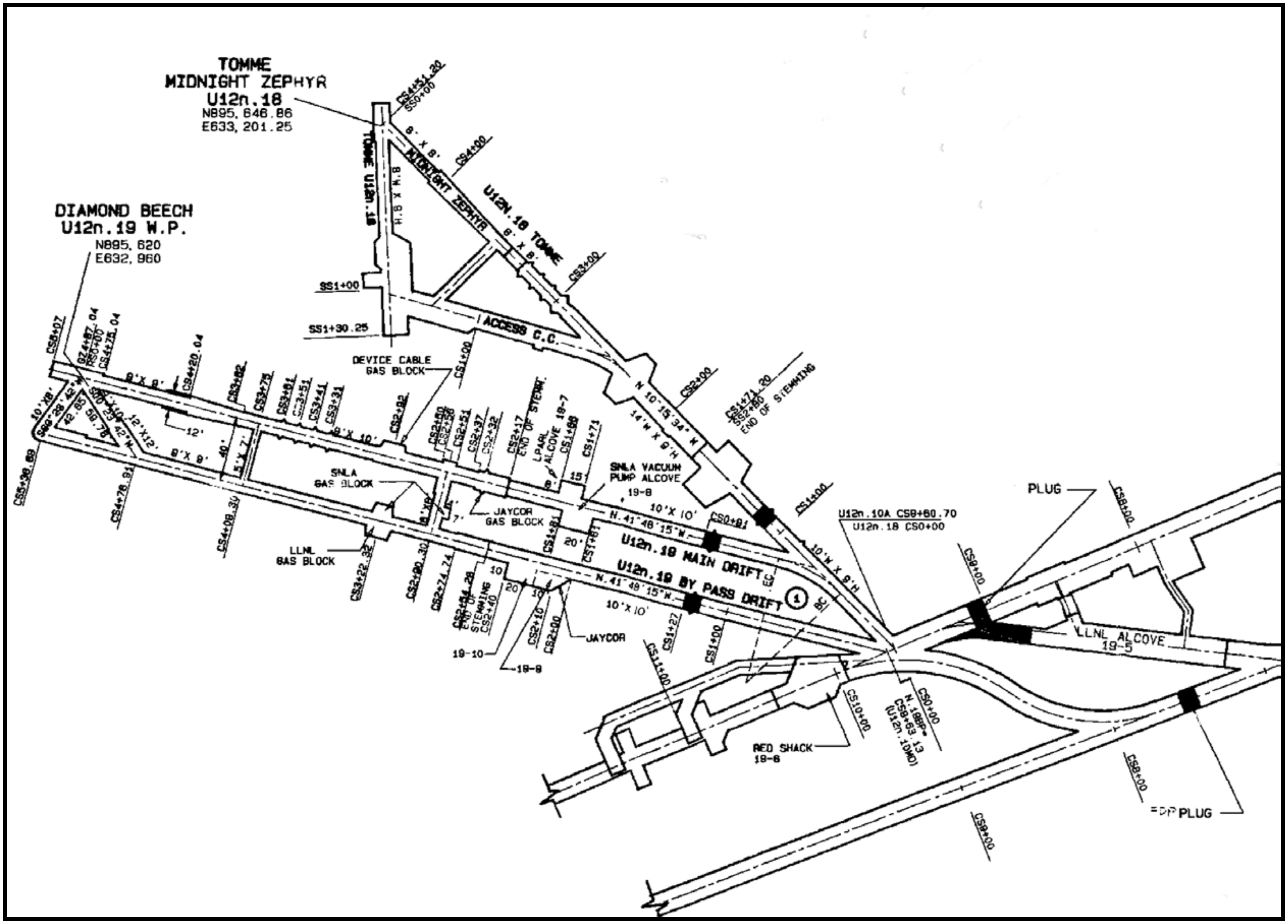


Figure 82. Plan of the U12.19 drift for the Diamond Beech test (modified from drawing JS-012-U12n.19-C4.4, on file at Archives and Records Center, Mercury).

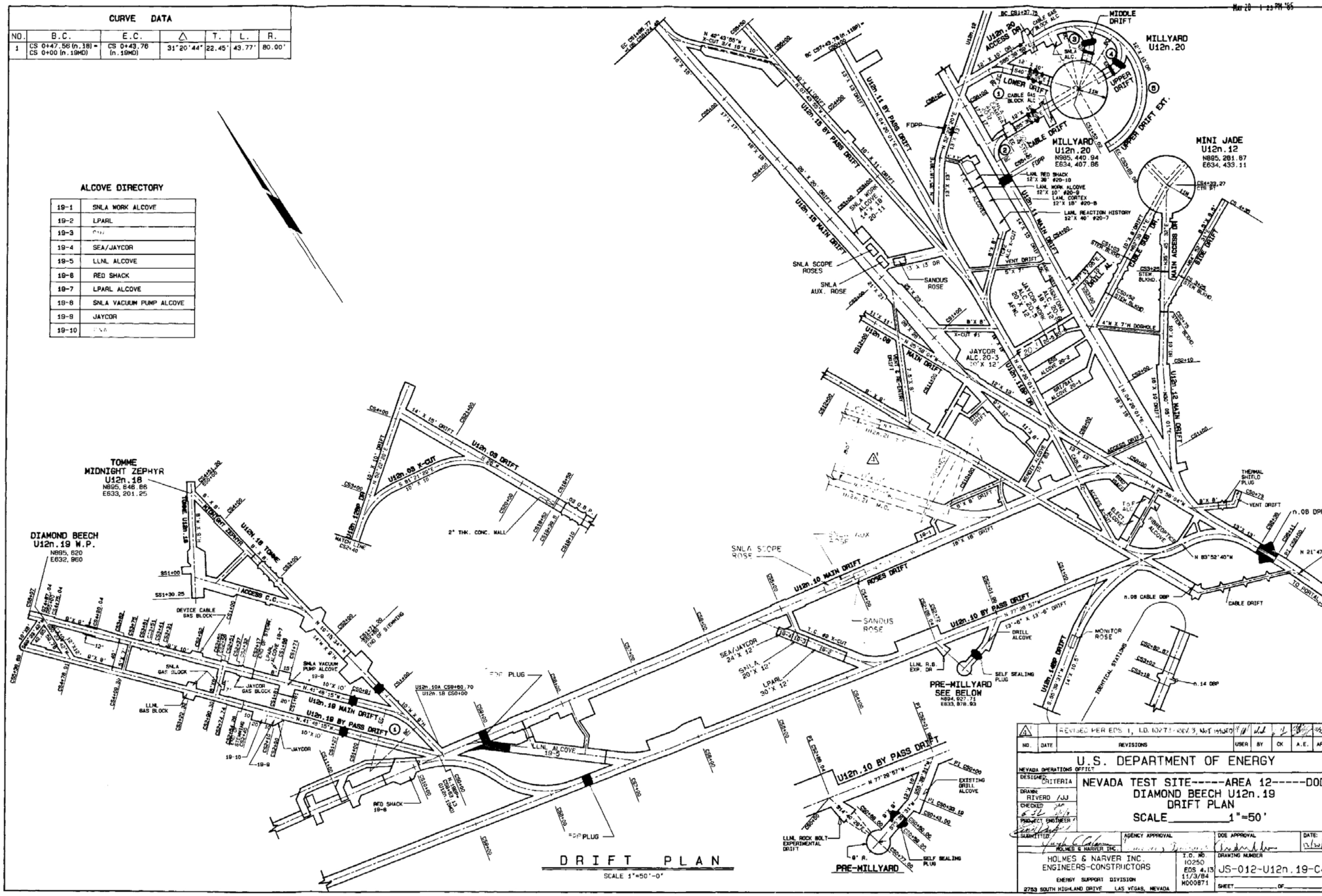


Figure 83. Construction plan of the U12n.19 drift for the Diamond Beech test, 1989 (drawing JS-012-U12n.19-C4.4, on file at Archives and Records Center, Mercury, Nevada).

or circle back to the working point as in the other test drifts; rather, it connected to the working point by a crosscut at the end that angled back to the working point. This crosscut measured 10 ft wide and 8 ft (2.4 m) high. The working point was also accessed by a second crosscut that angled forward from the bypass drift and it measured 12 ft (3.7 m) wide and high at the start and decreased to 9 ft wide and 10 ft high where it intersected the line-of-sight drift. LLNL used this crosscut for their experiments. A crosscut to the fast acting closure measured 5 ft (1.5 m) wide and 7 ft (2.1 m) high and was mined from the bypass drift to the line-of-sight drift. A larger crosscut, also mined between the two drifts, was used as a vacuum pump alcove by Sandia National Laboratories. It measured 20 ft (6 m) wide and 10 ft (3 m) high.

The line-of-sight pipe was 250 ft (76 m) long (Schoengold 1999:90). The pipe was made up of continuously diverging conical steel pipe sections from the working point out to 108 ft (33 m), a fast auxiliary closure from 108 ft to 122 ft (37 m), and hardened thick-walled pipe sections from 122 ft to 150 ft (46 m). By the end of 1984, the crosscuts for experiments and diagnostics, the instrument drill holes, the crosscut to the fast auxiliary closure, and alcove preparations were completed. The zero room and the line-of-sight invert were poured with grout and all drilling was finished by March 1985. By July, decontaminated equipment from the Misty Rain test, experiments, and associated hardware were installed and most of the stemming for the line-of-sight drift completed. The vacuum system was in place by September. Stemming for both the line-of-sight and bypass drifts extended out 270 ft (82 m) from the working point (Figure 84), while the zero room was left void (Schoengold 1999:94). The facility drift protection plugs in the line-of-sight and bypass drifts consisted of 10 ft (3 m) concrete plugs.

The mandatory full power dry runs for both tests were conducted on September 24. The Mill Yard dry run was successful, while the Diamond Beech dry run had to be conducted again the following day because the cryogenic and diffusion pumps were not on. The second dry run for Diamond Beech was successful and the nuclear devices for both tests were inserted on September 26. Final stemming in the bypass drift started after device insertion and all stemming was completed by October 6. Final briefings, arming the device, and final button-up activities for both the Mill Yard and Diamond Beech tests were conducted in the early morning of October 9, 1985 (Schoengold 1999:103). Following a weather delay, the Diamond Beech device was detonated at 3:20 in the afternoon. Radiation monitoring at the control point remote area monitoring system monitor room indicated that conditions in the tunnel were normal. The cavity collapsed eight minutes after detonation (Townsend et al. 2007).

Following the Diamond Beach and Mill Yard tests the DOE test controller gave permission to proceed with the initial reentries to the portal and mesa areas. The portal and mesa areas were found to be free of any radiation or unwanted gasses. Remote readings for radiation and toxic or explosive gasses were taken inside the tunnel on the working point side of the plugs. A small amount of radiation was found on the working point side of the facility drift protection plug in the U12n.10 drift. Samples taken 15 minutes later did not show any radiation. The decision was to let it sit over night and start again the next day.

On October 10, D+1, the reentry support teams arrived at the portal. The reentry teams dressed, the portal control team set up their equipment, and the work team headed underground to open the gas seal door. Measurements for radiation and toxic and explosive gasses on the working point side of

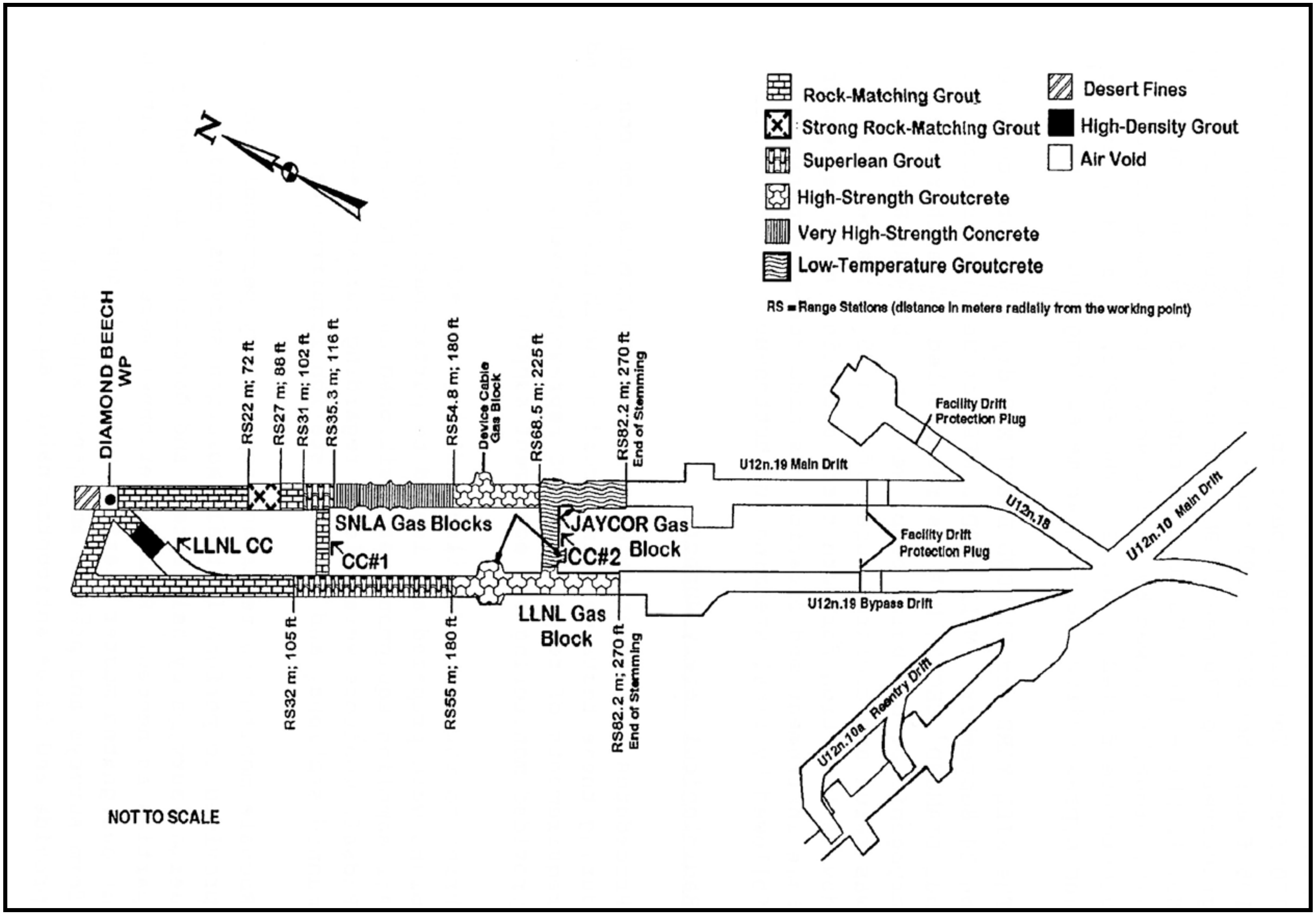


Figure 84. Stemming plan of the U12n.19 drift for the Diamond Beech test (Schoengold 1999:93).

the door were reported to the reentry controller. With permission, the work team opened the small man door and checked for water; none was seen. The work team then opened the large trainway doors, reinstalled the rail line, and reestablished ventilation to the portal side of the gas seal plug. The work team then returned to the portal and the first reentry team proceeded to the portal side of the gas seal plug. The reentry team made their usual measurements and after receiving permission from the reentry controller opened the tube turn door and connected the ventilation system together. This established ventilation to the portal side of the U12n.08 drift protection plug. The reentry team then proceeded to the U12n.08 drift protection plug where they repeated their measurements for the working point side. The personnel tube turn door was opened and the team proceeded to the thermal shield plug, opened the two doors, reconnected the vent line, and requested the fans on the mesa be started. This provided improved ventilation to the forward parts of the tunnel. Following the Mill Yard test, the control point monitors had noted increased radiation activity near the U12n.20 cavity. With this in mind, the reentry teams did not go toward the Mill Yard area but went along the U12n.10 drift toward the Diamond Beach test area. At the U12n.10 facility drift protection plug they sampled the working point side, reported the results, and returned to the portal. This completed D+1 activities.

On October 11, D+2, the reentry team reentered the tunnel and returned to the U12n.10 facility drift protection plug. They took their measurements again and with permission went through the plug and on toward the friction plug. They detected elevated radiation readings before arriving at the friction plug. The reentry was terminated for the day and the first of two controlled releases through the ventilation system began and lasted for 18 hours (Schoengold 1999:84). On October 17, or D+8, the second controlled release of radioactive gases, lasting 24 hours, was conducted. Sampling and recovery of experiments began on October 22, D+13 (Schoengold 1999:108), with recovery of equipment commencing on October 29, D+20, and continuing intermittently through July 1986 (Schoengold 1999:110).

U12n.20 Drift - Mill Yard

The Mill Yard nuclear test, the sixteenth in U12n Tunnel, was conducted on October 9, 1985 in the U12n.20 drift (Schoengold 1999:82). It was the first of two nuclear tests in the U12n Tunnel that day, the other being Diamond Beech in the U12n.19 drift. LANL supplied the Mill Yard nuclear device and the yield was less than 20 kilotons (DOE/NV 2000). Vertical depth of the test below surface was 1,230 ft (375 m). Similar to the Mini Jade test, objectives of the Mill Yard test were to study energy coupling, ground motion, air blast and cratering effects, and to measure electromagnetic pulse signals in sensors (Schoengold 1999:82). The Mill Yard test bed was a hemispherical cavity with the flat surface down. The flat surface consisted of porous desert sand. In contrast, the Mini Jade test surface was a wet volcanic tuff. The Mill Yard device was placed a short distance above the flat surface to simulate a near surface nuclear burst.

Mining for the U12n.20 drift started on July 31, 1984 (Bennett 1991), from a point 625 (191 m) into the U12n.11 main drift. The U12n.20 drift turned 90 degrees to the right off the U12n.11 drift and ran straight for 137.75 ft (42 m) where it became circular with an 80 ft (24 m) radius paralleling the 36 ft (11 m) radius cavity, and had a 12 degree incline (Figures 85-86). It ended at 394 ft (120 m) from the U12n.11 main drift. The main features of the Mill Yard test were the hemispherical cavity, the main access drift, a cable drift, the lower, middle, and upper extension drifts, and alcoves for the

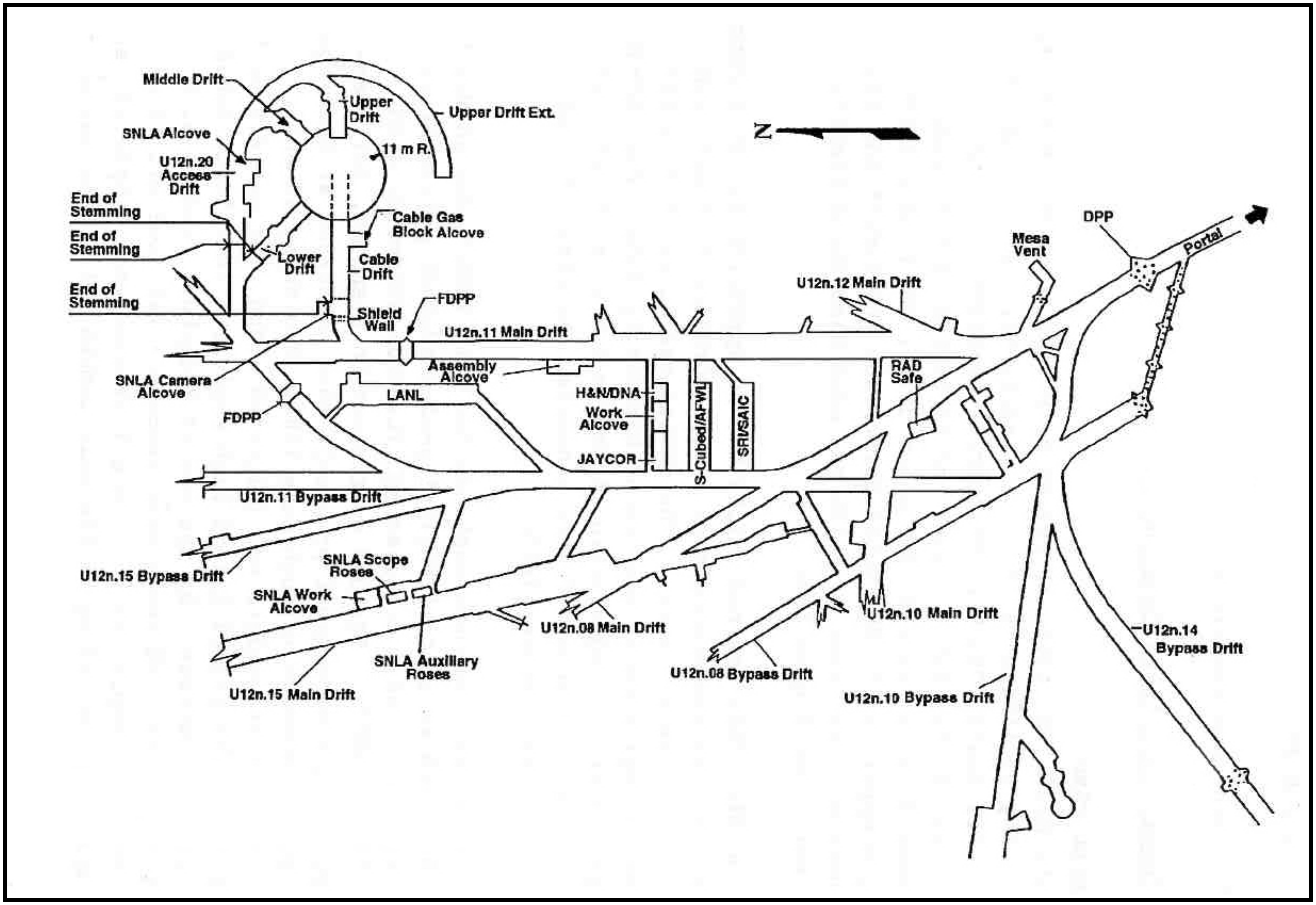


Figure 85. Plan of the U12n.20 drift and adjacent alcoves for the Mill Yard test (Schoengold 1999:86).

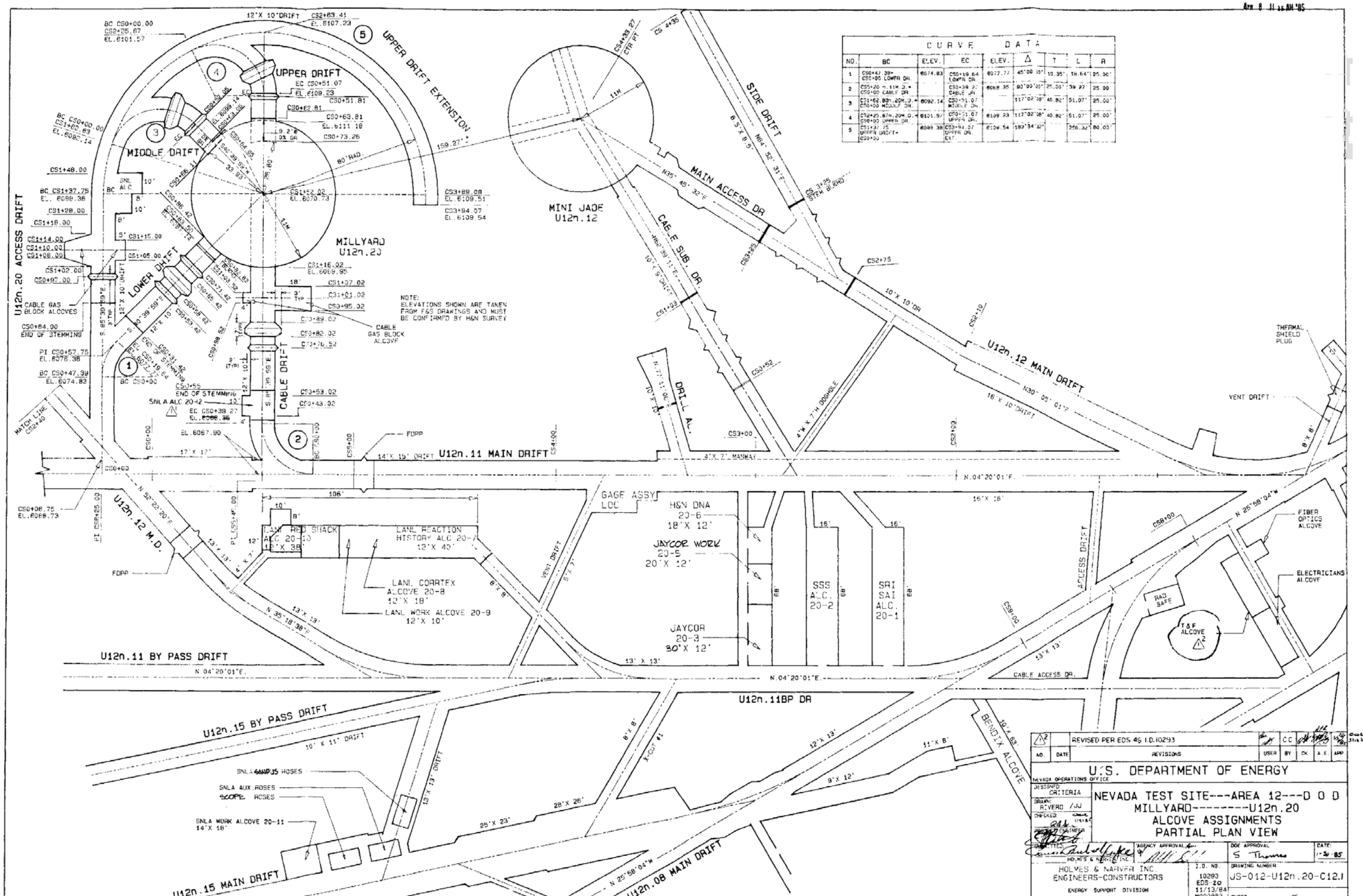


Figure 86. Construction plan of the U12n.20 drift for the Mill Yard test, 1985 (drawing JS-012-U12n.20-C12.1, on file at Archives and Records Center, Mercury, Nevada).

experimenters (Schoengold 1999:85). All drifts were 12 ft (3.7 m) wide by 10 ft (3 m) high. The cavity had a cylindrical base 72 ft (22 m) in diameter and a depth of 16.5 ft (5 m). The lower, middle, and upper extension drifts turned off the main drift at three different elevations: at the bottom, center, and near the top of the hemispherical cavity. The cable drift curved to the right from the U12n.11 main drift and was 121 ft (37 m) long where it intersected the bottom of the cylindrical base. The cylindrical base was backfilled with Yuma sand delivered from the Yuma, Arizona test site. The sand had a four percent moisture content and, after an initial layer of pea gravel, was placed in layers or lifts and compacted with mechanical tampers (Ashbaugh and Griffin 2009; Hendrickson 1986:21). All cabling from the numerous experiments positioned in the Yuma sand were routed out through the cable drift to the experimenter's alcoves.

A camera hole, U-12n.20 peep hole #1A, was drilled from the mesa into what would become the top of the cavity when it was mined (Figure 87). A 1,250 ft (381 m) deep hole was drilled in August 1984 (Bennett 1991). The hole was 4ft (1.2m) in diameter for the first 10 ft (3 m), 2.5 ft (0.8 m) in diameter for the next 803 ft (245 m), and 2 ft (0.6 m) in diameter for the remaining distance. It was cased from the surface to the total depth of 1,250 ft. After mining the cavity and removing the casing at the bottom of the peep hole, it was reduced to a depth of 1,196 ft (364m). The casing was cut off just below the back of the cavity and a door was welded to the pipe. The hole was stemmed for the test with sand, grout, and mechanical packers. The mechanical packers were at different levels in the hole and a high strength grout plug was at the bottom (Hendrickson 1986:38).

The mandatory full power signal dry run was successfully completed on September 24, 1985 and the device was inserted on September 26 (Hendrickson 1986:77). Stemming for button-up began and the last stemming plug was poured on October 2. Each drift that went into or around the cavity was stemmed with cementitious materials (Figures 88-90). The stemmed drifts included the cable, lower, middle, and upper extensions, and the main access drift that continued into the upper drift extension. The cable drift was stemmed for 61 ft (19 m), the lower drift for 55 ft (17 m), the middle drift for 66 ft (20 m), and the upper drift for 73 ft (22 m). The main access drift and the upper drift extension were stemmed from the end of the drift out 310 ft (94m). Facilities drift protection plugs were located in the U12n.11 main drift on the portal side of the cable access drift and in the U12n.22 bypass drift on the portal side of the U12n.11 main drift. The U12n.08 drift protection plug, the U12n main drift gas seal plug and gas seal door, and the U12n extension drift gas seal plug and friction plug were all stemmed for the Mill Yard and Diamond Beech tests.

A final dry run was conducted on October 8 and final preparations for the Mill Yard and Diamond Beech tests began at midnight when all personnel left the tunnel and muster areas, except those needed to arm the devices, button-up the tunnel, and for security (Hendrickson 1986:77; Schoengold 1999:103). Permission to arm the devices was given at 1:45 in the morning and by 6:15 button-up was completed. By 6:52, all personnel were out of the area. The Mill Yard nuclear device was planned for detonation at 8:00 on the morning of October 9, 1985, but was delayed due to weather conditions. It was detonated at 1:40 that afternoon when weather conditions improved. As designed, the cavity mined for the test did not collapse (Townsend et al. 2007).

All remote area monitoring system units were operational immediately after detonation. All but nine located underground in the U12n.20 and neighboring drifts read normal levels of radiation (Schoengold 1999:104). Radiation levels continued to rise at these nine locations, reaching their

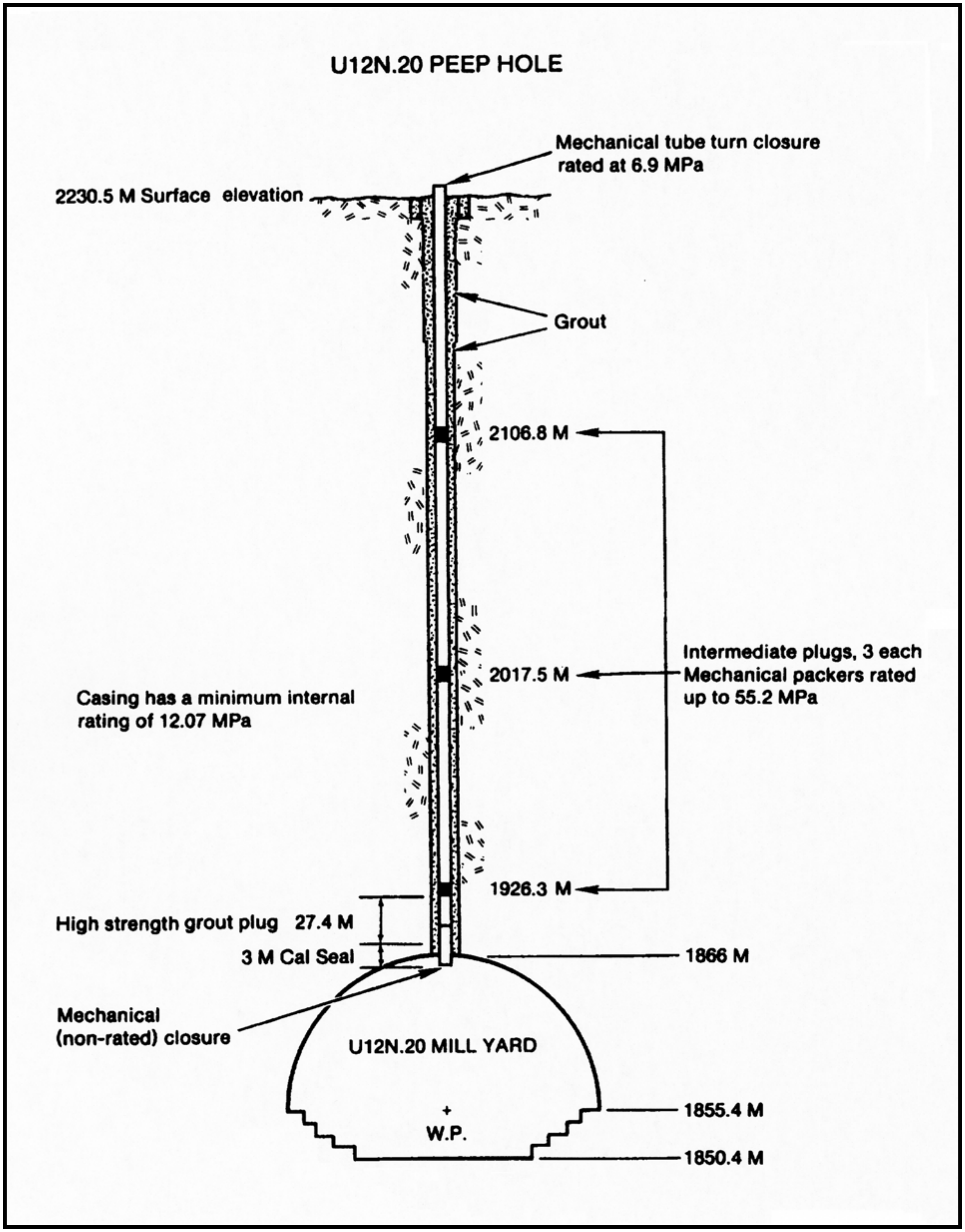


Figure 87. Peep hole for the Mill Yard test in the U12n.20 drift (Hendrickson 1986:38).

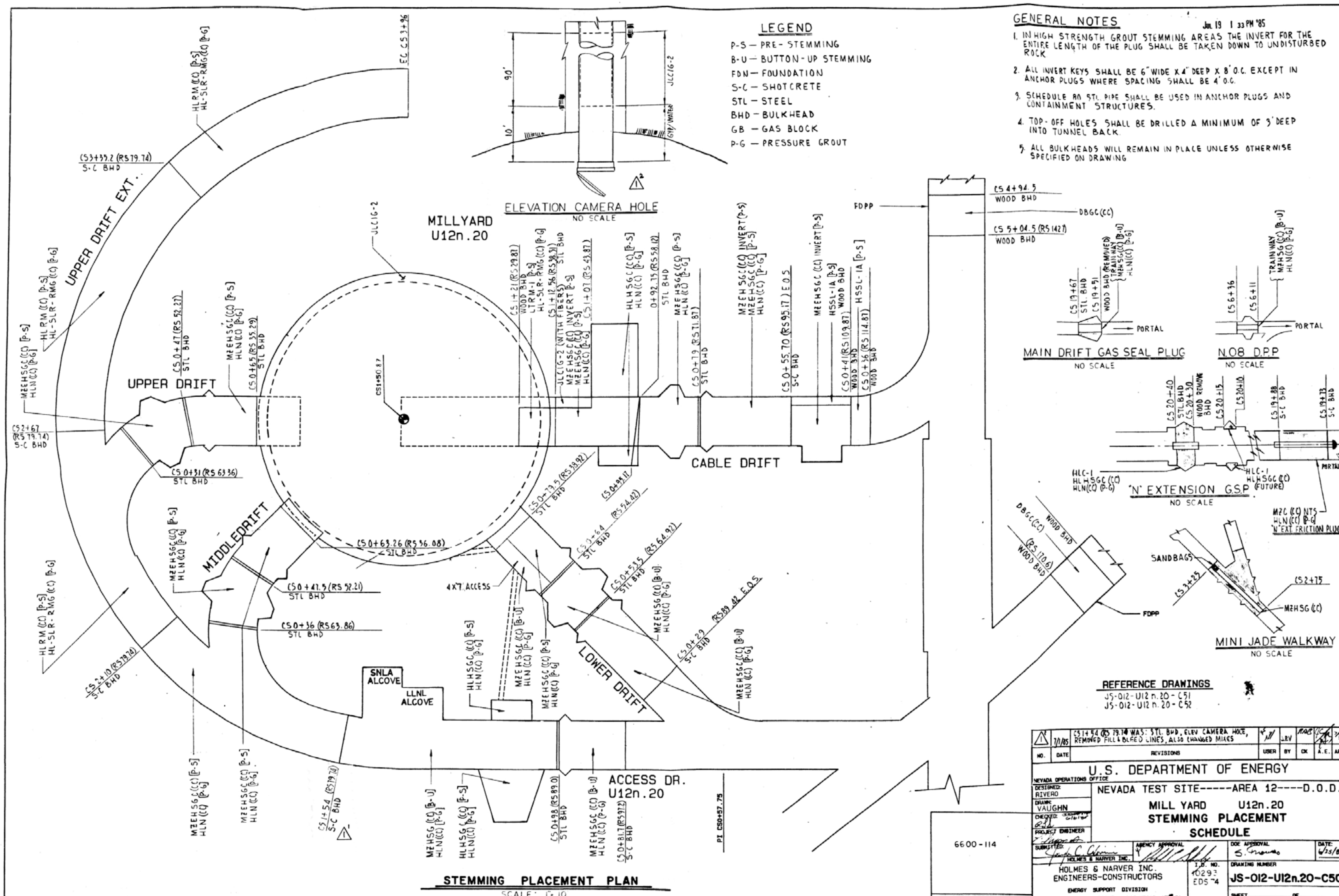


Figure 88. Stemming plan of the U12n.20 drift for the Mill Yard test, 1985 (drawing JS-012-U12n.20-C50.1, on file at Archives and Records Center, Mercury, Nevada).

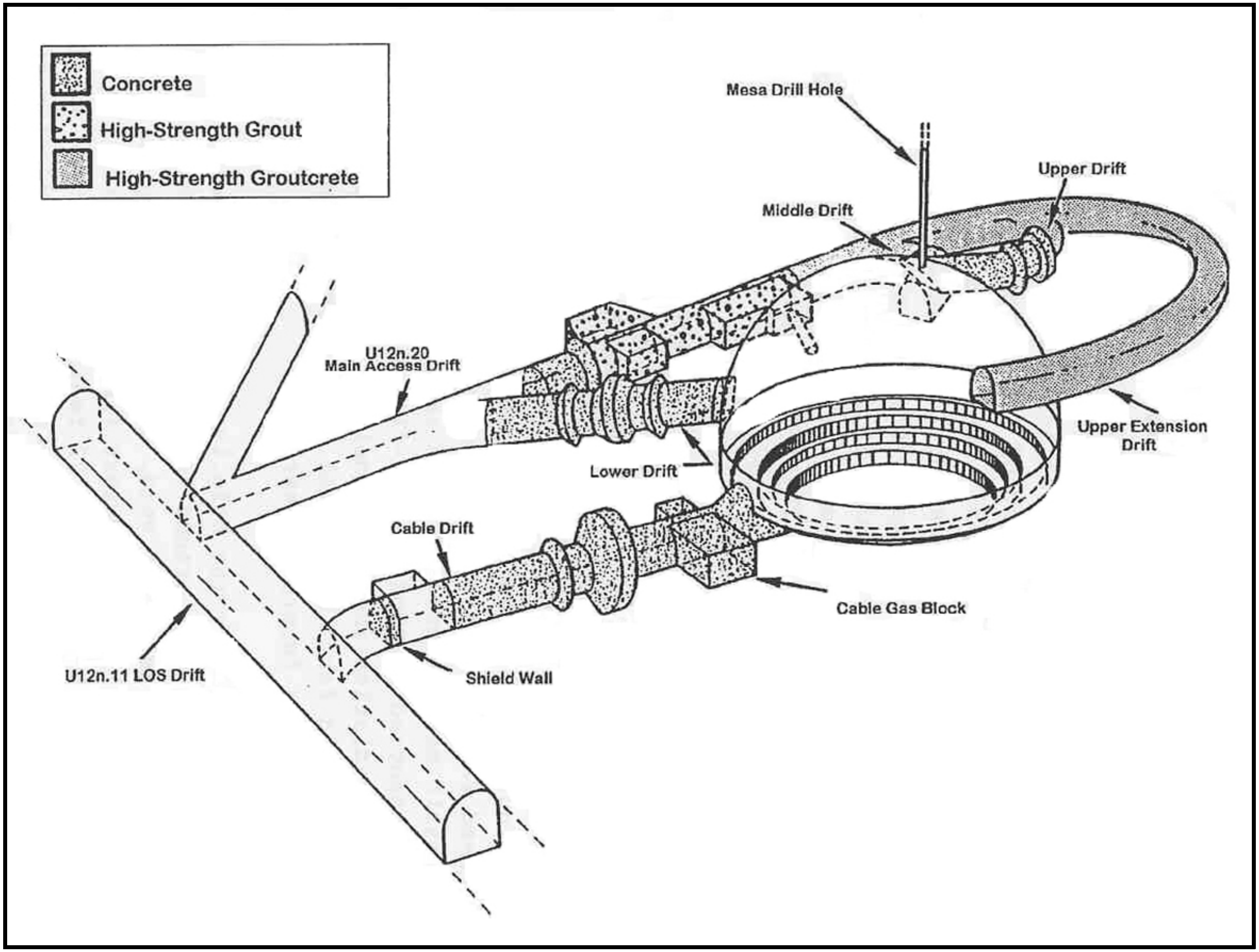


Figure 89. Three dimensional view of the U12n.20 drift and stemming plan (Schoengold 1999:91).

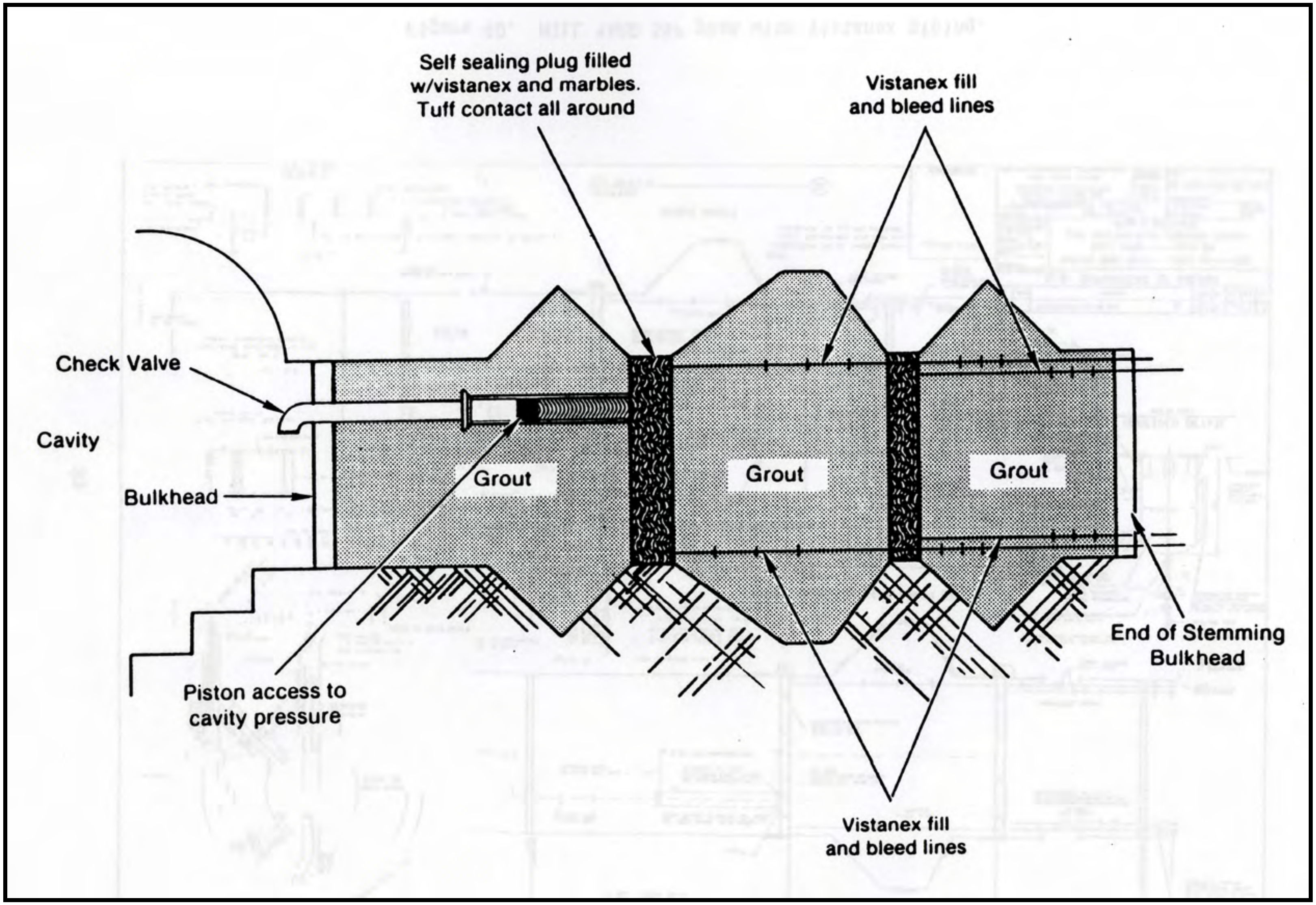


Figure 90. Self-sealing plug for the Mill Yard test (Hendrickson 1986:47).

maximum a few hours after detonation, and then began to fall. The greatest reading, as might be expected, was in the U12n.20 drift closest to the working point. The units were secured on October 23 when only two units were reading slightly above normal levels. A small amount of radioactive gas was remotely detected on the working point side of the U12n.08 drift protection plug where it was contained and later released into the atmosphere when ventilation was reestablished in the drift (Schoengold 1999:82). A hole 500 ft in length was drilled into the Ming Blade cavity in the U12n.08 drift to vent the Mill Yard test (Hendrickson 1986:74). This controlled release was for approximately 12 hours, between the second and third days (D+2 and D+3) after detonation (Schoengold 1999:104). A second controlled release was made from the U-12n.20 peep hole #1A over a two day span, two weeks after detonation. No radioactive materials from the two releases were detected beyond the boundaries of the NNSS (Schoengold 1999:84).

Initial reentry into the portal and mesa areas had to wait until after the Diamond Beech device was detonated on the same day approximately 1 hour and 40 minutes later in the U12n.19 drift. The first reentry team was dispatched about 5:30 in the afternoon from control point and the initial surveys of the exterior portal area and ventilation pad above the portal were completed by 6:00 pm (Schoengold 1999:105). No elevated radiation levels were detected. The team then began remote gas sampling inside the tunnel, finding elevated levels of radiation and explosive and toxic gases at the facility drift protection plug in the U12n.19 drift for the Diamond Beech test. Samples were taken again 15 minutes later and no elevated readings were found. The initial reentry was completed by 9:00 pm and by 10:00 pm all personnel had left the tunnel area.

On October 10, D+1, reentry support teams arrived at the portal. The reentry teams dressed in protective clothing, the portal control team set up their equipment, and the work team proceeded underground to open the gas seal door. Air quality measurements were taken on the working point side of the gas seal door and the results were reported to the reentry controller. With permission, the work team opened the smaller man door and checked for water; none was seen. The work team then opened the larger trainway door, reinstalled the rail line, and reestablished ventilation through the gas seal door to the portal side of the gas seal plug. The work team returned to the portal and the first reentry team proceeded to the portal side of the gas seal plug. The reentry team made their usual air quality measurements and after receiving permission from the reentry controller opened the tube turn containment door and connected the ventilation system together. This established ventilation to the portal side of the U12n.08 drift protection plug. The reentry team then proceeded to the U12n.08 drift protection plug where they repeated their measurements for the working point side. The tube turn containment doors were opened and the team proceeded to the thermal shield plug in the vent drift, opened the containment doors, reconnected the vent line, and requested the ventilation fans on the mesa be started. This provided improved ventilation to the forward parts of the tunnel. With the radiation results seen further in the tunnel, toward the Mill Yard test, it was decided to terminate the D+1 activities and return the next day after the tunnel had a chance to ventilate with the fans on. Prior to leaving, the team was directed to go into the U12n.10 drift to inspect tunnel conditions up to the U12n.10 facility drift protection plug. They took measurements on the working point side of the facility drift protection plug and reported them to the reentry controller. They then departed the tunnel for the day.

On October 11, D+2, the reentry team reentered the tunnel and proceeded to the portal side of the U12n.10 facility drift protection plug. They again took measurements and with permission from the reentry controller went through the facility drift protection plug and on toward the friction plug. They detected elevated readings before arriving at the friction plug. The reentry was terminated for the day and the first of two controlled releases through the ventilation system began and lasted for18 hours (Schoengold 1999:84).

Post test reentry mining began in the late afternoon on October 10, or D+1, with removal of the grout in the U12n main drift gas seal plug trainway (Schoengold 1999:108). This task was completed the next day and removal began of the remaining plugs. Work on the U12n.20 drift started on October 17, or D+8. Gas sampling of the cavity was done through a sampling port in the main access drift. Sampling was discontinued on November 1 and radiation surveys, reentry mining, and cleanup ceased on November 12 until the post test work for the Diamond Beech test was completed.

Post test drilling operations at U-12n.20 peep hole #1A on top of the mesa began on October 22, 1985 in order to lower a camera into the cavity (Schoengold 1999:108). After detonation, the tube turn containment door at the surface was opened on the drill hole and the mechanical packers removed (Schoengold 1999:109). Drilling into the grout plug set at 1,095 ft (334 m) below surface began on October 28 and the next day the cavity was breeched. A camera was lowered into the hole on several occasions, but problems were encountered and a laser tool was inserted instead to map the cavity and resulting crater. After mapping was completed, the cavity was pressurized by way of the drill hole and gas samples were collected from the cavity sampling port underground. These operations ended on October 31 and the drill rig and equipment were removed. Operations began again in February 1986, focusing on the downhole camera tasks and this time they were successful. Remapping of the crater with a laser tool was also conducted. Readings from inside the cavity showed low levels of radiation and toxic and explosive gases. A final camera operation was conducted on July 29, 1986. Core samples were removed from the hole in December 1986 and on February 18, 1987 a concrete plug was set and the hole capped.

U12n.21 Drift - Middle Note

Middle Note was the eighteenth nuclear test in the U12n Tunnel and was executed on March 18, 1987 in the U12n.21 drift (Schoengold 1999:140). LLNL provided the nuclear device and it had a yield of less than 20 kilotons (DOE/NV 2000). Vertical depth of the test was 1,309 ft (399 m) below surface. The Middle Note test was the first horizontal line-of-sight low yield, full-scale effects test (Peterson, Rimer, et al 1993:4)

Mining of the U12n.21 drift began in July 1985 and consisted of a line-of-sight drift, a bypass drift, a zero room, and alcoves for experiments, support, and the vacuum pumping station (Schoengold 1999:142). Work on the drift was interrupted in September because of the Mill Yard and Diamond Beech nuclear tests. Work resumed in the middle of October. The line-of-sight drift began to the right from the U12n.10 main drift, while the bypass drift began to the left from the U12n.08 bypass drift (Figures 91-92). The U12n.21 main drift was 19 ft (5.8 m) wide and 18 ft (5.5 m) high where it began and decreased incrementally in size to 9 ft (2.7 m) wide and high on the working point side of the gas seal auxiliary closure and maintained this size to the zero room. The bypass drift was 10 ft (3 m) wide and high the entire length. The line-of-sight pipe was 810 ft (247 m) long, 10 ft in diameter at the portal end, and contained a fast auxiliary closure, a gas seal auxiliary closure, a tunnel-and-pipe-seal, a debris barrier system, three test chambers, and two scatterer stations. The

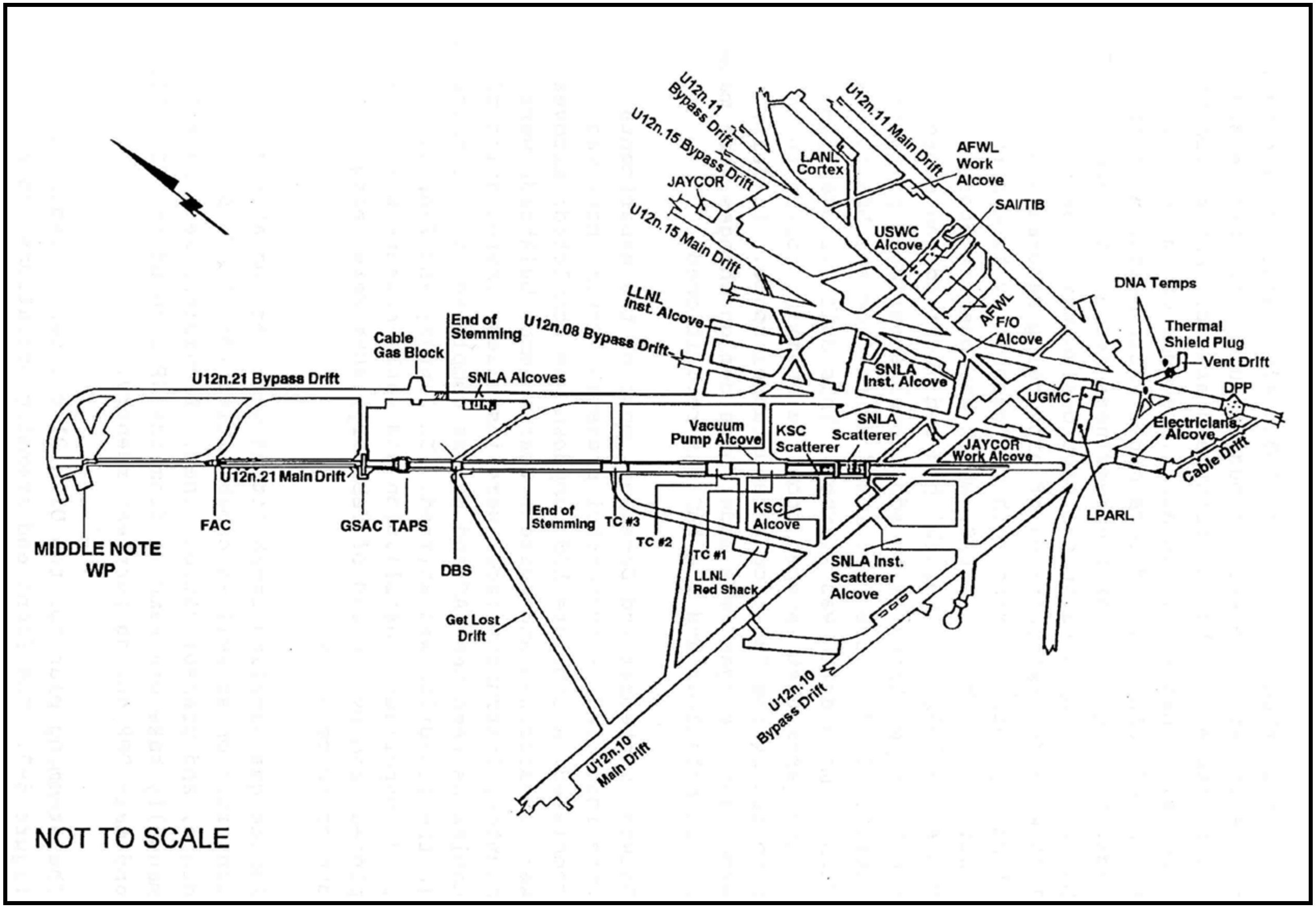


Figure 91. Plan of the U12n.21 drift for the Middle Note test (Schoengold 1999:143).

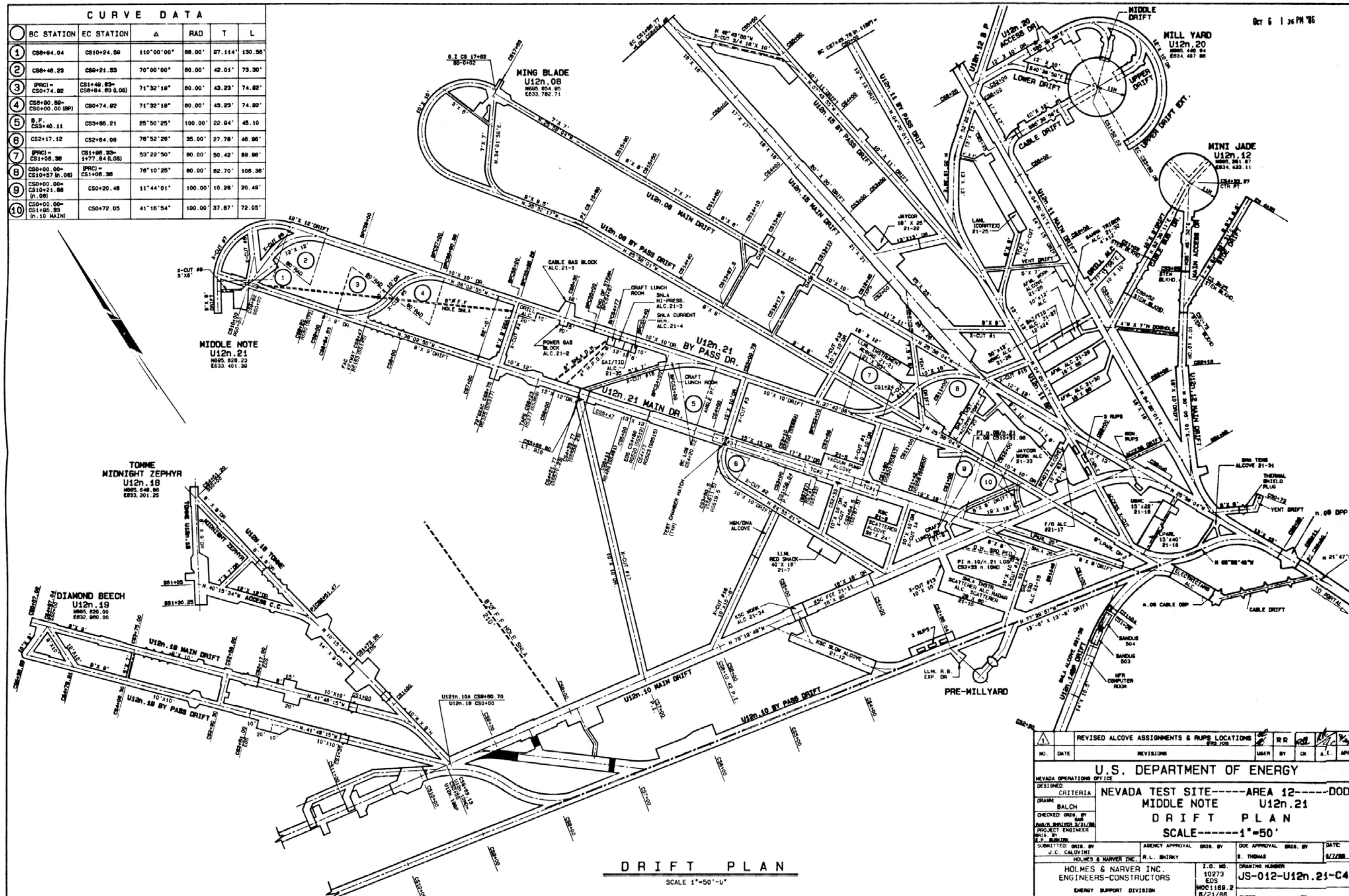


Figure 92. Construction plan of the U12n.21 drift for the Middle Note test, 1986 (drawing JS-012-U12n.21-C4.1, on file at Archives and Records Center, Mercury, Nevada).

scatter stations were located toward the portal end of the pipe. A scatterer deflected radiation flux from the line-of-sight pipe into an experiment alcove or station. Kaman Sciences Corporation and Sandia National Laboratory fielded the two scatterer stations. The debris barrier system had been in storage for 15 years and was refurbished and modified to provide additional experiment protection (Schoengold 1999:144). A "get lost" side drift connected to the U12n.10 main drift was added to the line-of-sight drift at the debris barrier system. The get lost side drift served as a passageway for radioactive gases diverted by the system into unused tunnel space. Stemming extended out from the working point to 520 ft (158 m) in the line-of-sight drift and 430 ft (131 m) in the bypass drift (Schoengold 1999:146). Grout and concrete were placed from the working point out, while sand bags were used to fill the space behind it. Cables and water lines were gas blocked to stop seepage of radioactive gases along these routes.

Experiments and recording equipment were installed during the first months of 1987. Following about two months of dry runs a mandatory full power dry run was conducted on March 10, 1987. It was announced that the mandatory full power dry run was successful and the nuclear device was installed that afternoon. Final work on the experiment system and the button-up stemming took place and the final dry run was conducted on March 17. In the early morning of March 18, all personnel vacated the area except for the arming party, button-up party, and security (Schoengold 1999:155). Detonation was set for 7:00 in the morning, but was delayed 3.5 hours because a faulty valve had to be replaced. The Middle Note nuclear device was detonated at 10:30 on the morning of March 18, 1987. The cavity collapsed 25 minutes after detonation (Townsend et al. 2007).

All remote area monitoring system units except for 12 units closest to the working point read background radiation levels just after detonation (Schoengold 1999:155). Radiation readings from these 12 units decreased through time, with 7 reaching background levels when the units were secured on March 20. Five units in the line-of-sight drift were still reading elevated levels of radiation when the units were secured. Initial reentry to the portal and the portal ventilation pad commenced just before noon on March 18 and finished by 12:15. Radiation readings at these locales were at background levels. Remote gas sampling in the tunnel did not detect explosive or toxic gases. Data recovery was then conducted at the portal. The nuclear detonation was successfully contained with no release of radioactive material to the atmosphere.

Reentry into the tunnel started the next day, or D+1. While the reentry teams were suiting up, the work team proceeded to the portal side of the gas seal door where they took readings for gasses and radiation on the working point side. After reviewing the results, the reentry controller gave them permission to open the man door and check the working point side for water. There was none and they then opened the trainway door and reinstalled the rail lines through the plug. Following the reentry controller's briefing, the first reentry team proceeded underground to the U12n main drift gas seal plug and the U12n.08 drift protection plug. The same procedure for going through the gas seal door was followed for each successive plug until the reentry team opened the containment doors at the thermal shield plug and reestablished ventilation to the mesa. The mesa fans were turned on, providing good ventilation to the remainder of the tunnel inside the U12n.08 drift protection plug. The team then proceeded to the U12n.21 line-of-sight drift and, following the same procedures, passed through the first and second shield walls. Toxic gases were present at both shield walls and elevated radiation readings were detected at the second shield wall. Elevated radiation readings and toxic and explosive gases were also found at the third test chamber (Schoengold 1999:158). The first reentry team returned to the U12n.08 drift protection plug to be replaced by the second reentry team who proceeded to the U12n.21 facility drift protection plug on the portal side of test chamber 1. After detecting toxic and explosive gases on the working point side of the facility drift protection plug, they opened the crawl tube and established ventilation to the working point side (Schoengold 1999:158). The second reentry team then went to the first test chamber and found elevated radiation levels and toxic and explosive gases. The LLNL and the bypass drift alcove protection plugs were checked and only background radiation levels detected. The alcove protection plugs were opened and ventilation was established through these plugs into the alcoves. Data recovery was undertaken at the LLNL and Sandia alcoves.

On March 20, or D+2, the reentry team surveyed the alcoves in the U12n.21 bypass drift, noting some damage along the way and at the alcoves, but nothing of great concern. Ventilation was established to the alcove and stub pipe areas (Schoengold 1999:158). Next, scientific assessment and data recovery teams entered the test chambers and alcoves to recover data and assess equipment and experiments for removal. Recovery of equipment and experiments continued for the next two months into May, but most of the equipment and experiments were removed by the end of March.

Post test reentry mining also commenced on March 20, or D+2, with removal of the U12n main drift gas seal plug trainway and the drift protection plug trainway in the U12n.08 drift (Schoengold 1999:159). Mining in the U12n.21 drift began on March 24, or D+6, in the bypass drift, at the facility drift protection plug, and at the line-of-sight drift shield walls. Crosscuts were mined to the fast acting closure, gas seal auxiliary closure, and the tunnel-and-pipe-seal from April to July and sections of the line-of-sight pipe were removed in September. Clean up and maintenance of the alcoves continued intermittently until April 1988. Core drilling and sampling from around the working point started in the bypass drift in late November 1988 and was finished by February 1989 (Schoengold 1999:160).

U12n.22 and U12n.22a Drifts - Mineral Quarry and Randsburg

Mineral Quarry and Randsburg, the twentieth and twenty-first nuclear tests in the U12n Tunnel, were detonated at the same time on July 25, 1990 and in the same drift complex. Mineral Quarry was in the main U12n.22 line-of-sight drift and Randsburg in the U12n.22a drift. Both nuclear explosions were less than 20 kilotons in yield, with LANL supplying the Mineral Quarry device and LLNL the Randsburg device (DOE/NV 2000). Both tests were located in the upper part of geological Tunnel Bed 4 and at vertical depths of 1,276 ft (389 m) below the surface.

Mining of the U12n.22 drift complex began in January 1988 and, as shown in Figures 93-94, started in a northwest direction off the U12n north extension drift (Schoengold 1999:254). In the beginning, work progress was intermittent because miners and equipment were allocated to the final preparations of the Misty Echo test in the U12n.23 drift. After the Misty Echo test, the focus shifted to the U12n.22 drift complex and the mining for both the line-of-sight and bypass drifts was completed in March 1989. The Mineral Quarry line-of-sight drift was mined 1,222 ft (372m). It started at the intersection of the U12n.22 drift and the U12n extension north drift and extended in a northwesterly direction to a point 14 ft (4.3 m) beyond the working point. A portion of the U12n extension north drift was used as a slow alcove for recording the test (Figure 95). An extension of the line-of-sight drift, named the stubs drift, was mined 121 ft (37 m) south of the U12n extension

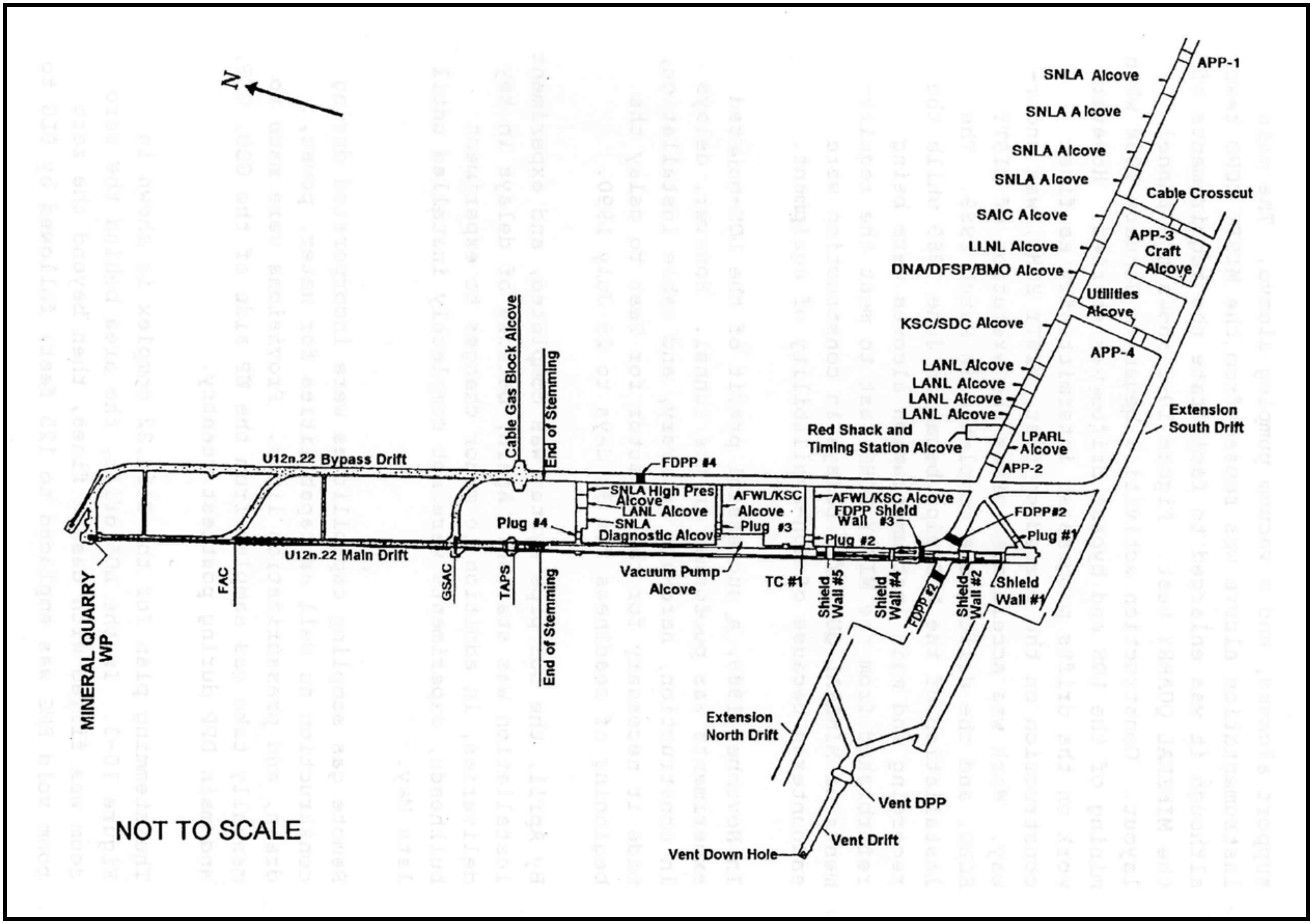
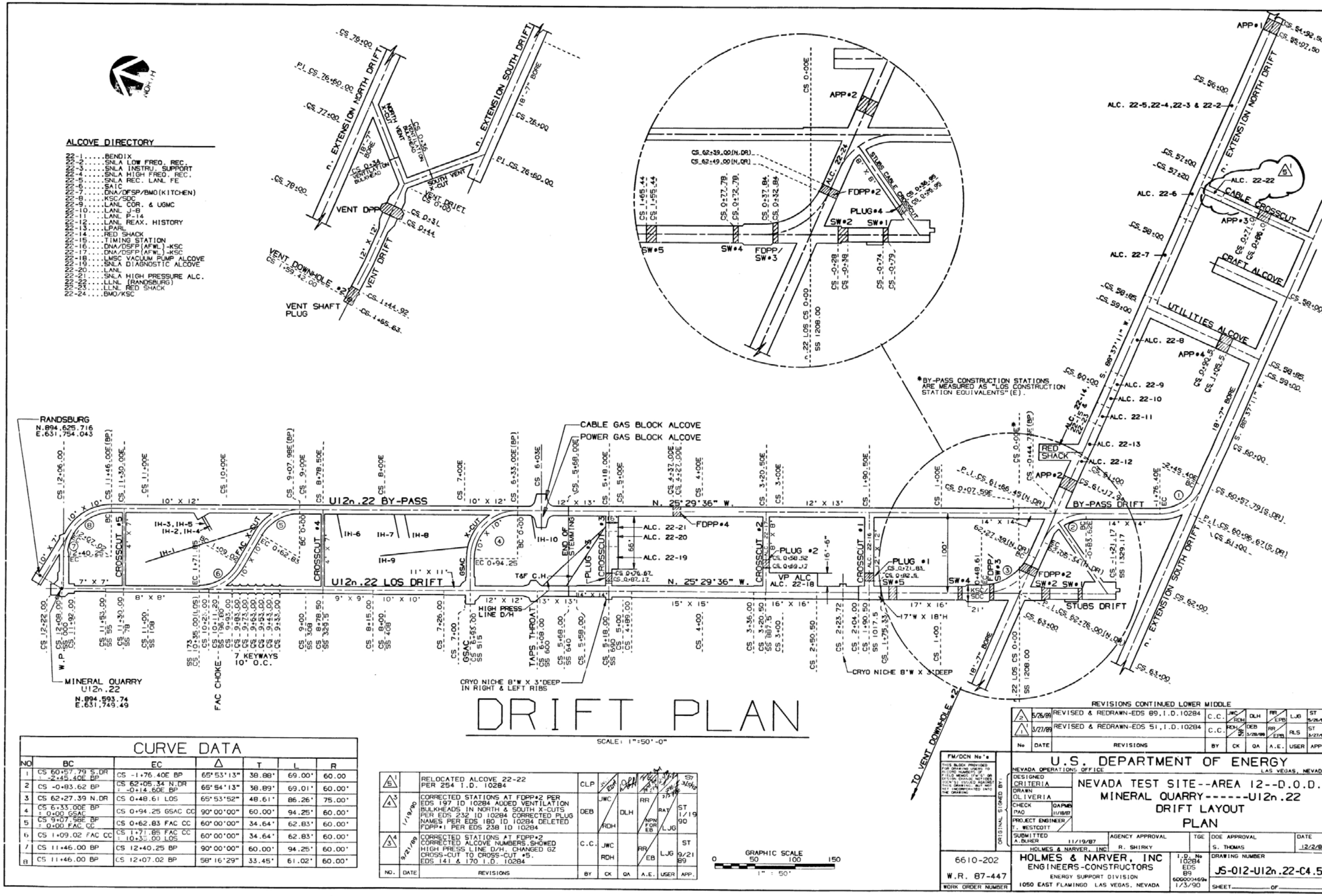


Figure 93. Drift plan of the U12n.22 drift for the Mineral Quarry and Randsburg tests (Schoengold 1999:256).



NO	BC	EC	Δ	T	L	R
1	CS 60+57.79 S.DR = -2+45.40E BP	CS -1+76.40E BP	65°53'13"	38.88'	69.00'	60.00
2	CS -0+83.62 BP	CS 62+05.34 N.DR = -0+14.60E BP	65°54'13"	38.89'	69.01'	60.00'
3	CS 62+27.39 N.DR	CS 0+48.61 LOS	65°53'52"	48.61'	86.26'	75.00'
4	CS 6+33.00E BP = 0+00 GSAC	CS 0+94.25 GSAC CC	90°00'00"	60.00'	94.25'	60.00'
5	CS 9+07.98E BP = 0+00 FAC CC	CS 0+62.83 FAC CC	60°00'00"	34.64'	62.83'	60.00'
6	CS 1+09.02 FAC CC	CS 1+71.85 FAC CC = 10+35.00 LOS	60°00'00"	34.64'	62.83'	60.00'
7	CS 11+46.00 BP	CS 12+40.25 BP	90°00'00"	60.00'	94.25'	60.00'
8	CS 11+46.00 BP	CS 12+07.02 BP	58°16'29"	33.45'	61.02'	60.00'

Figure 94. Construction plan of the U12n.22 drift for the Mineral Quarry test, 1987 (drawing JS-012-U12n.22-C4.5, on file at Archives and Records Center, Mercury, Nevada).

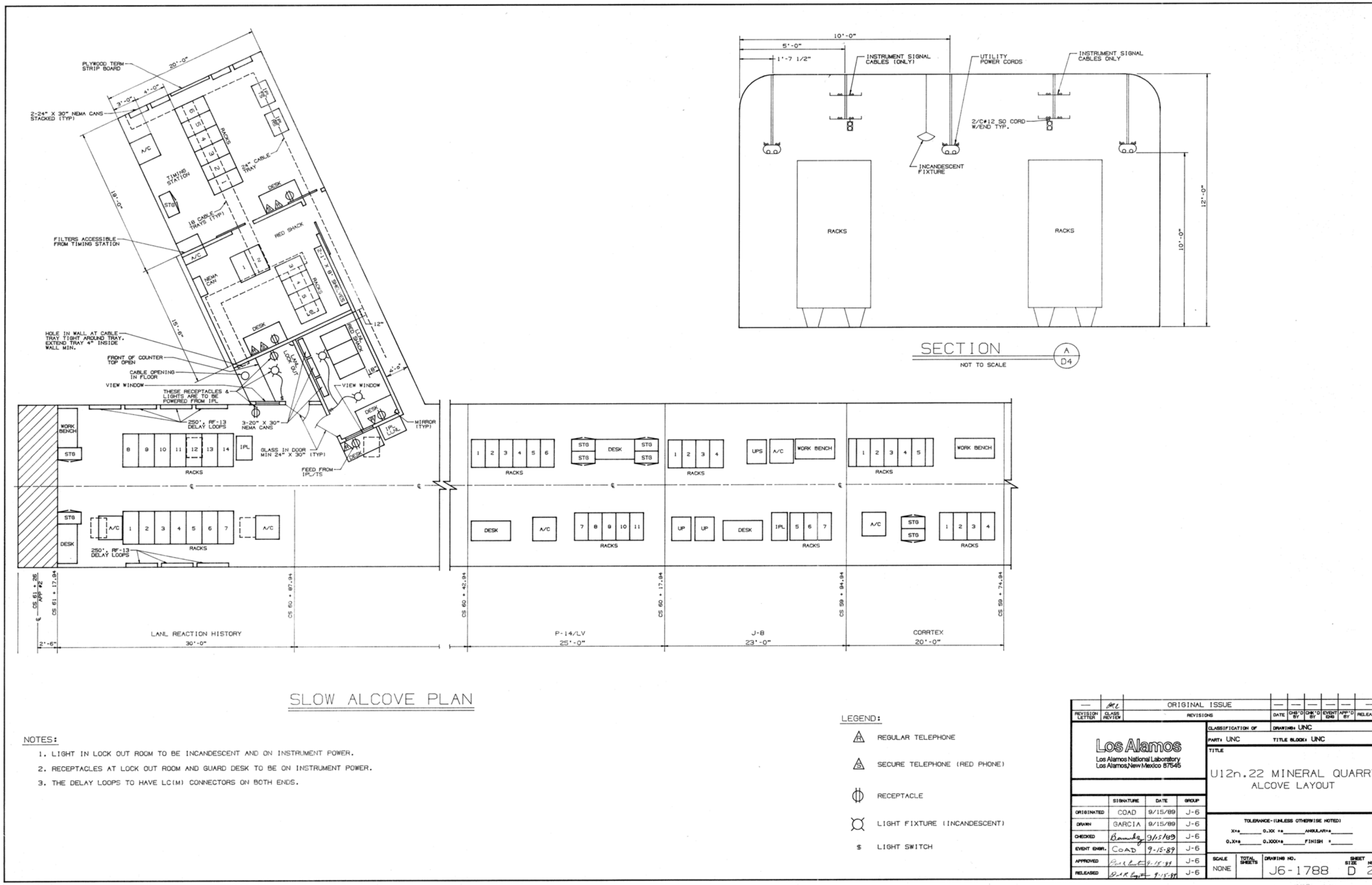


Figure 95. Plan of the slow alcove in the U12n.22 drift for the Mineral Quarry test, 1989 (drawing J6-1788-D-2, on file at Archives and Records Center, Mercury, Nevada).

north drift. The bypass drift turned off the U12n extension south drift at 6,058 ft (1,846 m), curving to the northwest and paralleling the U12n.22 line-of-sight drift. From center line to center line, the line-of-sight drift and the bypass drift were 100 ft (30m) apart. The bypass drift continued northwest for 1,146 ft (349 m) where it took a 90 degree turn to the left toward the working point. The bypass drift measured 14 ft (4.3m) wide and high at the start and decreased to 10 ft (3m) wide and high where it intersected the zero room. Eight crosscuts were mined between the line-of-sight and bypass drifts. Two of the crosscuts accessed the fast acting closure and the gas seal auxiliary closure.

The U12n.22a drift, also known as the Randsburg experiment drift, was approximately 80 ft (24 m) long, and mined to the right of the bypass drift at 1,207 ft (368 m). It measured 10 ft wide and high at the start where it conformed to the size of the bypass drift and 10 ft (3 m) wide and 7 ft (2.1 m) high where it intersected the zero room. The zero room measured 13 ft (4 m) wide and high. The Randsburg working point was 32 ft (9.8 m) and 8 degrees northeast of the Mineral Quarry working point.

The line-of-sight pipe for the Mineral Quarry test was 1,032 ft (315 m) long and the inside diameter ranged from several inches at the working point end to approximately 12 ft (3.7 m) at the other end. The first three sections of pipe were made of stainless steel, while the remainder were of mild steel (Burres 1991a). Experiment protection in the pipe included a fast acting closure, a gas seal auxiliary closure, and a tunnel-and-pipe-seal. The tunnel-and-pipe-seal was recovered from the Mission Cyber test conducted in the U12p Tunnel in 1987. A device protection barrier with six interlocking panels was placed on the working point side of the tunnel-and-pipe-seal. A decoupler was positioned in the pipe on the portal side of the tunnel-and-pipe-seal and after the end of stemming. Attached to the pipe were four experiment bulkhead stations, five radiation diagnostic stub pipes, and six experiment stub pipes. The experiment bulkhead stations ranged in length from approximately 25 ft (7.6 m) to 30 ft (9.1 m) and, corresponding to position in the line-of-sight pipe, internal diameters from approximately 8.5 ft (2.6 m) to 12 ft (3.7 m). A 7 ft (2.1 m) diameter cylindrical chamber 30 ft (9 m) long with its own ventilation system was inserted into the stub pipe system for housing experiments. The stub pipes varied in diameter from 10 inches (25 cm) to 4 ft (1.2 m) and in length from 31 ft (9.4 m) to 290 ft (88.4 m). The line-of-sight drift extended about 120 ft (36.6 m) south of the U12n north extension drift to accommodate the stub pipes. The overall length of the pipe system, from the working point to the end of the furthest stub pipe, was 1,290 ft (393 m). Installation of the line-of-sight pipe began in June 1989 and did not finish until April 1990 because of delays in construction, cable installation, and delivery of hardware (Schoengold 1999:255). The experiment bulkhead stations were installed by May 1990 (Burres 1991b:3). Two 20-inch cryogenic pumps were placed in the A-box at the working point and four 35-inch cryogenic pumps and two standard vacuum pump modules were placed outside stemming to provide a vacuum to the pipe in order to simulate a high altitude environment (Burres 1991a). Experiments and related hardware were installed from April to July 1990. The Mineral Quarry line-of-sight drift was stemmed with various types of grout and concrete out to 640 ft (195 m). The Randsburg line-of-sight drift was fully stemmed with grout and the Mineral Quarry bypass drift was stemmed with various types of grout and concrete for 712 ft (217m) (Schoengold 1999:258).

The mandatory full-power dry run was completed on July 11, 1990, the nuclear devices inserted, and final stemming began the next day (Schoengold 1999:259). Stemming behind the devices consisted of fine desert sand. The final pump down of the vacuum system began on July 20 (Burres 1991b:4).

A final dry run was completed on July 24. By midnight, all non-essential personnel had left the area, leaving only the arming parties, the button-up teams, and security (Schoengold 1999:267). By 7:00 on the morning of July 25, both devices had been armed, button-up procedures completed, and all personnel cleared from the area. The Mineral Quarry and Randsburg nuclear devices were detonated an hour later at 8:00 in the morning. All remote area monitoring system units except those in the Mineral Quarry line-of-sight drift read normal background levels of radiation after detonation and continued to do so until they were secured on July 31, or D+6 (Schoengold 1999:267). As expected, the highest reading was from the remote air monitoring system unit at the end of stemming in the line-of-sight drift, but the readings for it and the other units in the drift rapidly decreased to safe conditions within 24 hours. The chimney collapsed 11 hours and 43 minutes after detonation (Townsend et al. 2007). As suggested by Townsend et al. (2007), the long interval between detonation and collapse may be attributed to the strength of the geological medium and the absence of earlier nuclear explosions nearby which would have weakened the surrounding rock.

Initial reentry to the portal began about 1.5 hours after detonation and the team completed their survey of the area within 30 minutes (Hernandez and Jacklin 1992; Schoengold 1999:268). No radiation levels above normal background were detected. Remote gas sampling within the tunnel was then conducted. Samples were obtained from inside the gas seal plug, the portal and working point sides of the drift protection plug, the end of stemming in the bypass drift, the line-of-sight drift, and inside the line-of-sight pipe. No toxic or explosive gases were detected. The next day, or D+1, the work team proceeded to the gas seal door where they measured gas and radiation levels on the WP side. After receiving approval from the reentry controller, the work team opened the personnel door, checked for water on the working point side, and established ventilation to the portal side of the gas seal plug. They then opened the large door and reinstalled the rail line through the door and walked back out to the portal, a distance of about 1,740 ft (530 m). The first reentry team then proceeded from the portal to the gas seal plug by man train where they completed assigned tasks at the gas seal plug and then the drift protection plug on their way to reestablish ventilation from the mesa at the U12n.08 thermal shield plug. The reentry team then came back out the U12n.08 drift to the U12n.05 line-of-sight drift, then proceeded to the U12n extension utilities drift through the alcove protection plug to the extension north drift, and eventually to the U12n.22 drift complex for the Mineral Quarry and Randsburg tests. Walking in total darkness except for their headlamps and each wearing a self contained breathing apparatus, the reentry team systematically checked the physical condition of the tunnel and the presence of toxic gas, explosive gas, or radiation. The first reentry team had advanced to the craft alcove in the extension south drift when their scheduled time with the supplied air from the self contained breathing apparatus was running out. They departed the tunnel and were replaced by the second reentry team. The second team arrived at the U12n.22 drift where they opened the required alcove protection plugs and checked tunnel conditions along the way to the Mineral Quarry line-of-sight drift. They checked out the test chambers, reporting the gasses and radiation data to the reentry controller and returned to the portal. The initial reentry operations were then completed. Some data recovery teams entered the tunnel about 6:00 in the evening to retrieve data from their respective alcoves and were finished around 7:30.

Mining of trainways through the containment plugs began on July 27 or D+2. Reentry teams completed the assessment of the tunnel, opened vent hole 2 to increase the ventilation, and established electrical power. The test chamber was opened and elevated radiation and toxic gas levels were detected inside. A vent line was connected to the test chamber to purge the line-of-sight pipe system, which aided the recovery operation. A scientific assessment team entered the tunnel on July 30, or D+5, to evaluate conditions inside the line-of-sight pipe. From August 1 to 13, most of the experiments were recovered from the line-of-sight drift; data recovery from the stub pipes continued until September 6. From October to December 1990, one post test probe hole (U12n.22 RE-1) was drilled from crosscut 3 toward and 150 ft (46 m) above the working point to collect gas samples and determine the size of the chimney. The drill hole was filled with grout about two months after sampling was completed. No other post test drilling or mining activities were conducted.

U12n.23 Drift - Misty Echo

The Misty Echo nuclear test was conducted on December 10, 1988 in a hemispherical cavity in the U12n.23 drift (Schoengold 1999:206). It was the nineteenth nuclear test in the tunnel and its purpose was to investigate the phenomenology of ground shock and cratering as produced by a nuclear device positioned near the floor of a cavity. LANL supplied the nuclear device and it had a yield of less than 150 kilotons (DOE/NV 2000). Vertical depth of the test was 1,313 ft (400 m) below the surface.

Mining of the U12n.23 drift began May 7, 1987 (Bennett 1991). It consisted primarily of an access drift 1,901 ft (579 m) long, equipment alcoves, support alcoves, and a mined hemispherical cavity at the end of the access drift (Figures 96-97). The Misty Echo access drift started 5,654 ft (1,723 m) from the U12n extension drift portal. It turned nearly 90 degrees to the south of the U12n extension drift and was mined 14 ft (4.3m) high and wide at this juncture. While the width was maintained, it decreased to 10 ft (3 m) in height after 821 ft (250 m) and until it entered the cavity. A wide zone in the access drift near the cavity was 22 ft (6.7m) wide by 46 ft (14m) long. Mining of the drift was slower than anticipated because of delays selecting the cavity location and there were concerns about a geological fault in the area. Compounding the situation were delays due to craft labor issues.

The cavity location was finally established in February 1988, when the access drift was about halfway complete. Mining of the cavity began in March 1988 and was finished in early July. It measured 59 ft (18 m) high total and had a diameter of 72 ft (22 m) at the widest (Figure 98). The upper portion of the cavity was a hemisphere with a radius of 36 ft (11m), while the lower portion descended 23 ft (7 m) in a decreasing stair-step fashion to a circular-shaped floor with a diameter of 26 ft (8 m).

A second access drift was mined that went up to the base elevation of the upper hemispherical portion of the cavity. It started at the point of intersection of where the first access drift turned left to the cavity and the second one went straight ahead. The point of intersection was at 1,756 ft (535 m) into the first access drift. The second access drift was 230 ft (70m) long when it reached the proposed location of the cavity. The inclined portion started 8 ft (2.4m) from the point of intersection and went up at 17 degrees. It leveled off 131 ft (40) meters from the start. The remainder of the second access drift remained level.

Mining of the upper hemispherical cavity started from the end of the second access drift where a ramp took a sharp turn to the right and spiraled around the outer edge of the cavity in an upward direction until the back or ceiling of the ramp was equal to the apex of the cavity. From there, level horizontal cuts were mined downward for an additional 24 ft (7.3 m) to reach the invert elevation

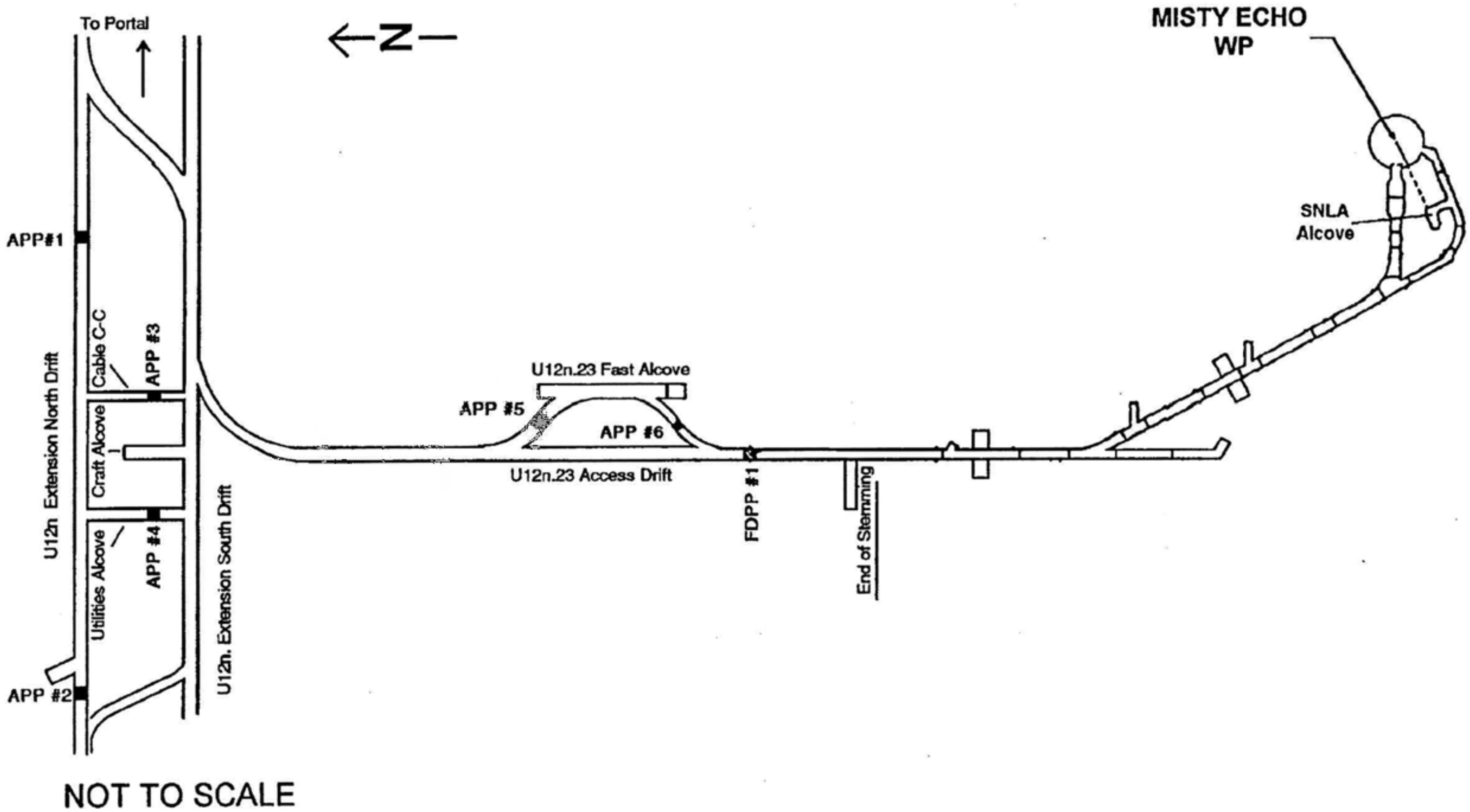


Figure 96. Plan of the U12n.23 drift for the Misty Echo test (Schoengold 1999:209).

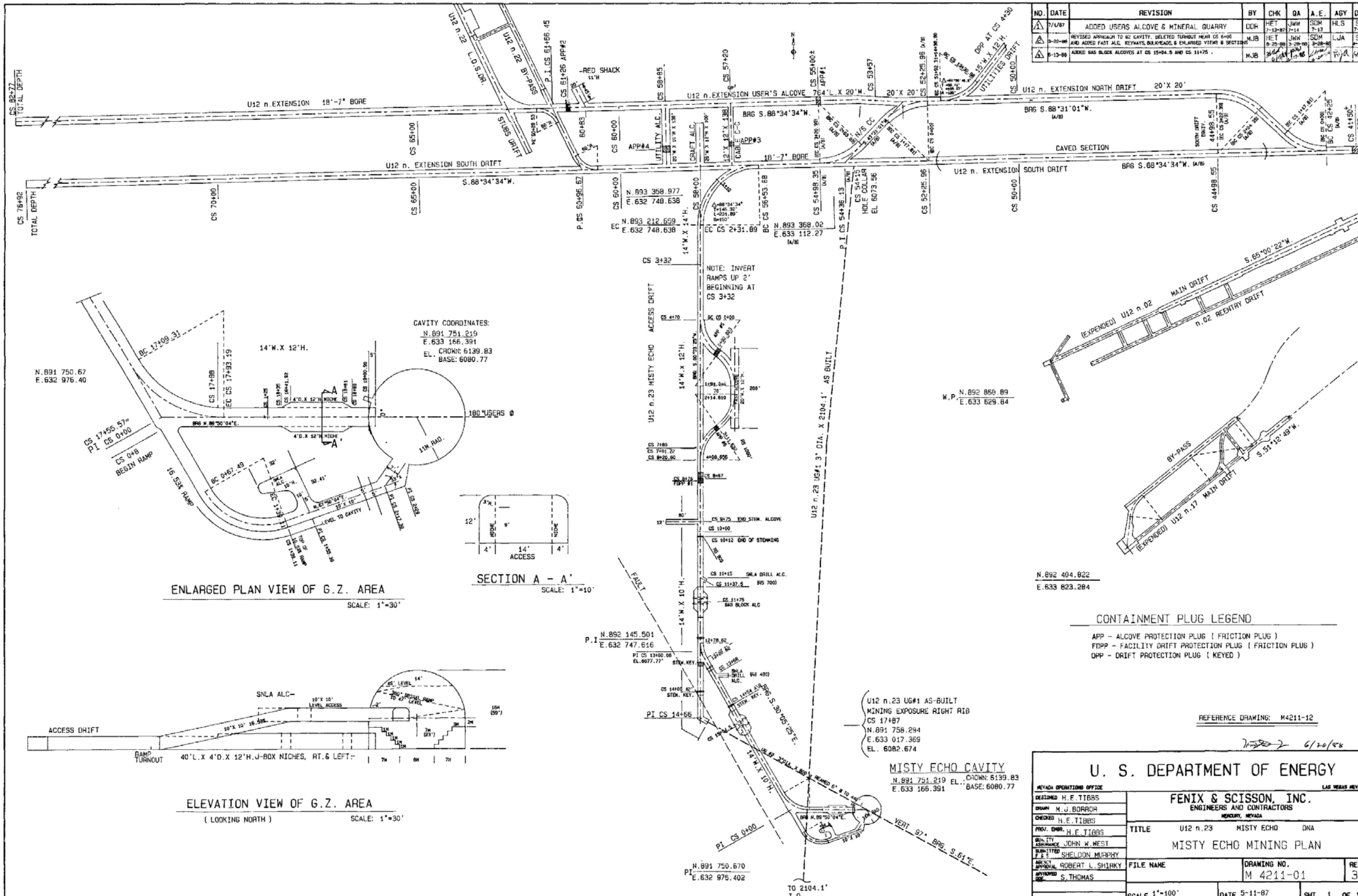


Figure 97. Construction plan of the U12n.23 drift for the Misty Echo test, 1987 (drawing M 4211-01.3, on file at Archives and Records Center, Mercury, Nevada).

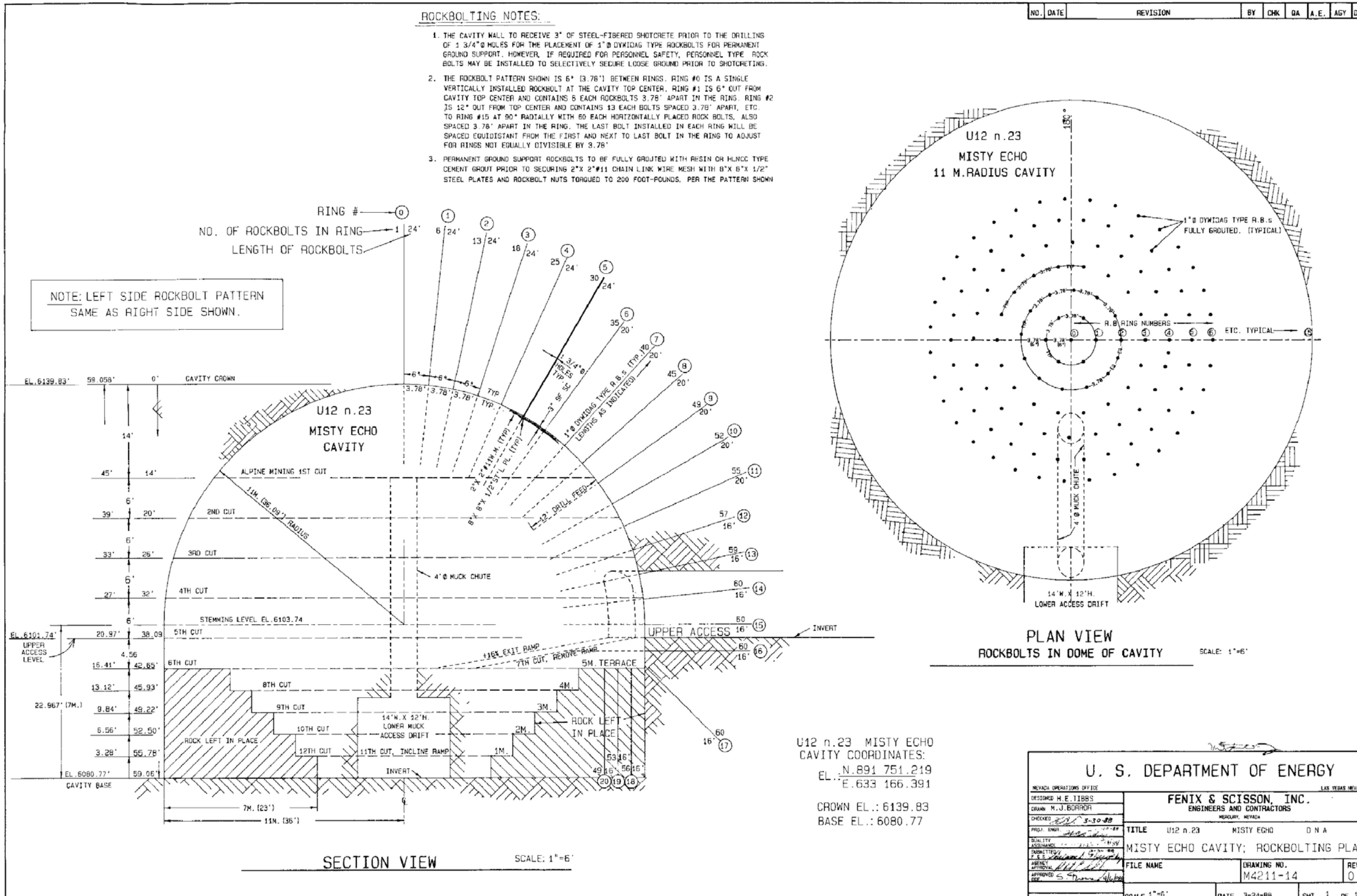


Figure 98. Plan and section of the cavity in the U12n.23 drift for the Misty Echo test, 1988 (drawing M 4211-14, on file at Archives and Records Center, Mercury, Nevada).

of the upper access drift. After mining the upper portion of the cavity, the bottom 23 ft (7m) of the lower cavity was mined out in 6 horizontal step-down lifts, reducing the 72 ft (22m) cavity diameter to a base diameter of 26 ft (8m) in diameter.

Installation of a large fiberglass structure to support cables and experiments began in July 1988, with cable installation completed by late August (Schoengold 1999:210). Construction continued over the summer and experiments and supporting equipment began to be set in place. Installation of the experiments and associated equipment and filling the cavity floor with grout were completed by November (Schoengold 1999:213).

Stemming of the U12n.23 access drift with grout extended 889 ft (271 m) from the working point (Figure 99). A facility drift protection plug was set just behind the end of stemming. Two alcove protection plugs were placed on each end of the U12n.23 drift fast alcove, a facility drift protection plug was installed in the curve going back into the U12n extension south drift, two alcove protection plugs were placed in the U12n extension north drift, and two alcove protection plugs were placed in the crosscuts between the extension north and south drifts (Schoengold 1999:209). A drift protection plug, a gas seal plug, and a friction plug were placed in the U12n extension drift. The nuclear device was installed and final stemming completed by early December. In the U12n main drift, the gas seal plug trainway was poured and the gas seal door was closed during final stemming operations.

Final preparations, including arming the device and tunnel button-up, for the Misty Echo nuclear test were conducted on December 8, 1988 for a planned detonation on that day. Poor weather conditions, however, delayed detonation until December 10, when conditions became favorable to proceed with the test (Schoengold 1999:220). The Misty Echo nuclear device was detonated at 12:30 in the afternoon (Schoengold 1999:221). Following the test, all remote area monitoring system units were reading background levels of radiation in the remote area monitoring system monitor room at control point and continued to do so until they were secured on December 13, or D+3. Initial reentry to the portal area began about an hour after detonation and the survey found only background levels of radiation. Remote gas sampling of the tunnel at the containment plugs did not detect toxic or explosive gases. The cavity collapsed 48 minutes after detonation (Townsend et al. 2007). The detonation was successfully contained within the tunnel.

Tunnel reentry began on the morning of December 11, or D+1 (Schoengold 1999:222).The reentry control personnel at the portal received radiation readings from the remote area monitoring system monitor room at control point. They were also briefed on the weather for the day. With conditions acceptable, reentry support personnel proceeded to the portal and started preparations for reentry. The work team was given a health and safety briefing before proceeding underground to the portal side of the gas seal door while the reentry teams finished dressing and radsafe and industrial hygiene technicians readied their equipment. The work team took measurements from the working point side of the gas seal door, received permission from the reentry controller to proceed, and opened the personnel door to determine if any water had accumulated behind the plug; there was none. They then opened the trainway door, reinstalled the rail line, and opened the vent line valve to establish ventilation to the portal side of the gas seal plug. The work team then returned to the portal and the first reentry team proceeded to the main gas seal plug and the U12n.8 drift protection plug where they checked the working point sides of each plug for toxic or explosive gases and radiation, opened

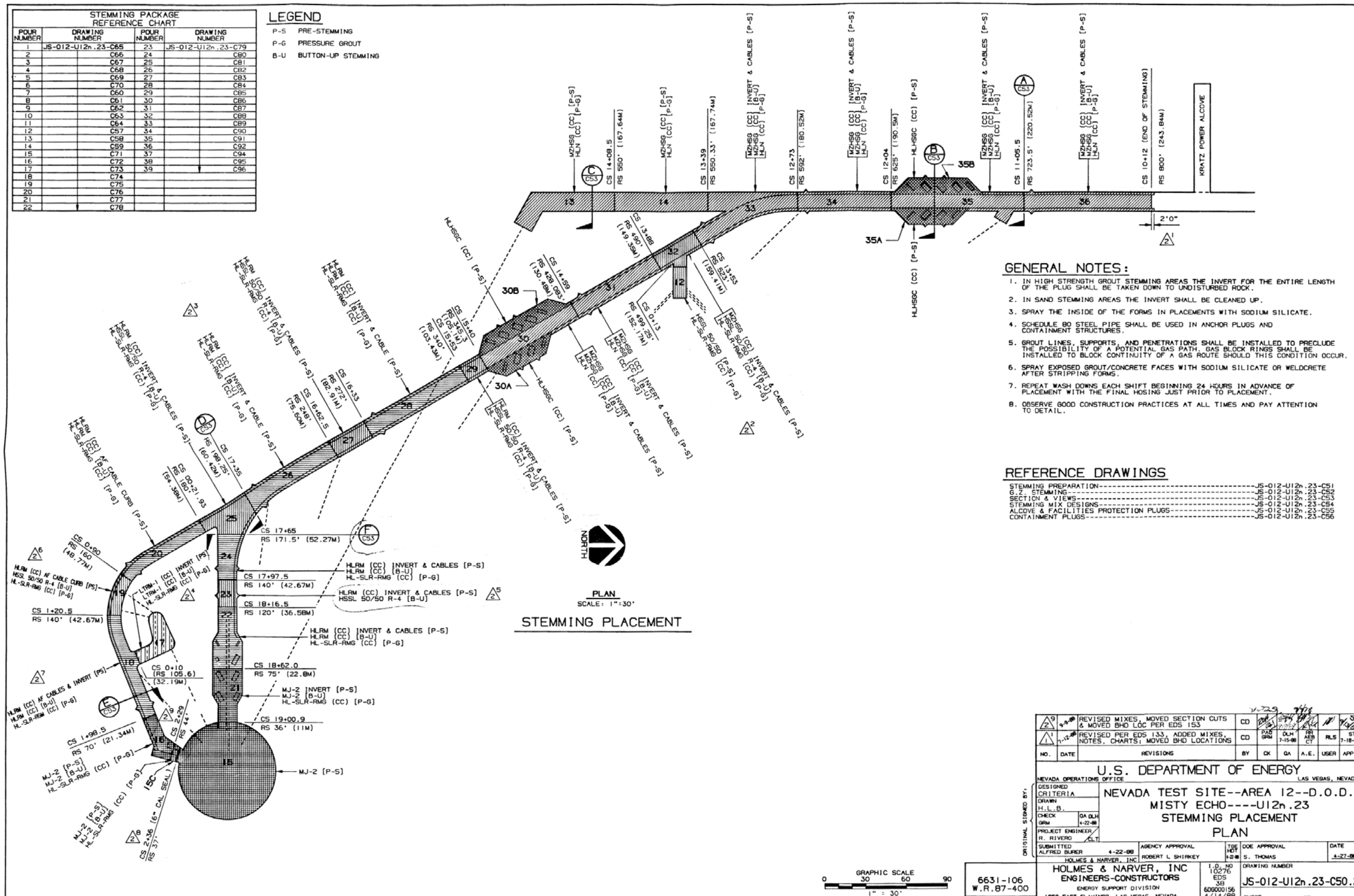


Figure 99. Stemming plan of the U12n.23 drift for the Misty Echo test, 1988 (drawing JS-012-U12n.23-C50.2, on file at Archives and Records Center, Mercury, Nevada).

the personnel tube turn containment doors, established ventilation forward, and methodically continued onward with their reentry work. They continued to the U12n.08 thermal shield plug leading to the vent hole. They opened the crawl way through the plug, entered, opened the bottom door on the mesa vent tube, reconnected the vent line and asked for the mesa fans to be turned on. They then went to the U12n extension utilities drift protection plug, opened it and established ventilation to the first alcove protection plug in the U12n extension north drift. No toxic or explosive gases nor radiation levels above normal were found at any of these locations. The first reentry team then returned to the portal as their SCBA supplied air tanks were running low. The second reentry team proceeded to the utilities drift protection plug in the entrance of the U12n.23 drift and then to the fast alcove and the facility drift protection plug to reestablish ventilation. Radiation levels were at normal background at all these locations, but some toxic and explosive gases were detected on the working point side of the facility drift protection plug (Schoengold 1999:223). Some data were recovered from the tunnel, and later that night at 11:00 pm, post test reentry mining started with the removal of the gas seal plugs.

Through the rest of December, all the protection plugs were removed, rail lines installed, some cleanup of the alcoves and drifts conducted, materials and equipment removed from the tunnel, instrument racks removed from the fast alcove, and cables removed from the alcoves and in the U12n.23 main access drift to the end of stemming (Schoengold 1999:223). In January, a reentry drift was started from the U12n.23 main access drift and a reentry drill hole, RE #1, was started from the fast alcove. When the drill hole had reached the cavity wall, a 10 week long gas diagnostic experiment was conducted. It extracted gasses from the cavity through the drill hole, through the monitoring equipment, and then released them into the ventilation system. In February, when the reentry drift was within 375 ft (114 m), probe holes were drilled into the face of the drift for sampling ahead of the mining. Crosscut 1 was mined to within 35 ft (10.7 m) of the cavity. Work continued, thereafter, extending the reentry drift, mining a second crosscut, removing equipment, rehabilitating the main drift, conducting hydrofrac studies, and photography. This work continued through April 1990.

U12n.24 Drift - Hunters Trophy

The Hunters Trophy nuclear test on September 18, 1992 represents the last nuclear test and the twenty-second in the U12n Tunnel and the next to last on the NNSS. It was a weapons effects test and evaluated the reliability of the United States deterrent forces (DOE/NV 2000). LLNL provided the nuclear device and emplaced it in the U12n.24 drift at a vertical depth of 1,264 ft (385 m) below the surface. It had a yield of less than 20 kilotons (DOE/NV 2000). Two other nuclear tests, designated Hydro Ace for a low yield cavity experiment and Huron Forest as a low yield add on test, were once proposed to be detonated at the same time as the Hunters Trophy test (Peterson, Rimer, et al. 1993:44-45).

The U12n.24 drift was started on August 10, 1990 (Bennett 1991), and mined to the right in a northeast direction from the U12n extension north drift (Figures 100-101). The U12n.24 drift complex included a line-of-sight drift, a bypass drift, a cable drift, a horizontal line-of-sight pipe with three experiment protection closures, one test chamber, seven stub pipes, a zero room, an air scatterer, and a vacuum system (Schoengold 1999:326). Mining of the U12n.24 drift complex started in November 1990, with the line-of-sight and bypass drifts completed by May 1991. As with Mineral

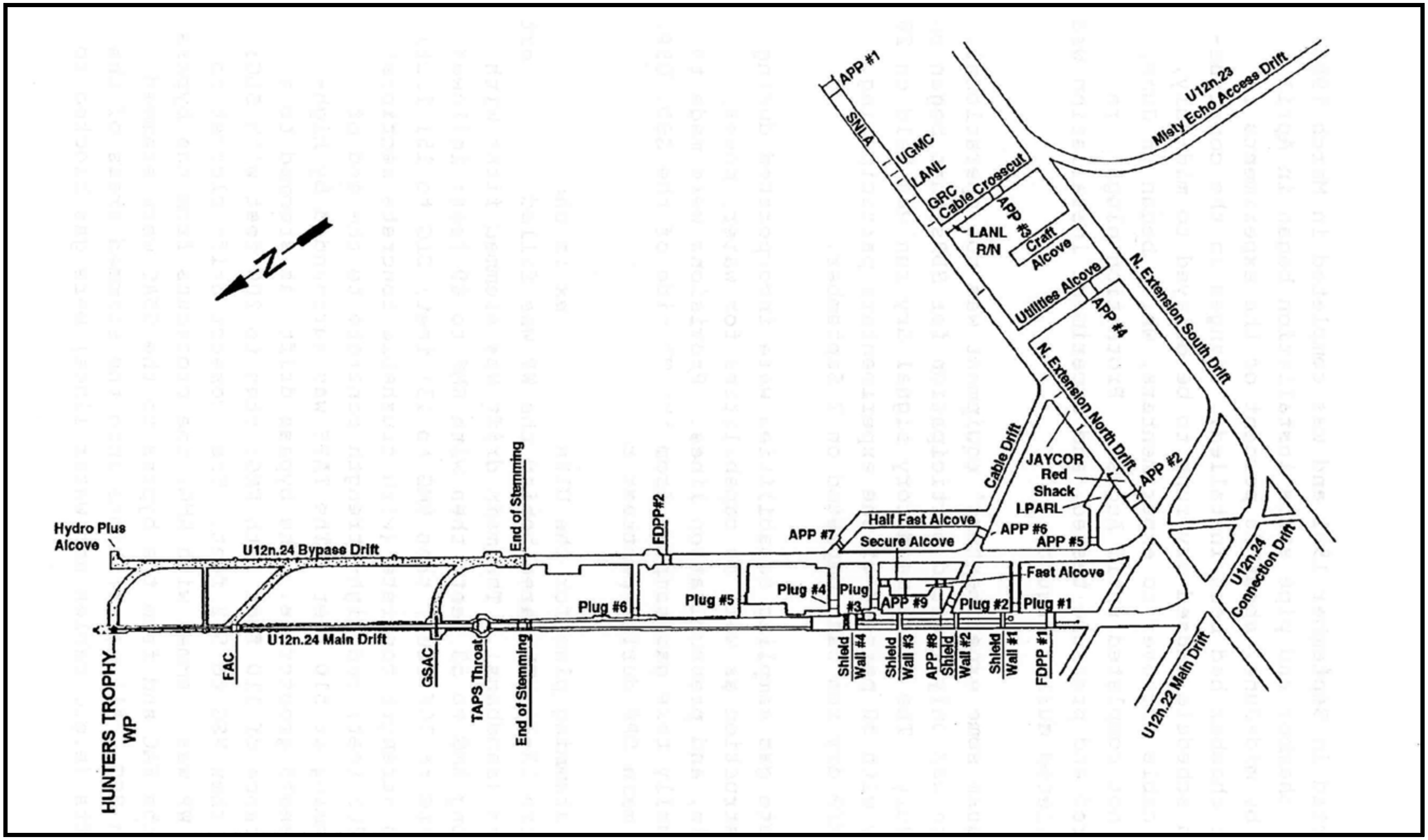
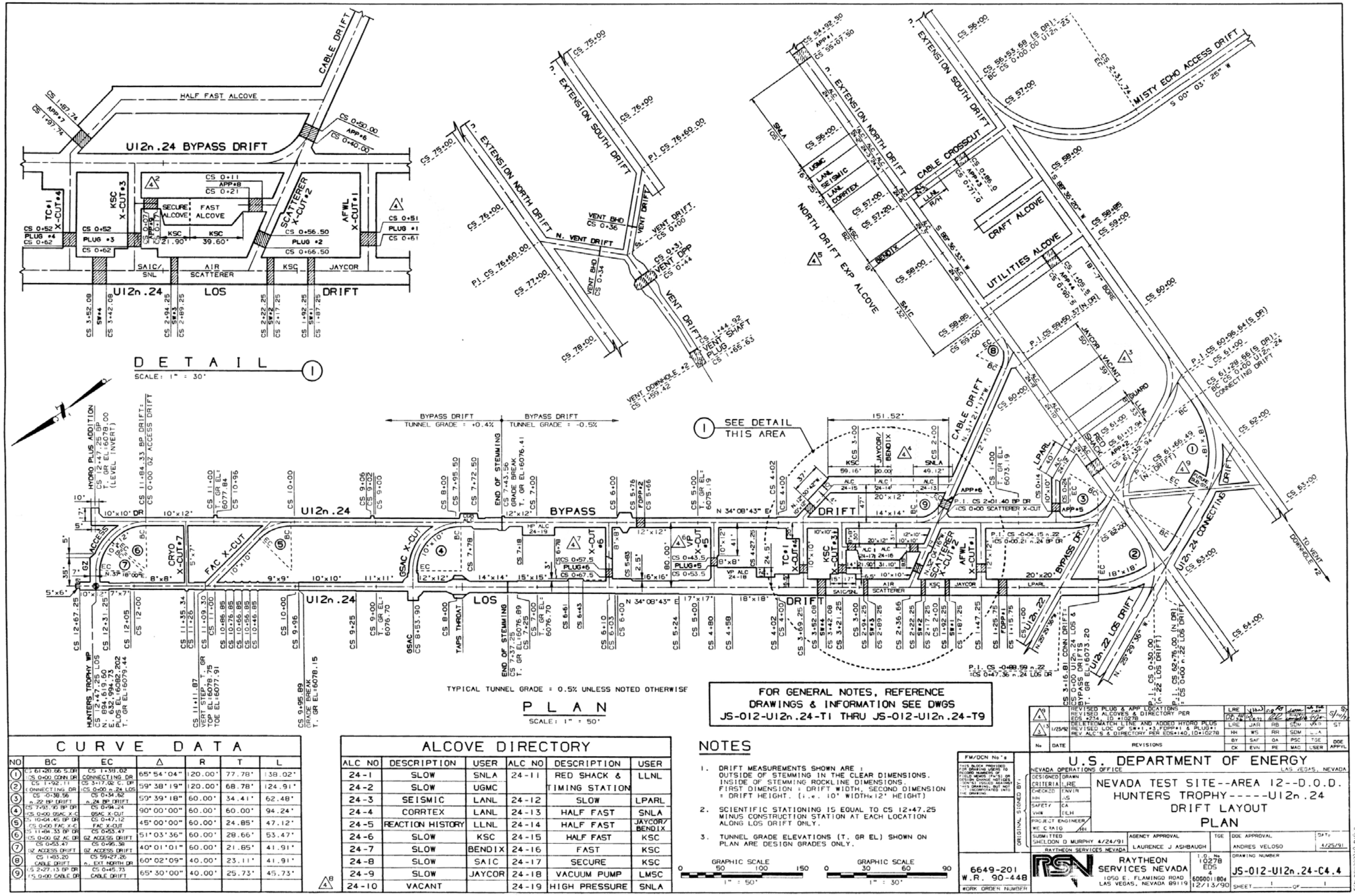


Figure 100. Plan of the U12n.24 drift for the Hunters Trophy test (Schoengold 1999:327).



NO	BC	EC	Δ	R	T	L
1	CS 61+28.66 S.DR =CS 0+00 CONN DR	CS 1+38.02 CONNECTING DR	65°54'04"	120.00'	77.78'	138.02'
2	CS 1+92.11 CONNECTING DR	CS 3+17.02 C. DR =CS 0+00 n.24 LOS	59°38'19"	120.00'	68.78'	124.91'
3	CS -0+38.56 n.22 BP DRIFT	CS 0+34.62 n.24 BP DRIFT	59°39'18"	60.00'	34.41'	62.48'
4	CS 7+93.90 BP DR =CS 0+00 GSAC X-C	CS 0+94.24 GSAC X-CUT	90°00'00"	60.00'	60.00'	94.24'
5	CS 10+04.45 BP DR =CS 0+00 FAC X-C	CS 0+47.12 FAC X-CUT	45°00'00"	60.00'	24.85'	47.12'
6	CS 11+84.33 BP DR =CS 0+00 GZ AC DR	CS 0+53.47 GZ ACCESS DRIFT	51°03'36"	60.00'	28.66'	53.47'
7	CS 0+53.47 GZ ACCESS DRIFT	CS 0+95.38 GZ ACCESS DRIFT	40°01'01"	60.00'	21.85'	41.91'
8	CS 1+83.20 CABLE DRIFT	CS 59+27.26 n. EXT NORTH DR	60°02'09"	40.00'	23.11'	41.91'
9	CS 2+27.13 BP DR =CS 0+00 CABLE DR	CS 0+45.73 CABLE DRIFT	65°30'00"	40.00'	25.73'	45.73'

ALC NO	DESCRIPTION	USER	ALC NO	DESCRIPTION	USER
24-1	SLOW	SNLA	24-11	RED SHACK & TIMING STATION	LLNL
24-2	SLOW	UGMC			
24-3	SEISMIC	LANL	24-12	SLOW	LPARL
24-4	CORRTEX	LANL	24-13	HALF FAST	SNLA
24-5	REACTION HISTORY	LLNL	24-14	HALF FAST	JAYCOR/BENDIX
24-6	SLOW	KSC	24-15	HALF FAST	KSC
24-7	SLOW	BENDIX	24-16	FAST	KSC
24-8	SLOW	SAIC	24-17	SECURE	KSC
24-9	SLOW	JAYCOR	24-18	VACUUM PUMP	LMSC
24-10	VACANT		24-19	HIGH PRESSURE	SNLA

Figure 101. Construction plan of the U12n.24 drift for the Hunters Trophy test, 1991 (drawing JS-012-U12n.24-C4.4, on file at Archives and Records Center, Mercury, Nevada).

Quarry, the Hunters Trophy line-of-sight and bypass drifts began near the U12n extension north drift. The drifts were parallel to each other and 80 ft (24 m) apart at the center lines. The construction starting point designation for each drift was construction station (CS) 0+00. The line-of-sight drift ended in the zero room. Completing the line-of-sight drift was a 317 ft (97 m) long connecting drift that extended from CS 0+00 in the U12n.24 line-of-sight drift to CS 61+29 in the U12n extension south drift. The connecting drift utilized the 121 ft (37 m) long Mineral Quarry stubs pipe drift and had curves on both ends that joined the U12n.24 line-of-sight drift and the U12n extension south drift. The U12n.24 bypass drift extended from CS 0+00 to the U12n extension south drift by utilizing a section of the existing Mineral Quarry bypass drift. A short curve connected the two bypass drifts. The U12n.24 bypass drift ended at CS 11+84. From CS 11+84, the bypass drift was connected to the zero room by a 115 ft (35 m) long access drift.

The line-of-sight drift measured 20 ft (6 m) high and wide at the start to the vacuum pump alcove and beyond the vacuum pump alcove the drift decreased in size by 1 ft (30.5 cm) increments to 7 ft (2.1 m) high and wide at the zero room (Rivero 1992:3). The U12n.24 bypass drift, from the U12n extension south drift to the working point, was approximately 1,575 ft (480 m). The bypass drift included a section of the U12n.22 bypass drift from the U12n extension south drift to a common point at the start of the U12n.24 bypass drift and through the curve leading into the zero room. The bypass drift measured 14 ft (4.3 m) high and wide at the start in the U12n extension south drift and 12 ft (3.7 m) high and 10 ft (3 m) wide at the end. The zero room access drift was 12 ft (3.7 m) high and 10 ft wide the entire length except for the last 30 ft (9 m) where the right rib was widened by 2 ft (61 cm) to support the LLNL experiment stub pipe. Ten crosscuts were mined between the two drifts for access routes to the line-of-sight drift. Some of the crosscuts also served as experimenter alcoves. The bypass drift was used to install the nuclear device after the line-of-sight drift was stemmed and ready for the test.

Installation of the line-of-sight pipe started in September 1991 and finished in March 1992 (Schoengold 1999:328). The pipe measured 850 ft (259 m) long and included a fast acting closure, a gas seal auxiliary closure, and a tunnel-and-pipe-seal for containment. The pipe also had a debris barrier system, a bellows decoupler, and 10 experiment bulkhead stations (Rivero 1992:1). The fast acting closure and the gas seal auxiliary closure were newly manufactured for this test, the tunnel-and-pipe-seal was recovered and rehabilitated from the Mineral Quarry test in the U12n.22 drift, and the debris barrier system was recovered from the Disco Elm test in the U12p Tunnel (Rivero 1992:2).

The A-box for Hunters Trophy was cylindrical and 12 ft (3.7 m) long and 4 ft (1.2 m) in diameter (Rivero 1992:2). A cylindrical B-box was attached. LLNL and LANL conducted front end experiments close to the working point. LLNL had a reaction history experiment located in the access drift and attached to both the A and B boxes. The LANL Hydro Plus verification experiment was in a small alcove extending from the bypass drift with four drill holes oriented from the experiment toward the working point. One hole measured 4 inches (10 cm) in diameter and the other three 12 inches (30.5 cm) in diameter (Rivero 1992:3).

Substation 12-5, located at the portal, provided electrical power to both the portal and the underground areas (Rivero 1992:10). Substation 12-5 connected to the NNSS electric system by way of overhead lines to the Rainier Mesa substation 2.5 miles (4 km) away. Water for cooling the underground equipment was pumped from the portal to two 12,000 gallon storage tanks in the utilities alcove (Rivero 1992:37). An underground loop system distributed the cooled water to various size air conditioning units for the alcoves, crosscuts, stub pipe areas, front end experiments, vacuum equipment, cryo compressors, and the chillers for the ROSES. Four pumps on skids next to the storage tanks circulated the water through the underground loop and were capable of providing 700 gallons per minute to the system. These pumps could only be operated manually and before the test all four were started during the button-up stage and left running. The primary ventilation system for the tunnel consisted of drawing air into the main and extension access drifts and through the tunnel to the second vent raise where it was pulled to the surface of Rainier Mesa, 1,200 ft (366 m) above (Rivero 1992:40). A 350 hp fan at the surface drew the air up the vent and exhausted it to the atmosphere. Secondary ventilation systems underground used various size auxiliary fans and ventilation ducts for specific areas, such as the Hunter Trophy drift complex. The air drawn from these areas exhausted to the bottom of the second vent raise to join with air from the primary ventilation system to exhaust upward.

Workers had installed the test chamber and stub pipes to the end of the line-of-sight pipe by June (Schoengold 1999:326). Experimenters installed their experiments during July and August. Test personnel conducted a mandatory full participation dry run on September 2, 1992. The line-of-sight drift was stemmed with grout and concrete to a distance of 510 ft (155 m) from the working point. Grout was used the first 151 ft (46 m) out from the working point and then concrete the remaining distance. The space behind the working point was filled with sandbags. After the nuclear device was inserted, the zero room access drift and the bypass drift to 556 ft (169 m) and the three most forward crosscuts were stemmed with various types of grout and concrete.

Final preparations for the test started late evening on September 17, 1992 and continued into the next morning (Schoengold 1999:339). Button-up activities were completed by 9:00 and by 9:30 all personnel had left the area. The Hunters Trophy nuclear device was detonated at 10:00 on the morning of September 18. All remote area monitoring system units, except those in the U12n.24 drift complex, read normal background radiation levels. The highest readings were in the line-of-sight drift, but within 30 minutes radiation levels had decreased tenfold. The initial survey team departed for the portal shortly after 11:00 and just before noon completed the survey of the portal area. All radiation readings for the portal area were at background levels. Remote gas sampling within the tunnel was undertaken and no explosive gases or elevated radiation levels detected (Schoengold 1999:340). The tunnel was secured by 2:45 in the afternoon and all personnel were cleared of the area. The cavity collapsed 17 hours and 13 minutes after detonation (Townsend et al. 2007).

Initial reentry into the tunnel began on September 19, or D+1 (Schoengold 1999:340). Remote gas sampling and radiation readings were taken at the portal while the reentry teams were dressing and preparing their equipment. The work team entered the tunnel and went to the gas seal door where they took readings on the working point side of the door, and after permission was given by the reentry controller, opened the man door and checked for water on the working point side. Next, they opened the large door, established ventilation to the portal side of the gas seal plug, and replaced the rail line through the gas seal door. The initial reentry team entered the tunnel and went to the working point side of the gas seal plug where they took the required readings and when approval was given, opened the tube turn door and established ventilation to the utilities drift protection plug. The reentry team then proceeded to the utilities drift protection plug and repeated the procedure. They then proceeded through the utilities drift protection plug, through the first alcove protection plug in the U12n extension north drift, and into the U12n extension drifts, when a warning signal on one of the team members air tanks went off and the team had to return to the portal. The second team received a briefing from the first team chief and the portal reentry controller prior to entering the tunnel. The second team then followed the route of the first team and went to the craft alcove in the U12n extension south drift. They then proceeded to the U12n.24 drift complex where they opened all the plugs necessary for examining the line-of-sight drift, test chambers, alcoves, and stub pipe areas. While at the test chambers they detected elevated levels of radiation inside and connected the tunnel ventilation system to the line-of-sight pipe to ventilate it. With permission from the portal reentry controller the team departed the U12n.24 drift complex and proceeded to vent hole 2. When they arrived at the drift protection plug in the vent drift, they opened the containment doors and crawled through the drift protection plug to the vent shaft plug. After opening the containment door at the bottom of the vent shaft, the team retreated to the portal side of the drift protection plug in the vent drift. The team chief then requested the mesa fan be turned on, which quickly improved tunnel ventilation. Reentry team 2 then returned to the portal. The distance between the vent shaft plug and the portal was over 1.5 miles (2.4 km).

Data recovery teams then began to retrieve data from the scatterer area, the stub pipes, and the slow alcove and finished by 6:00 that night (Schoengold 1999:342). The scientific assessment team began their work in the test chamber and experiment areas on September 24 and recovery of experiments began on September 28 in the scatterer area, the alcoves, and in the test chamber. Most of the data recovery was completed by October 9, 1992.

Mining out the plugs in the U12n main and extension drifts began on September 19, and on September 21 work began on opening all the remaining plugs to the U12n.24 work area. (Schoengold 1999:342). No other mining activities were conducted. One drill hole from the high pressure alcove in the bypass drift near the end of stemming was drilled into the chimney to obtain gas samples and determine chimney radius. The drill hole was grouted two weeks later with the completion of sampling.

U12n.25 Drift - Non-Proliferation Experiment

LLNL conducted the Non-Proliferation Experiment, consisting of two separate high explosive tests, in the U12n.25 drift (Denny 1994; Hannon 1994; Thompson and Miller 1994). The first test, On-Site Seismic Yield (OSSY-3), was on October 30, 1992 and composed of 300 pounds of an ammonium nitrate and fuel oil (ANFO) mixture. Its purpose was to establish calibration within the U12n Tunnel environment for the second and larger test in the drift. The second high explosive test, Chemical Kiloton (cf. Rimer et al. 1994), was conducted on September 22, 1993 and consisted of 1,423 tons (1.29 kilotons) of ANFO. The objective of the Non-Proliferation Experiment was to obtain data to determine similarities and differences between an underground nuclear test and a chemical test conducted in the same geology with similar yields. This was done in order to address a verification issue in the Non-Proliferation Treaty. Just in the United States alone, there were a great number of large chemical explosions of 50 tons (45 metric tons) or more everyday and a few per year greater than one kiloton in industrial mining and quarrying activities (Richards 1994). These types of explosions could potentially provide the same imprint or signature as a nuclear explosion and on a worldwide basis be used to disguise a nuclear explosion. Additionally, if characteristics of chemical explosions could be identified from the Non-Proliferation Experiment, then it might be possible to use chemical explosions to seismically differentiate between explosions and earthquakes for a given region.

The U12n.25 drift was started off the left rib of the U12n.23 drift fast alcove and mined 250 ft (76 m) long and 11 ft (3.4 m) high and wide (Thompson and Miller 1994; Figures 102-103). The first high explosive test, OSSY-3, was conducted in a 17-inch diameter horizontal drill hole, 30 ft (9 m) long, at the end of the drift. For the second test, Chemical Kiloton, a chamber 50 ft (15.1 m) in diameter and 16.5 ft (5 m) high was mined. Both high explosive tests for the experiment were located at the same working point underground, at 1,280 ft (390 m) below the surface. The first test, consisting of the smaller explosion, was conducted before the chamber for the second explosion was excavated. A hole in which the explosive was inserted was drilled into the center point from the face of the drift. Afterward, the chamber for the second test was excavated. The walls of the chamber were straight. The opening to the chamber was sealed with two sets of steel doors with 6 inches (15 cm) of fill between. The invert or floor of the chamber was below the invert of the access drift and a downward ramp was excavated at the end of the drift to facilitate mining the lower levels of the chamber. Rockbolts were placed in the roof or back and the ribs or sides of the chamber for ground support. Arrayed inside the chamber were cables, thermocouples, and pressure gauges for measuring and monitoring the explosion. Five booster charges, each with an electronic detonator, were mounted at even intervals on a vertical steel cable that delineated the central axis and attached to the back and invert of the chamber (McKown 1994). The top, middle, and bottom booster charges initiated the explosion and the remaining two were detonated at the time as the shockwave.

Dyno Nobel, Inc. and Alpha-Ireco, Inc., manufacturing plants in Lehi, Utah and Lincoln, California, respectively, supplied the ingredients for the explosion (Mammele 1994). The explosive mixture consisted of 50 percent emulsion and 50 percent ANFO in order for it to have enough fluidity to flow evenly and fill the test chamber without the aid of personnel inside. The mixing station at the portal was approximately 150 ft (46 m) in front of the extension drift and included mixing trailers, an emulsion silo, a diesel tank, electric motors, and a standby mix truck (Thompson and Miller 1994). Fire extinguishers were placed throughout the work area and a fire truck was standing nearby. The ingredients making up the explosive were stored at the back of the portal area and at least 600 ft (183 m) from the mixing area. When mixed, the ANFO mixture was placed into agitator or Moran cars and transported underground to the test chamber with a motor car by way of the rail line. The ANFO mixture was moved into the test chamber in two phases (Figure 104). In phase one, and before the entrance doors were closed, the mixture was emptied from the agitator car onto a chute extending into the chamber to fill the lower portion of the chamber. Phase two began when the ANFO mixture was high enough that the entrance doors to the chamber had to be closed to contain the mixture. The mixture was then poured into a hopper and by vertical and horizontal augers through an opening in the bulkhead above the steel doors filled the upper portion of the chamber. When the chamber was filled, sandbags were stacked 5 ft (1.5 m) thick behind the doors as a thermal barrier. The U12n.25 access drift was entirely stemmed with grout.

The Chemical Kiloton high explosion test was conducted on September 22, 1993. No surface effects were observed. Most of the damage in the tunnel occurred along the route from the north extension access drift to the U12n.23 fast alcove (Townsend et al. 1994). Damages consisted of caving, floor heaving, cracking of poured concrete inverts, and minor cracking and spalling of fibercrete. The

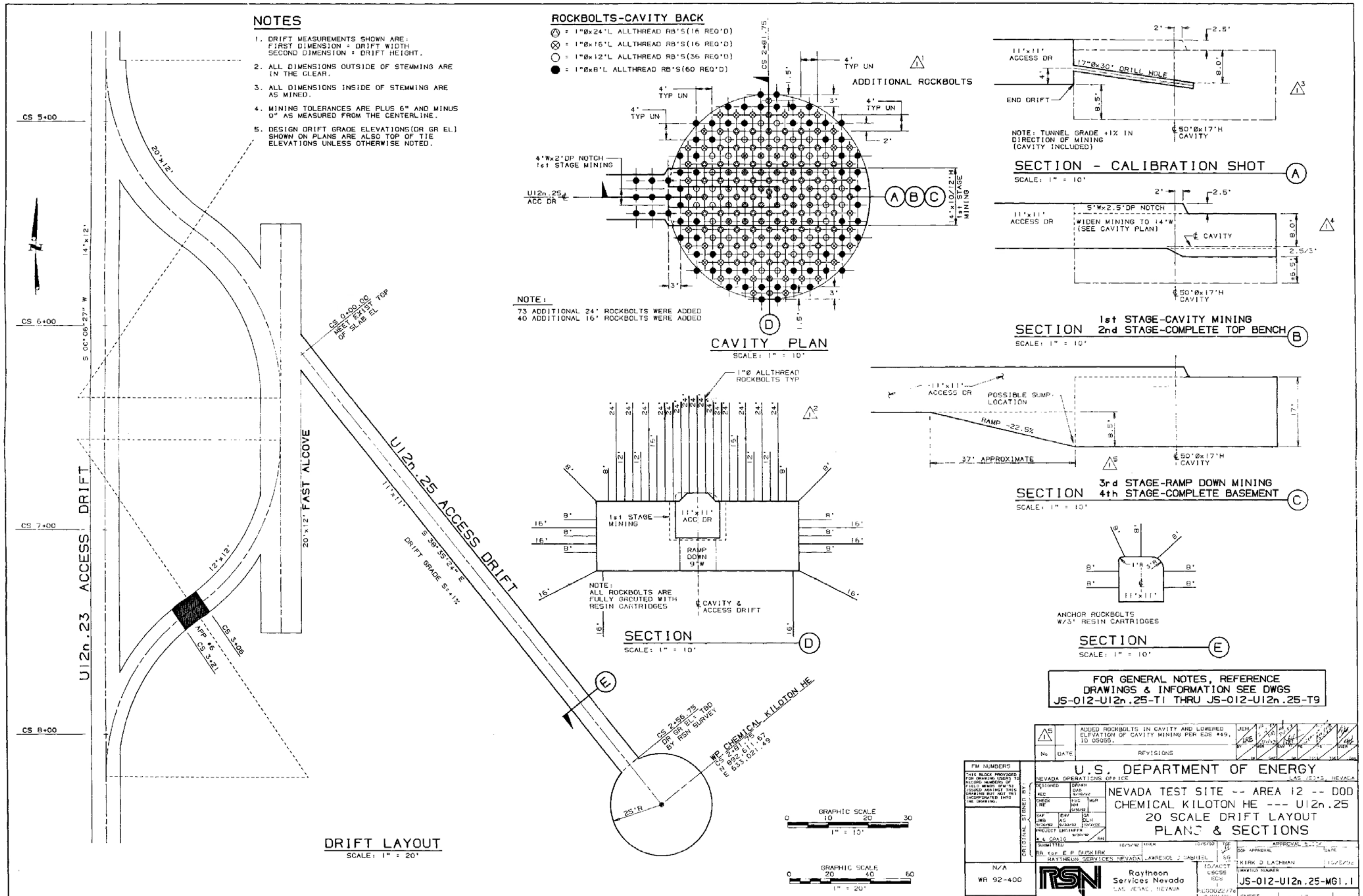


Figure 102. Plans and sections of the U12n.25 drift for the Chemical Kiloton test, 1992 (drawing JS-012-U12n.25-MG1.1, on file at Archives and Records Center, Mercury, Nevada).

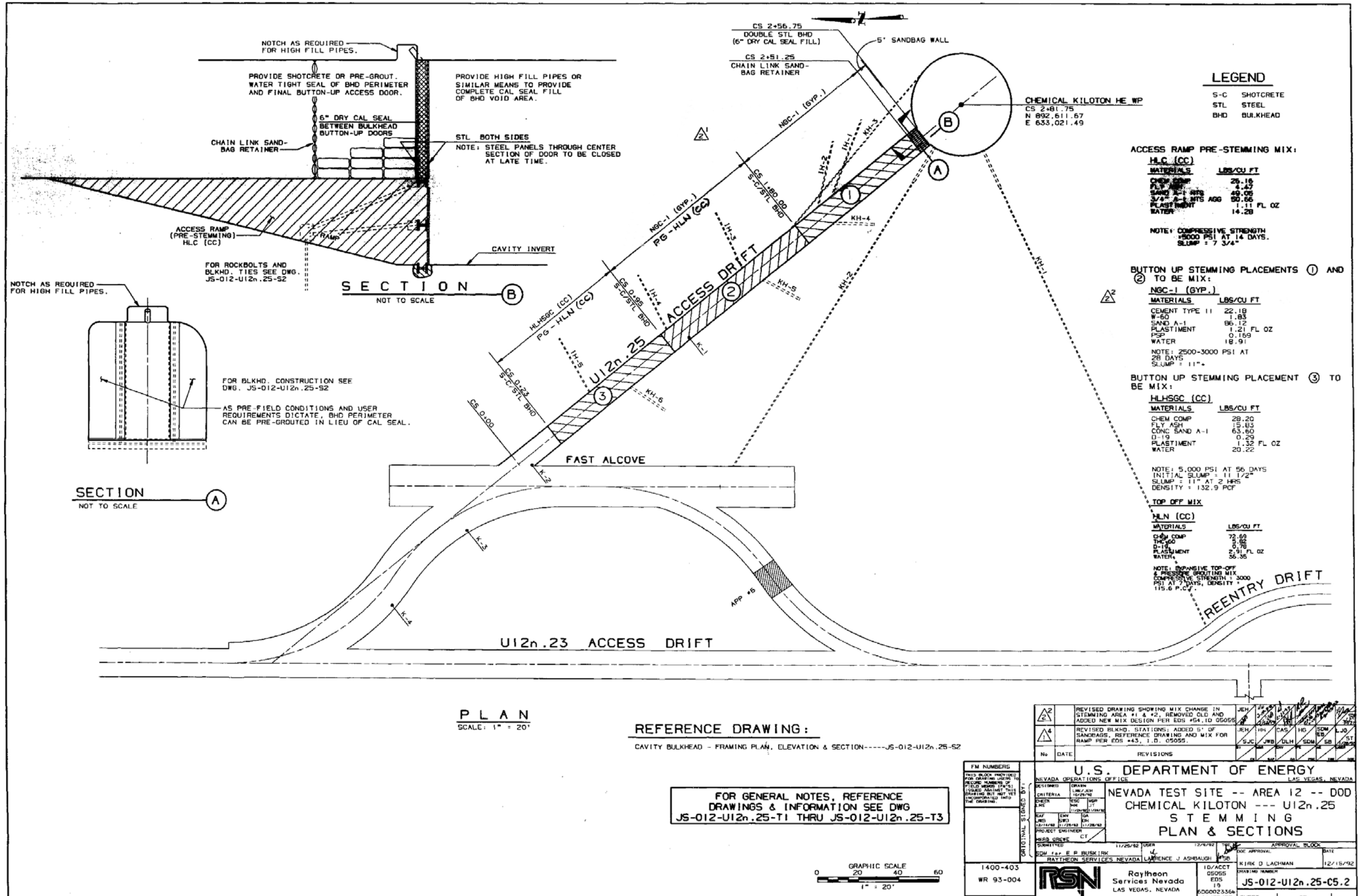


Figure 103. Stemming plan of the U12n.25 drift for the Chemical Kiloton test, 1992 (drawing JS-012-U12N.25-C5.2, on file at Archive and Record Center, Mercury, Nevada).

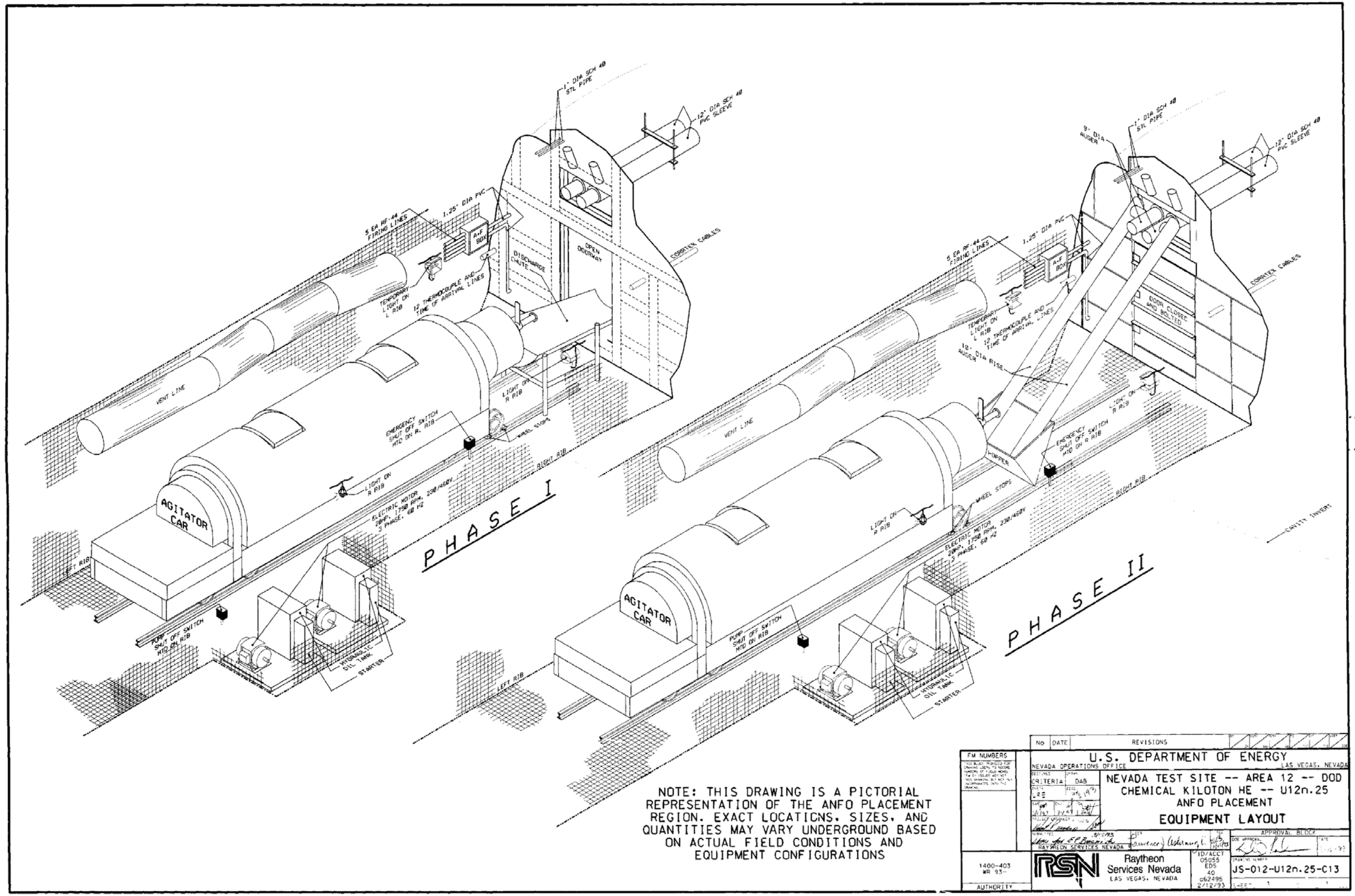


Figure 104. Schematic of ANFO placement in the U12n.25 cavity for the Chemical Kiloton test, 1993 (drawing JS-012-U12N.25-C13, on file at Archive and Record Center, Mercury, Nevada).

greatest damage was to the north access drift into the fast alcove from the U12n.23 main drift which was caved in and restricted access to the alcove and to the entrance of the U12n.25 drift.

Measurements taken on the large explosion were electrical and seismic soundings, hydrodynamic, electromagnetic pulse, ground motion, regional and teleseismic waves, hydroacoustic, multi-spectral imagery, infrasound, and ionosonde (Hannon 1994). Instruments were placed underground in the tunnel close to the explosion, on the surface above, and several kilometers away. Seismic stations across the United States, some several thousand kilometers away, and at some international locales measured the blast. The hydrodynamic measurements taken from within the blast chamber verified that all of the explosive ingredient had detonated. Hydroacoustic signals were recorded at a few hundred kilometers off the coast of California. Some of the results of the test indicated that a chemical explosion couples more energy into the ground than a nuclear explosion of similar strength and that aftershock rates and electromagnetic pulses varied from that of nuclear explosions and might be useful measurements to differentiate types of explosions when enough data has been collected (Denny 1994).

U12n Extension Drift - Dipole Hail

Construction of the portal for the U12n extension drift began on April 7, 1983 and mining of the extension drift began on April 14 with an Alpine miner for the first 88 ft (Morrill and Kensok 1986:24). Mining with a tunnel boring machine from that point inward began on June 13. The extension drift paralleled the U12n main drift for the first 1,500 ft (457 m), separated from it by 190 ft (48 m), and then slightly moved away from it to the left or southward (Morrill and Kensok 1986:3). The extension drift crossed the U12n.01, U12n.02, and U12n.06 drifts. Although the boring machine could move faster, excavation proceeded intermittently for a variety of reasons, including wet and unstable tunnel conditions, mucking, rockbolting, shotcreting, mining the invert, installing rail lines, installing ventilation lines and other support equipment, clean up, and machine maintenance. The cumulative average advance rate by the boring machine for the U12n extension drift was 3.7 ft (1.13 m) per hour and about 28.75 ft (8.76 m) per work shift (Morrill and Kensok 1986:29, 32). The cumulative use or operating time of the machine per shift averaged 23 percent, with the rest of the shift time, 77 percent, occupied by the activities mentioned above (Morrill and Kensok 1986:43). By December 1984, the U12n extension drift had reached 6,259 ft (1,908 m) in depth. The drift would eventually reach a distance of 8,277 ft (2,523 m) from the portal and provide an 18.5 ft (5.6 m) diameter access to the interior (Flangas 2009; Townsend et al. 2007).

The purpose of the extension drift was to extend the tunnel inward for constructing more test drifts and, due to its larger diameter, to accommodate the transportation of fully assembled hardware or equipment for testing (Ristvet 2009). Prior to this, larger size hardware had to be moved piecemeal into the tunnel and constructed underground at greater costs and less efficiency as compared to assembly outside the tunnel. The drift required a new gas seal plug which was constructed at approximately the same distance, 2,000 ft (610 m) from the portal, as the gas seal plugs in the U12n main drift and the utility drift runaround. Construction of the U12n extension drift gas seal plug satisfied the requirement for the Vessel 3 containment sphere. Also in the extension drift, an additional plug was constructed on the portal side of the gas seal plug and it was designated the friction plug. The friction plug was designed to function the same as the gas seal door in the U12n main drift. Because the extension drift had been driven far enough into the tunnel to support future tests, utilities for future tests were routed from the U12n.08 drift through a new utilities drift. The U12n extension utilities drift was started off to the left of the U12n.05 line-of-sight drift just past the U12n.08 drift turnout and intersected the U12n extension north drift. The utilities drift contained compressed air and water lines, power and signal cables, ventilation, and reentry control cables. A utilities drift plug was constructed in the utilities drift and became part of Vessel 2 containment.

Seven high explosive tests were conducted from May 1997 to April 1998 in the U12n extension drift (Table 2), and were part of the Dipole Hail project in support of the DTRA Hard Target Defeat Program. Sandia National Laboratory fielded the tests for DTRA. The objectives of the program in the U12n Tunnel were to evaluate the damage effects of various explosive materials against deeply buried, hardened targets and characterize the vulnerability of tunnels and portals located within dry or wet soft rock from attack by conventional munitions (Babcock and Rocco 2000; Hunt 2001:123; McMullan 2004:15; Rinehart 1998:4). The Dipole Hail tests at the U12n Tunnel consisted of a series of small explosions of 50 lbs (22.7 kg) or less on the portal side of the friction plug in theUl2n extension drift. The explosive devices were suspended 4 ft (1.2 m) above the invert and l,000 ft (305 m) inside the portal (Hunt 2001:120, 123). Other Dipole Hail tests on the NNSS were conducted at the U16a and U16b Tunnels (Babcock and Rocco 2000; Hunt 2001:119; McMullan 2004:15; Montoya 1999:13-14; Rinehart 1998:12).

GEOMORPHOLOGY OF U12n TUNNEL AREA

The character and shape of the U12n Tunnel exterior landscape has been modified over time by natural processes in addition to changes caused by adding or deleting structures or features to meet the needs of various operations at the tunnel. The geomorphic study area for this historical evaluation covers about 1,000 acres (405 hectares) in and around the portal area and the mesa top (Figures 105-107). The geomorphic study area is contained in two polygons, one in the U12n Tunnel portal area and one on the top of Rainier Mesa that encompasses areas of surface disturbance. The map area for the portal area is an elongated, northwest oriented polygon about 4,500 ft (1,372 m) long and about 1,500 ft (457 m) at the widest point; the U12n portal is situated near the west end of the map polygon. The mesa top polygon is a roughly square shape that is about 12,000 ft (3,658 m) long in the east-west direction and about 6,000 ft (1,828 m) wide in the north-south direction. Table 3 provides the map unit descriptions.

The Rainier Mesa Road, which is the principal access road to the U12n Tunnel complex is situated on the proximal fan area of the prominent axial stream valley of Tongue Wash. A secondary road from the main access road to the U12n portal area climbs above the valley floor and at the U12n portal area occupies a position at the base of the mesa. The portal area is situated at or near the level of a pre-existing drainage immediately north of the portal; construction of the portal work area from mine tailings results in the work area being approximately 60 ft (18 m) above the axial valley floor. Numerous modifications to the valley floor were made to accommodate the tailings area and to control runoff. An access road to pad areas on the steep slopes above the portal traverses artificial fill, hillslope colluvium, and bedrock units, which consist primarily of bedded Tertiary ash-fall and ash-flow tuff of the Paintbrush Tuff (Frizzell and Schulters 1990; Sargent and Orkild 1973; Gibbons et al. 1963), Belted Range Tuff (Frizzell and Schulters 1990; Sargent and Orkild 1973; Gibbons et al. 1963), and the Timber Mountain Tuff (Frizzell and Schulters 1990).

The top of Rainier Mesa in the study area consists of rolling topography found in the headwaters of The Aqueduct. With increasing distance downstream, the depth of incision into the mesa increases. Surface disturbance observed on the mesa top includes surface alteration by access road construction, trailer park pad preparations, borehole drilling sites, electrical transmission lines and generating stations, and local quarry and bedrock excavation for building pads. Drill pad sites were formed primarily by cut and fill construction techniques that resulted in low, vertical bedrock cuts of 6 to 15 ft (1.8 to 4.6 m) and fill pads derived from excavated bedrock, thin surficial deposits, and slope deposits.

Road disturbances on the mesa top are similar to those near the portal, although the regolith on the mesa top is generally thin and the road bed is commonly at or near bedrock. Based on the composition of road bed material, it appears that some exotic road-bed material was imported. Broad areas were leveled by blading (Ab) in addition to cutting and filling of bedrock slopes for preparation of trailer parks and temporary building sites (Figures 108-109). In some cases the welded tuff of Rainier Mesa was quarried as fill material and as part of site preparation for the trailer parks and pads. Borehole locations included leveled areas of fill for drill rig pads; small ponds for circulation fluids were typically made by moving the loose regolith at the site to form berms to retain the fluids. Roads were cut or bladed for transmission and communication lines.

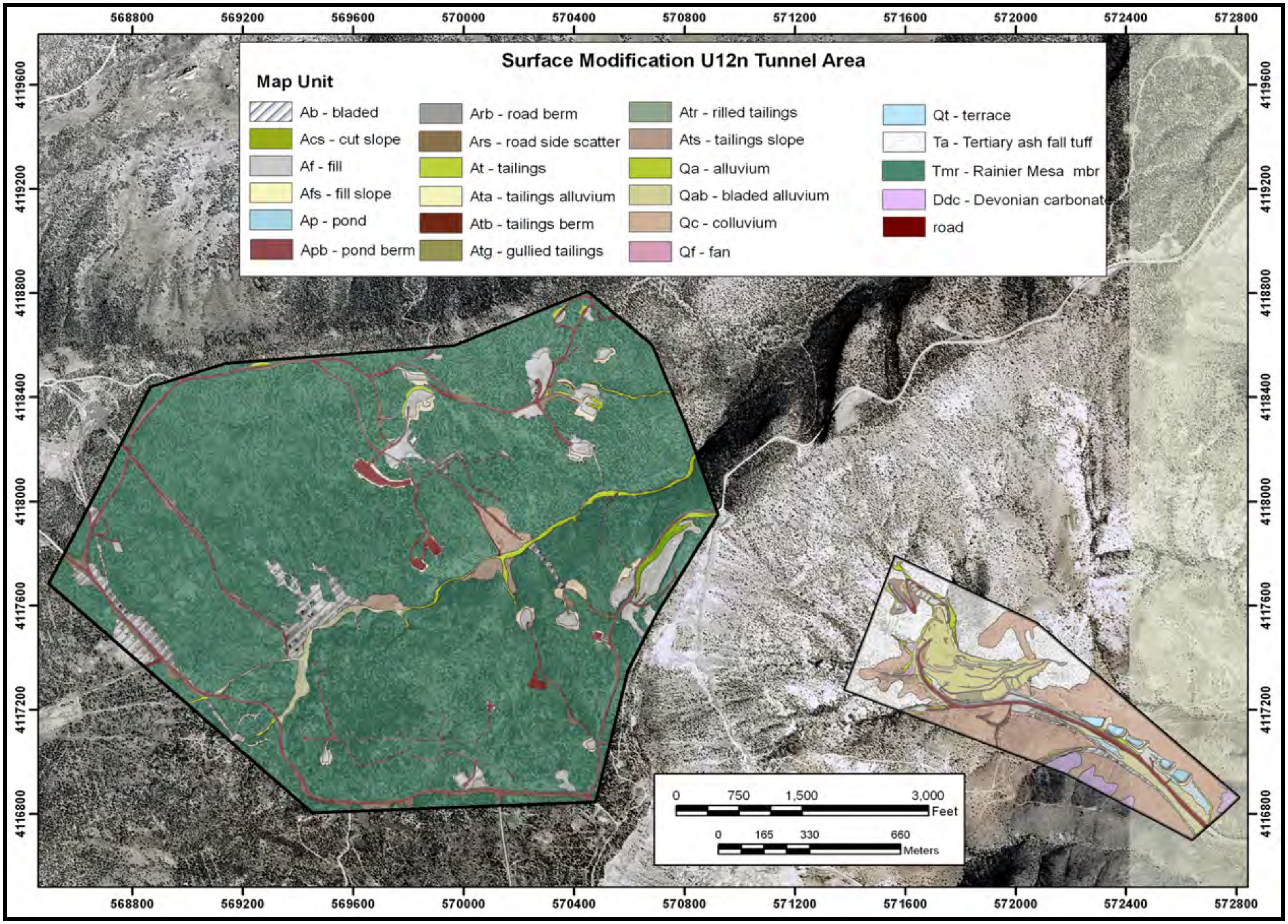


Figure 105. Surficial geologic map for the U12n Tunnel complex area. Map shows bedrock outcrop, surficial deposits, and areas disturbed during development in the portal area (right) and during mesa top activities (left).

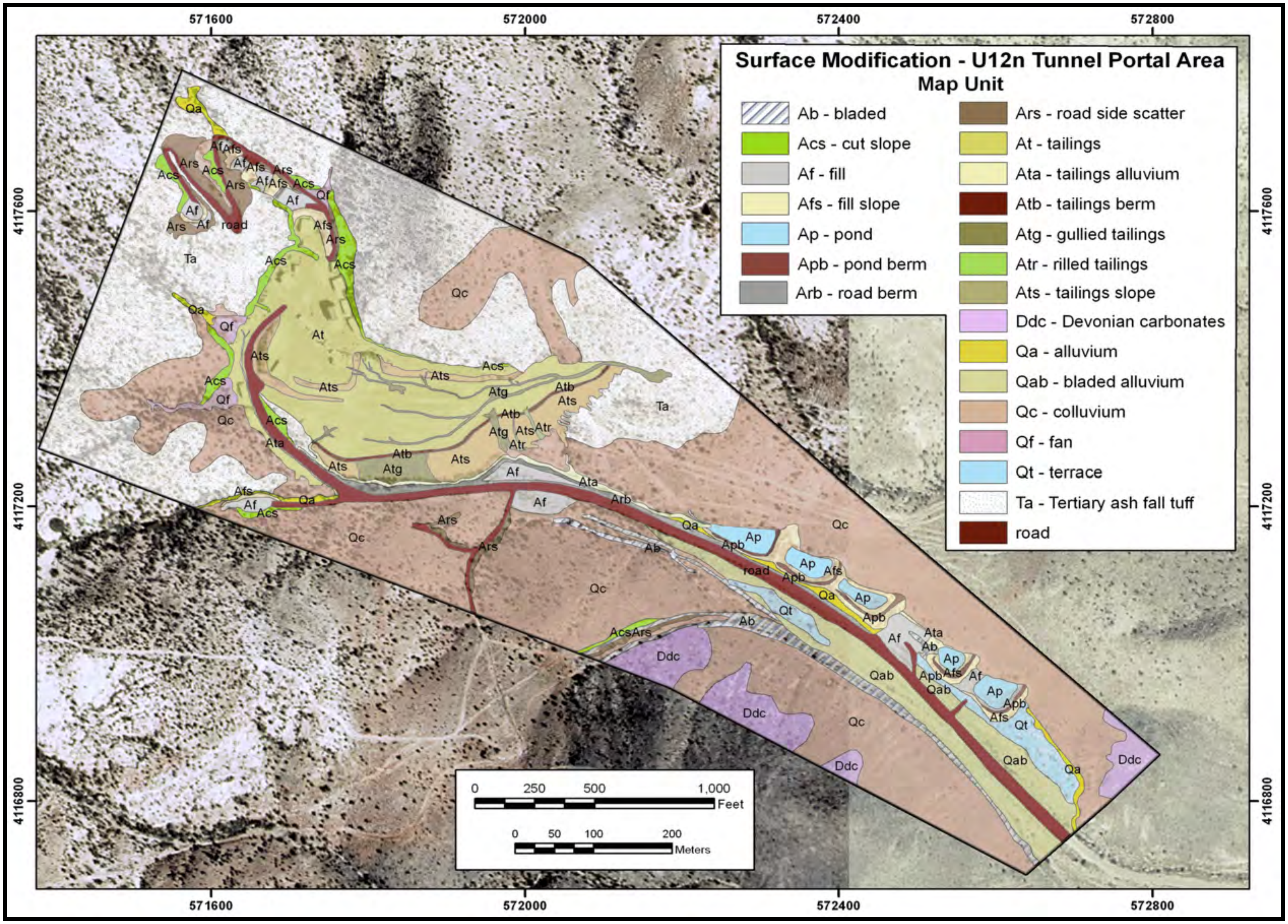


Figure 106. Surficial map for the U12n Tunnel portal area. Map shows bedrock outcrop, surficial deposits, and areas disturbed during development in the portal area.

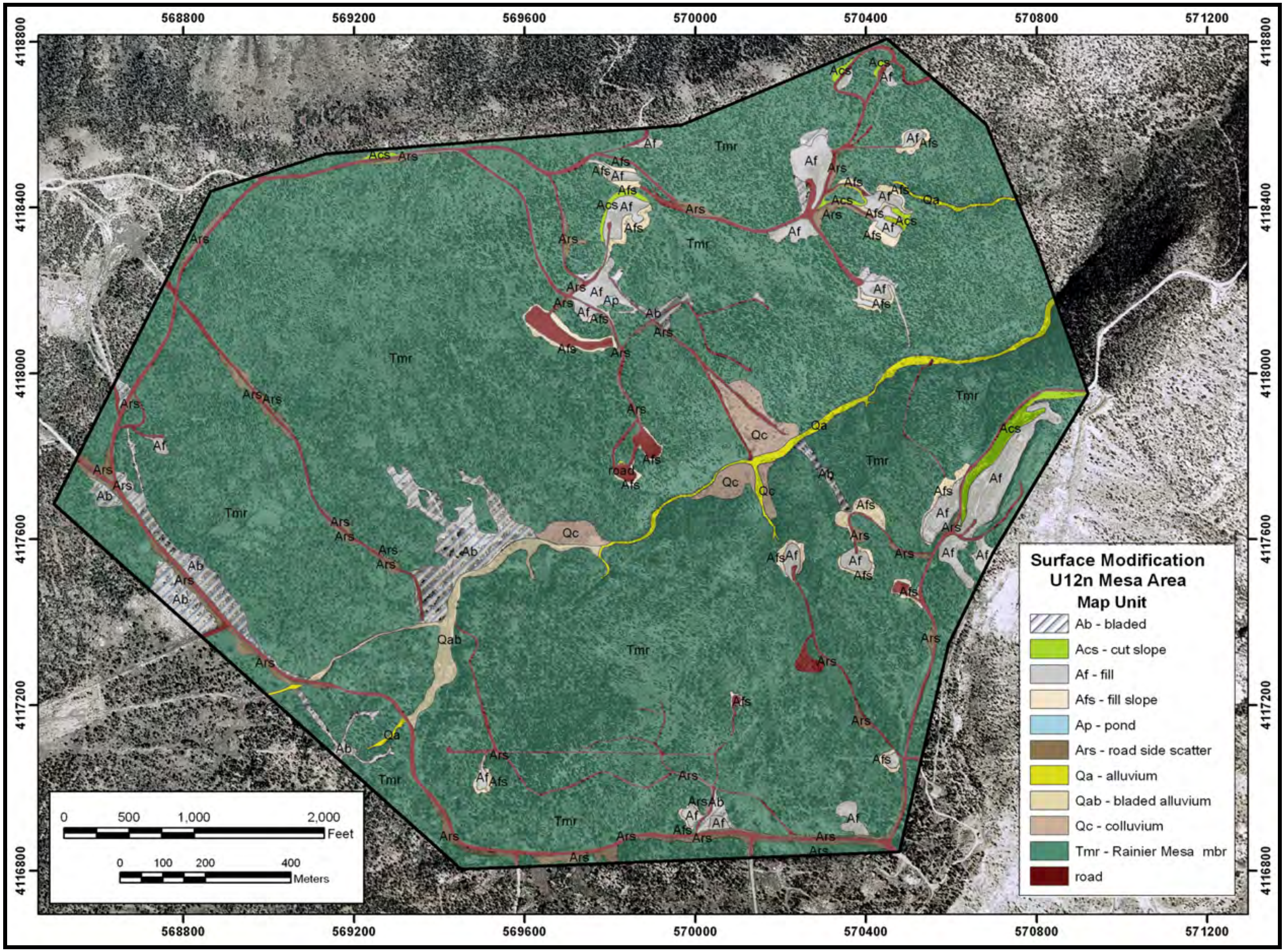


Figure 107. Surficial map for the U12n Tunnel mesa area. Map shows bedrock outcrop, surficial deposits, and areas disturbed.

Table 3. Legend for the Surficial Geologic Maps.

SYMBOL	UNIT	DESCRIPTION
Ab	Bladed area	Areas characterized by shallow blading and/or removal of colluvium and thin surface mantle; commonly results in bedrock surfaces.
Acs	Artificial cut slope	Slopes cut in bedrock or colluvium during road construction.
Af	Artificial fill	Mechanically placed fill derived primarily from tunnel development.
Afs	Artificial fill slope	Slopes formed adjacent to artificial fill, building pads, drill pads, etc.
Ap	Artificial pond	Shallow holding ponds to capture surface runoff; more recently used to retain water draining from U12n Main tunnel.
Apb	Artificial pond berm	Berm surrounding pond depression, commonly wide enough for a vehicle to transit.
Arb	Roadside berm	Low berm along margins of roads, generally a foot or less in height; purpose is to control runoff from road surface.
Ars	Road side-cast	Slope wash resulting from road grading and fill emplacement.
At	Tailings	Mine waste dumped on hill slopes; stable tailings vegetated.
Ata	Alluvium on tailings	Defined gullies, rills, and small channels on tailings.
Atb	Tailings berm	Berms constructed along the margin of the tailings to control runoff from tailings pad to tailings slope. Generally less than 2 ft high.
Atg	Gully	Deep, wide gullies formed on unvegetated tailings.
Atr	Rilled tailings	Small rills developed on tailing slopes, generally less than 1 ft deep.
Ats	Tailing slope	Slope formed on tailings deposits.
Road	Road	Principal access roads for the U12n Tunnel complex.
Qa	Alluvium	Late Holocene deposits associated with ephemeral stream channels.
Qab	Alluvium, bladed	Bladed, graded, or otherwise disturbed alluvium or colluvium.
Qc	Colluvium	Late Holocene mantle of bedrock derived colluvium and weathered surficial mantle.
Qf	Alluvial fan	Late Holocene alluvial fans and principal feeder channels found on the south facing slopes east of the U12n Tunnel complex and in the valley floor down valley from the artificial ponds.
Qt	Terrace	Holocene fluvial terrace situated above active floodplain.
Tmr	Rainier Mesa Member	Pliocene; pale-red to dark-brown nonwelded to densely welded rhyolite ash-flow tuff member of the Timber Mountain Tuff.
Ta	Ash Fall Tuff	Composite map unit including massive to bedded, reworked ash-fall tuff member and tuffaceous sandstone members of the Timber Mountain Tuff and Belted Range Tuff (Indian Trail Formation), and the Miocene age pale gray and red bedded peralkaline ash-fall tuff and tuffaceous sandstone of Tunnel Bed 4 of the Lower Member of the Indian Trail Formation.

Figure 108. View north of the U12n Tunnel trailer park. Illustrated are cut slopes in the Rainier Mesa Member of the Timber Mountain Tuff (Acs), fill areas (Af), hillslopes adjacent to fill pads (Afs), and road side cast (Ars). Area denoted Tmr is the Rainier Mesa Member of the Timber Mountain Tuff and is generally covered by a thin mantle of colluvium. (modified from photograph NF-13505, on file at the Remote Sensing Laboratory, Las Vegas)

Figure 109. View of U12n.03 cable hole #1 on Rainier Mesa. Shown are broad area of terraced artificial fill (Af) and fill slopes (Afs).

Landscape changes as the direct or subsequent result of nuclear detonations were not observed during the field visit. However, elsewhere on the mesa, evidence of surface change included fissuring and formation of small structural graben. The fissuring resulted from ground shaking as well as collapse of the underground blast cavity and chimney. In some cases vertical displacement of up to about 12 inches (30 cm) occurred on new fractures, and displacement on existing fractures and faults was observed (Snyder 1972).

Historic Deposits and Modifications to the Landscape

The historic deposits and modifications to the landscape represent the principal landscape modifications that occurred in association with 1) road building, including berms along the margin of roads (Arb), areas bladed by bulldozer or grader (Ab), cut slopes (Acs), and road side-cast (Ars); 2) use of mine tailings (At) and reworked natural deposits (Af) as fill in construction of building pads, road widening, road turnouts, retention pond dams, and benched fill for staging areas and slopes associated with large fill areas (Afs); 3) disposal of mine tailings (muck) on slopes during tunnel development (At), associated slopes (Ats), and construction of small berms (Atb) to control surface runoff; and 4) construction of retention ponds (Ap) and associated berms (Apb). Subsequent erosion of tailings and severely gullied tailings (Atg), rilled tailings (Atr), and small drainages and associated alluvium established on the tailings (Ata) are mapped as discrete units. Roads are included as separate units of historic deposits and modifications. Figures 105 and 106 show the distribution of many of these map units in the U12n Tunnel portal and mesa areas.

Cut slopes (Acs) are formed principally during road construction and maintenance activities and during excavations for buildings. The cut slopes are commonly associated with small colluvial wedges of loose rock and soil shed from the cut slope, and in some cases small fans that have spread across roads and staging areas. Cut slopes are associated with access road preparation and are present along the valley margins on the main tunnel portal level in the equipment staging and storage areas, and on access roads to the mesa top. In general, large volumes of friable bedrock and colluvium may be removed during cutting depending on road alignment and space needs. Road cuts may be many meters tall where road alignment and topography require significant excavation into a hillslope. The material excavated from cut slopes is commonly used elsewhere in road construction, especially to fill low areas or to raise the elevation of the road bed. As the roadbed is constructed, material is bladed to the edge of the roadbed and may spill onto adjacent hillslopes. In the U12n Tunnel area, cut slopes are generally less than 6.6 ft (2 m) high occupy about 7 acres (2.8 hectares) or less than 1 percent of the geomorphic study area. Near the U12n tunnel portal, bedrock cut slopes are as much as 16 ft (5 m) high but are relatively stable (Figure 110). Cut slopes in colluvium are generally steep, unvegetated, and shed material onto the road and fill area. In some places near the portals, protective mesh was installed to reduce the hazard of rock fall. Where access roads are cut into hillslopes, there is a tendency for sediment to accumulate in roadside ditches thereby restricting drainage, causing ditch flow to flood onto the roadbed, and the formation of rills and gullies on the road bed.

Artificial fill (Af) deposits cover about 26 acres (10.5 hectares) or about 15 percent of the disturbed area and constitute significant volumes of material, which in terms of geomorphic process is essentially in temporary storage (Figures 108-109, 111-113). Many of the flat areas of artificial fill are vegetated with grasses and low shrubs. Artificial fill is commonly emplaced simply by dumping material derived from existing alluvium and colluvium, or material from cut slopes, into a

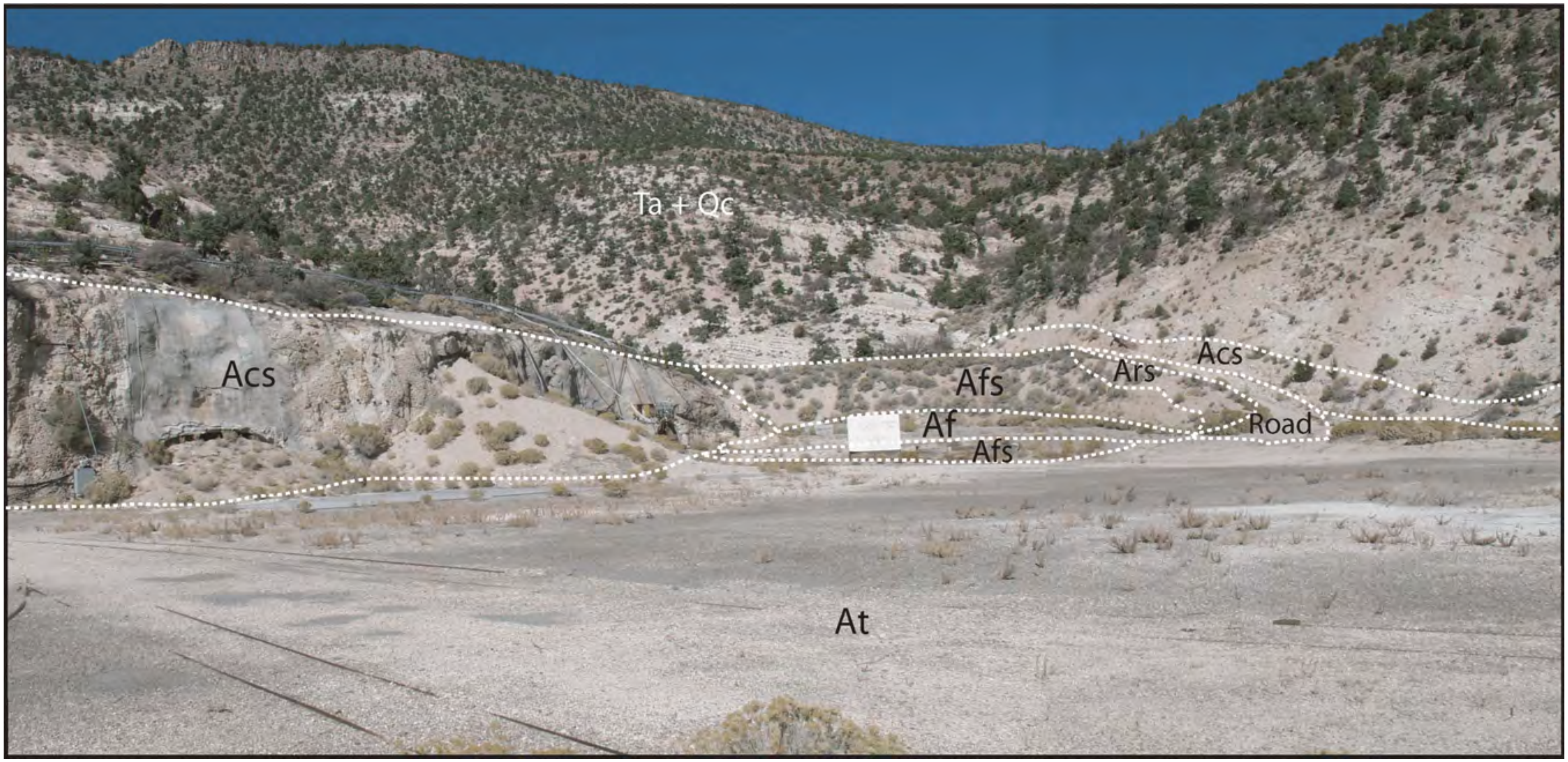


Figure 110. View northwest of the U12n Tunnel portal area with Rainier Mesa in the background. Shown are bedrock cut slopes (Acs), and fill slopes adjacent to fill pads. The road leads to additional pads higher up on the flanks of the mesa.

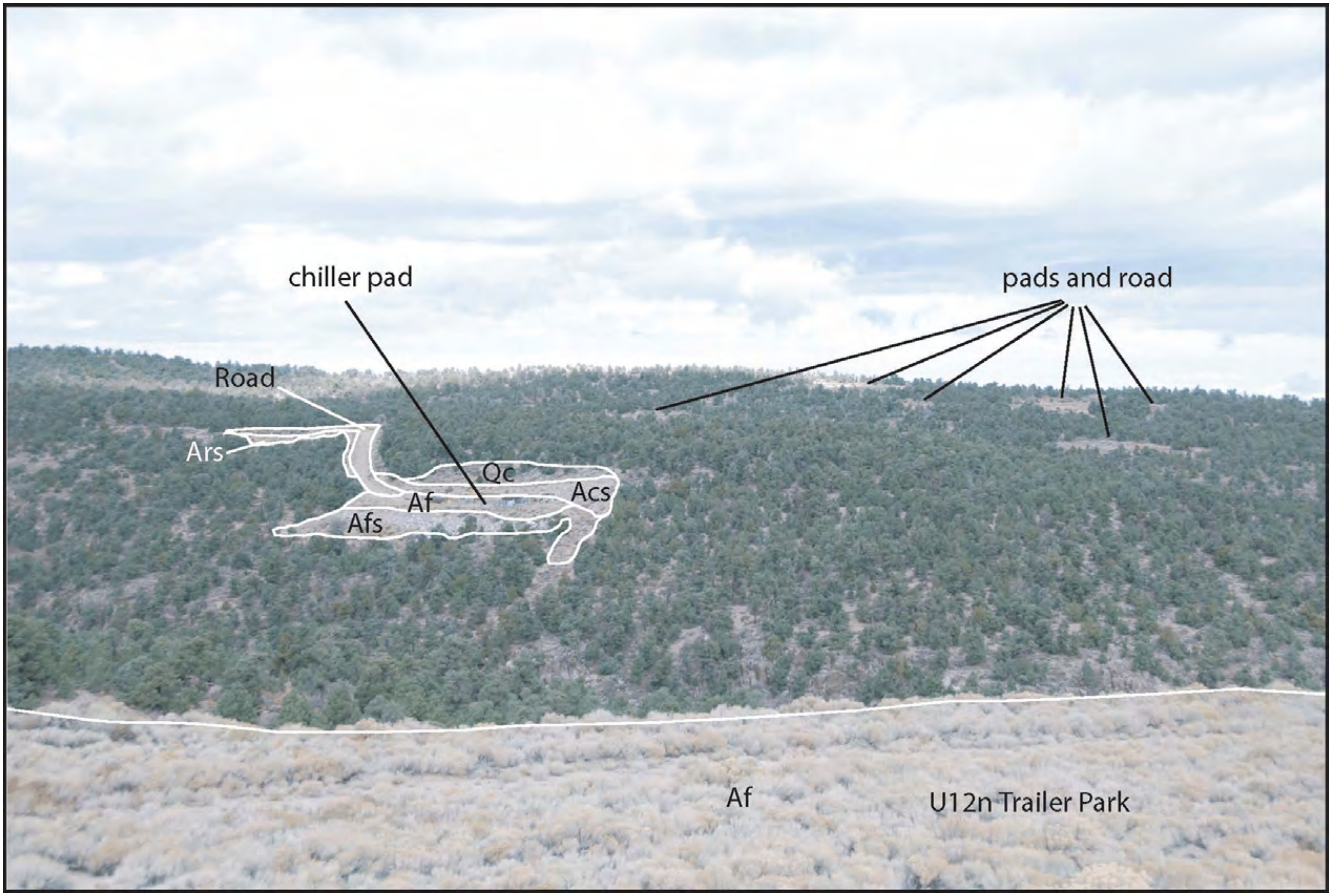


Figure 111. View west from the U12n Tunnel trailer park toward the vent hole No. 1 and chiller pad complex, showing areas of pads, roads, road side cast (Ars), bedrock cut slopes (Acs), and colluvium (Qc).

Figure 112. View of the U12n Tunnel vent hole No. 1 and chiller pad. Shown are bedrock cut slope (Acs) with bladed colluvium above the cut slope (Ab), fill pads (Af), and fill slopes (Afs). The excavated bedrock material was used in the development of the pad and facing of the fill slopes. (modified from photograph NF-13506, on file at the Remote Sensing Laboratory, Las Vegas)

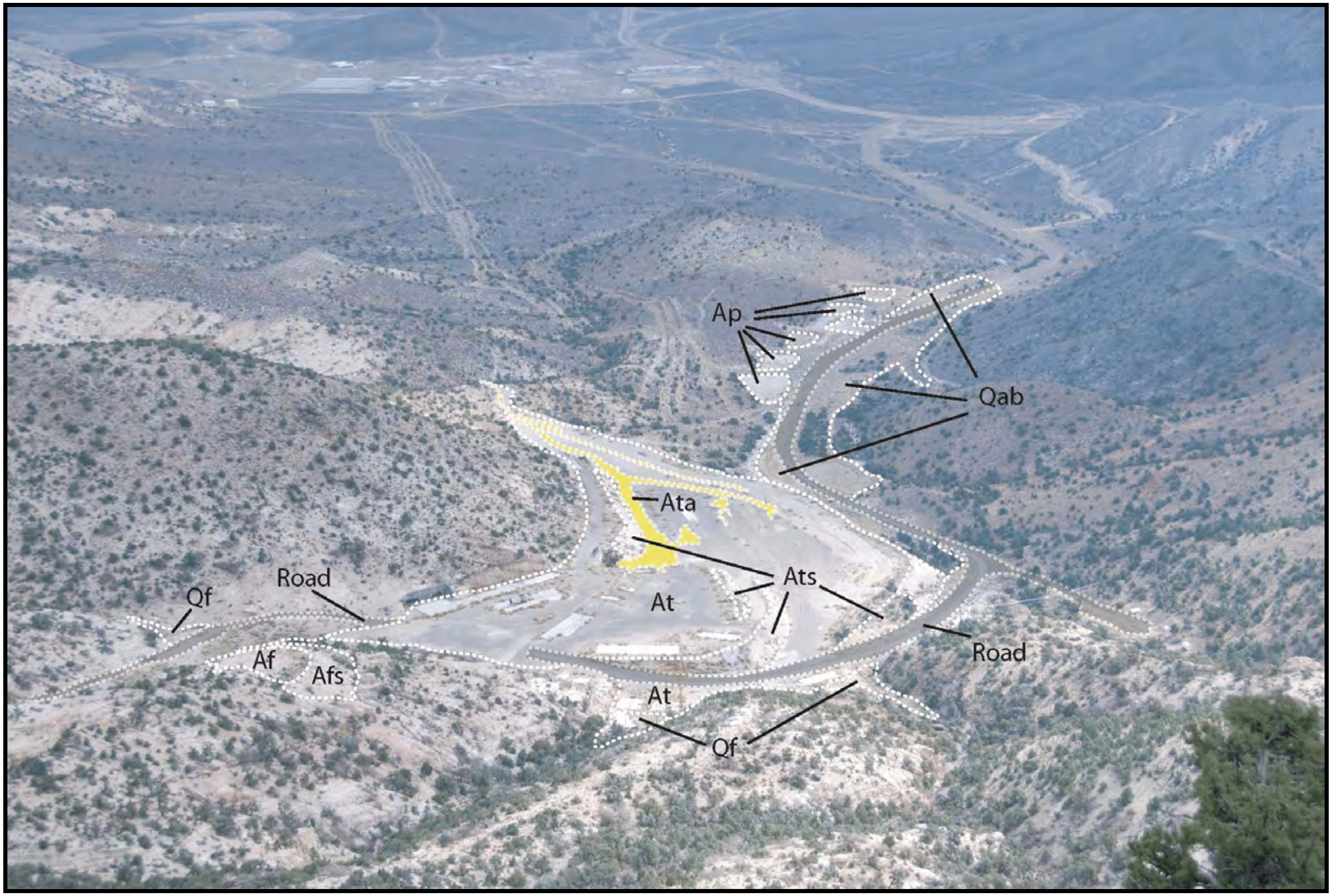


Figure 113. Overview of the U12n Tunnel portal area and several of the principal map units observed in the area, including tailings (At) and tailings slope (Ats), drainage developed on tailings (Ata), artificial fill pads (Af) and slopes (Afs), ponds (Ap), alluvial fans (Qf), and bladed alluvium (Qab).

topographic low and continuing to dump until the fill is built to the level desired, or by the same process but engineered by careful selection of material size and composition, adequate mixing, and compaction in designed layers, or lifts. For building and major highway construction, engineered fill is normally required. It is not known if the artificial fill in staging areas in the U12n Tunnel portal area and mesa top was engineered or simply dumped on the existing surface. Because there is no obvious cracking of concrete pads, or displacements of the fills after nearly 40 years, it is probable that some form of compaction was used. The composition of the fill indicates that the source of fill material was locally derived sediment as well as muck from the mining activities during U12n Tunnel development. Because of the similarity of geologic materials mined from the U12n Tunnel to the fill deposits, and the impracticality of transporting specialized fill to the site, it is unlikely that a prescribed mix of fill was required. Because muck from tunneling is commonly a mix of fine and coarse material, the U12n tunnel material would probably have served as adequate fill.

Rearrangement of the natural drainage in order to establish the main road in the valley has resulted in loss of natural riparian vegetation, and increased runoff and erosion from the road surface and roadside ditches. To control surface runoff from slopes above and below roads, ditches were constructed to intercept surface flow.

Retention ponds (Ap) are artificially constructed ponds for the purpose of capturing water used during mining activities before and after tests and dewatering of local aquifers if intersected. Water and sediment runoff from the tailings slopes are presently captured by the ponds. A series of five engineered ponds is located in the axial valley on a former fluvial terrace associated with the tributary to Tongue Wash (Figures 106 and 109). The ponds are situated at the toe of the tailings slopes and are unlined. The ponds cover an area of about 1.9 acres (0.8 hectares) or about 1 percent of the disturbed landscape within the study area.

Road side-cast (Ars) consists of road bed material that is graded from the road as part of the roadbed leveling and smoothing process and is pushed to the side of the road, often over the edge of steep slopes where it may be transported long distances down slope. The slope angle, material consistency, and amount of material govern the distance of down slope movement and subsequent impact on the hillslope system. For the purposes of this report, the road side-cast also includes fill material that is draped over hill slopes as a result of the process of creating fill areas such as road turnouts and staging areas. In the study area, the road side-cast covers about 14 acres (5.7 hectares) or about 8 percent of the area. The road side-cast is most notable on the slopes immediately west of the U12n Portal. The slope adjacent to the road is steep (greater than 70 percent) and a substantial amount of material was displaced during the cutting and filling when extending the road above the portal (Figures 114-116). Although difficult to determine without extensive field investigation, a visual inspection suggests that the most significant amounts of road side-cast material extend less than 30 ft (10 m) from the roadbed. The greatest impact from the perspective of modification to the landscape is confined to the area within 10 ft (3 m) of the road bed edge.

Mine tailings (At) consist of material mined during tunnel construction and post-event re-entry of the tunnels. In typical mining operations, as mining progresses, the muck removed following drilling and blasting is dumped on the hillslope at or near the tunnel portal. As additional material is removed, a broad area can be built up to accommodate necessary construction-related activities, buildings, equipment staging areas. Excess muck is pushed over the edge where it may travel down

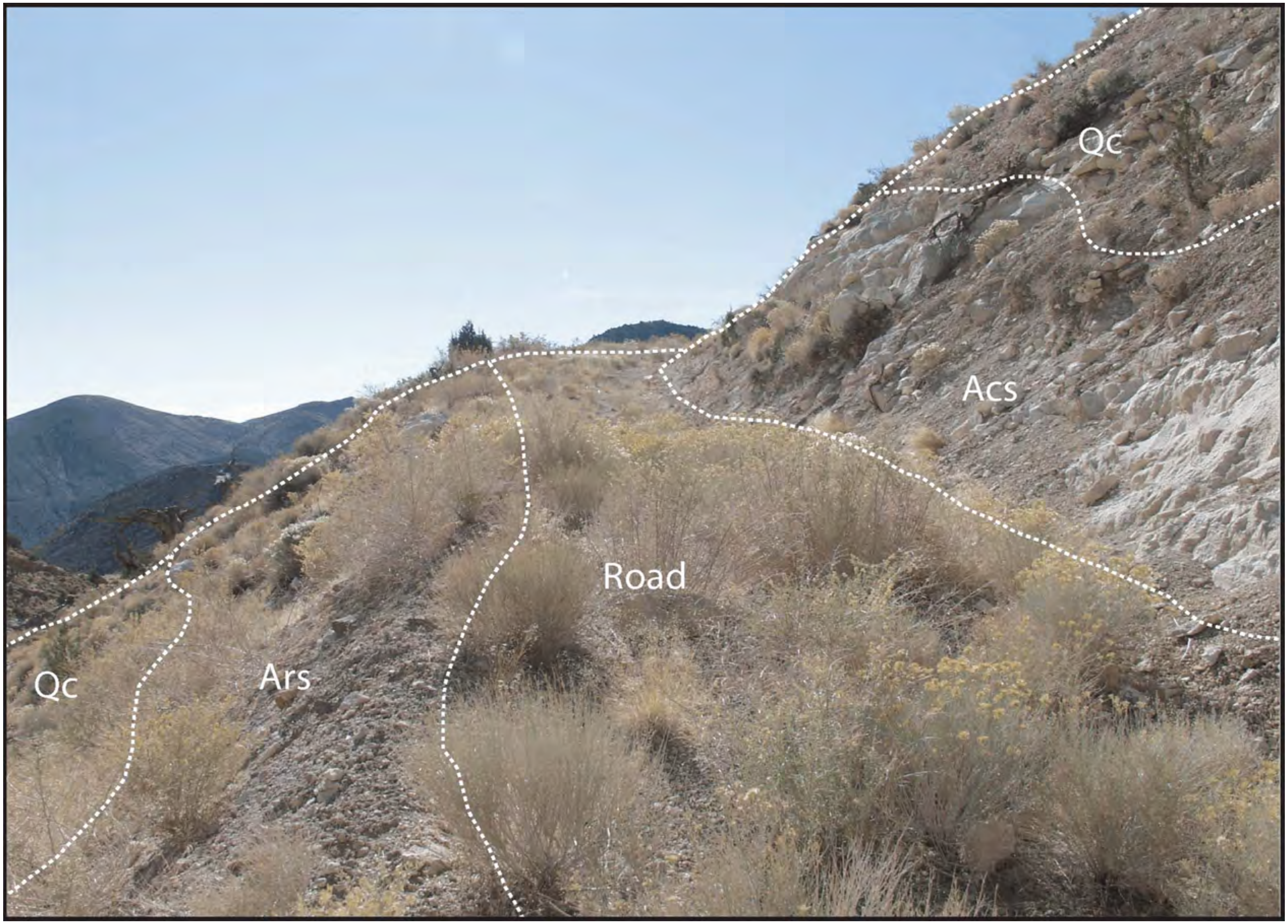


Figure 114. View south on road to upper pad above U12n Tunnel portal area showing cut slopes (Acs) in bedrock and colluvium and road side-cast (Ars) along the access road.

Figure 115. View north on road from upper pads above the U12n Tunnel portal area showing cut slopes (Acs) in bedrock and colluvium and a zone of road side-cast (Ars) along the access road. Colluvium from the upper slope and from the cut slope have covered a portion of the road making it impassable.

Figure 116. View east from the access road above the U12n Tunnel portal area showing the tailings (At), bedrock cut slopes (Acs), fill pads (Af) and fill slopes (Afs), and road side cast material.

slope until the angle of repose is attained (Ats) (Figures 106, 113, 117-118). There is no doubt that during initial tunnel development a certain volume of material was dumped directly onto the slope adjacent to the portal area, but as the U12n tunnel system became more extensive it was necessary to design an efficient system to distribute tailings in a systematic manner. At U12n Tunnel it is apparent that a significant operation was designed to transport muck by rail from the interior tunnel workings to a dumping station where heavy equipment redistributed the muck on the tailing pile. The tailings, including buildings and roads situated on the tailings, cover a large area of approximately 13 acres (5.3 hectares), and have filled a significant portion of the tributary drainage. The existing prism of mine waste is about 1,000 ft (305 m) long and 1,500 ft (457 m) wide. The greatest vertical thickness is about 60 ft (18 m) at the southernmost end of the tailing pile and tapers to a few feet at the eastern and western ends. Using a conservative estimate of average thickness of 10 ft (3 m), the volume of tailings disposed at the site may be upwards of many tens of millions of cubic feet. Much of the native vegetation was destroyed and little vegetation other than grasses and sparse sage and rabbit brush has established in the intervening decades since the last tunneling activities were undertaken. Small drainage networks have developed on the tailings and provide an effective transport linkage to the downstream geomorphic and hydrologic systems. Several large gully systems have formed resulting in the introduction of a large volume of sediment onto the lower slopes and into the system of five linked artificial retention ponds constructed adjacent to the principal road.

Rilled and eroded tailings occur on relatively unvegetated tailings slopes (Ats) (Figures 118-119) and are characterized by visible dendritic networks of rills, parallel rills, and shallow gullies less than 1 ft (30 cm) deep. Approximately 4 acres (1.6 hectares) of unvegetated tailings slopes (Ats) are present on the margins of the tailings area. The rills have supplied, and are capable of supplying, substantial volumes of fine-grained sediment to the retention ponds. Some of the eroded material is temporarily stored in small alluvial fans and drainages (Ata) that form on the tailings pad following precipitation events. The small deposits on the tailings cover about 0.9 acre (0.4 hectare).

Gullied tailings (Atg) are prominent sites of intense vertical and lateral erosion of the tailings slope (Figure 119). Mapped gullied tailings cover about 1.7 acres (0.7 hectares) of the study area, which represents about 30 percent of the tailings slopes. The gullied tailings occur on unvegetated portions of the tailings slope and may be 10 ft (3 m) or so deep and wide. The expansion of individual gullies commonly occurs by fluvial erosional processes, but localized slope failure of banks, localized debris flow, and sapping processes can also occur. In some locations the gullies have expanded into dendritic drainage patterns that extend to the head of the tailings slope and into the tailing pad. The major gullies are associated with poorly controlled surface drainage in the broad, relatively level areas or breaches in berms (Atb) constructed along the edges of the tailings pad.

Surficial Geologic Units

In addition to anthropogenic features, natural surficial deposits are present in the U12n Tunnel area. The deposits consist of alluvium, small alluvial fans, and colluvium (Figures 105-107). They are considered to be late Holocene because pedogenic features indicating appreciable soil development are not apparent on most deposits. Some small remnants of soils on older fluvial terraces and colluvial deposits are found in the area around the U12n Tunnel Portal. The steep hillslope environment of the area also contributes to the absence of well-developed soils on the upper slopes because of mixing of the soil caused by mass wasting processes.

Figure 117. Examples of tailings (At) and tailings slopes (Ats) below the dump station at the eastern edge of the staging and dump area in the U12n Tunnel portal area. Runoff from the tailings resulted in localized gullying and formation of shallow, ephemeral stream channels transporting alluvium derived from the tailings (Ata).

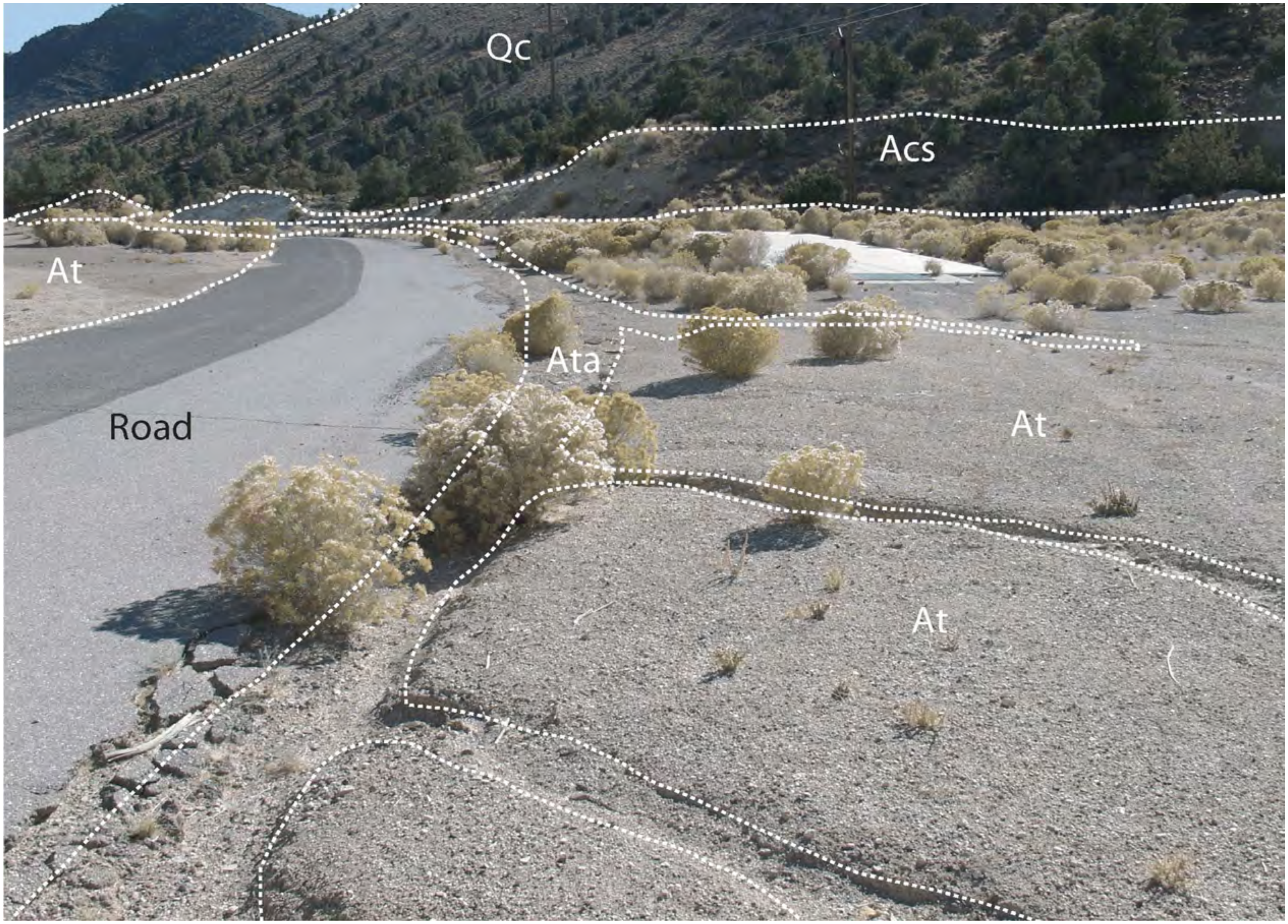


Figure 118. Example of drainage (Ata) developed on tailings (At) and alongside roads. Also shown in the figure are bedrock cut slopes (Acs) and colluvial mantled bedrock slopes.

Figure 119. An example of gullied (Atg) and rilled tailings (Atr) on the southeast edge of the tailings pile area at U12n Tunnel. An artificial berm was formed at the edge of the tailings pad to control runoff and development of gullies. The berm was breached in this and other areas.

Quaternary alluvium (Qa) is mapped along ephemeral stream channels and constitutes about 18 acres (7.3 hectares), or about 11 percent of the disturbed area. It consists of thin deposits of unconsolidated silt, sand, and gravel transported and deposited during rain events and snow melt of magnitudes sufficient to generate runoff. Approximately 11 of the 18 acres (about 60 percent) have been graded, bladed, or affected by other surface disturbing activities (Qab).

Quaternary fluvial terraces (Qt) are represented by small remnants (about 2 acres; 0.8 hectares) of fluvial terraces along the axial valley of the tributary to Tongue Wash. These remnants are situated about 3 to 8 ft (1 to 2.4 m) above the active floodplain and channel and are vegetated primarily by shrubs. Although the soil was not observed, elsewhere in the region, a soil having a weakly developed B horizon would likely be observed on these terraces. The extent of the terraces is unknown, but most likely terraces were destroyed or modified during road building and maintenance, and retention pond construction and maintenance.

Small alluvial fan deposits (Qf) are observed in the portal area where small tributaries have developed depositional loci at the base of the mesa. Alluvial fans cover approximately 0.7 acres (0.3 hectares), although their extent was likely greater prior to development in the portal area.

Quaternary colluvium (Qc) is mapped throughout the area and consists of a very thin veneer, generally 20 inches (50 cm) or less of silt, sand, gravel, angular cobbles, and angular boulders derived from bedded tuffs and welded tuff. Colluvium covers about 65 acres (26 hectares) of the geomorphic study area, although much of the area mapped as bedrock on Rainier Mesa could be considered to have a very thin mantle of colluvium. All grain sizes can be derived from the mechanical and chemical weathering of bedrock units in the area; however, a thin silty soil crust indicates that an eolian silt component is probably present.

Summary of the U12n Tunnel Geomorphology

At the U12n Tunnel complex, modifications to the landscape have resulted from four principal activities: 1) road construction and maintenance, 2) mining activities related to development of the U12n Tunnel complex, 3) site preparation for activities related to experiments and testing in the U12n Tunnel complex and on Rainier Mesa, and 4) construction of retention ponds in the alluvial valley. Despite the amount of construction activity, the footprint of the U12n Tunnel complex is relatively small.

Road construction resulted in the cutting of bedrock and colluvial slopes to create access roads to and around the U12n Tunnel site and on the top of Rainier Mesa. Many of the constructed road surfaces act as sources of sediment. Direct precipitation on the road surfaces generates runoff into roadside ditches supplying the main washes. On the steeper sections of the road, as it climbs the flanks of the mesa, most construction consisted of excavating hillslope colluvium and scraping bedrock, although, in places near the top of the mesa some blasting was necessary to create a path through the welded tuff of the Rainier Mesa member of the Timber Mountain Tuff. The excavating and scraping resulted in minor yet perceptible changes in bedrock outcrop morphology. Material side-cast from the roads and fill piles typically is restricted to a narrow corridor less than 16 ft (5 m) along the road, but in some cases the material has moved tens of meters down slope impinging on vegetation and altering local surface drainage and hydrology. On the mesa top, roads were constructed across streams by installing a culvert and placing fill over the culvert. In the cases of road crossings of this nature, infrequent culvert maintenance has resulted in restricted through flow and thick deposits of sediment backfilling valleys immediately upstream. In some locations it is apparent that substantial grading or blading occurred within the alluvial valley of the upper tributaries of The Aqueduct.

Mining activities associated with development of the U12n Tunnel complex are responsible for the dumping of tailings in front of the tunnel portal and construction of prominent tailings slopes. The broad, artificial fill terraces at the portal and adjacent areas attest to the large volume of material placed in the valley and adjacent hillslopes in the Tongue Wash tributary. The tailings locally are 2 to 3 ft (0.6 to 0.9 m) thick near the portal and up to 90 ft (27 m) thick at the east end of the tailings directly above the former stream valley. Small rivulets and second order stream networks have developed on the tailings pile and have been transporting fine grained tailings to the main tributary, into ponds, and to the lower part of the drainage systems. Small gully systems heading on the principal tailing area fronting the portal have incised up to about 10 ft (3 m) into the tailing slope and provide sediment to small alluvial fans formed at the base of the tailing pile. Two prominent gullies and numerous small rills eroded into the tailings slopes are linked directly to drainages feeding into the ponds.

Site preparation activities, primarily the emplacement of fill for the preparation of building sites and staging areas, has resulted in small but recognizable modifications of the natural landscape. The net effect of much of the activity related to development of the U12n Tunnel complex is that large volumes of fresh, erodible material has been made available for transport to the main stem of the tributary and eventually to the main stem of Tongue Wash. On the top of Rainier Mesa, road building activities, preparation of trailer parks, drill pads, and equipment sites resulted in the general redistribution of surficial deposits, and some bedrock quarrying. In steeper parts of the mesa, in particular along the channel of The Aqueduct, roads and bladed areas provide a linkage between eroding fill pads and the large drainage system.

Five retention ponds are situated on the valley floor on former fluvial terraces associated with the tributary to Tongue Wash. The ponds were used as settling ponds for water discharged as groundwater during tunnel excavation, water used in construction, and water produced during reentry activities following each tests. The upper pond is partially buried by sediment derived from the tailings pile. The dominant effect of the ponds is the disruption of the riparian community along the tributary valley and potential connection to the shallow aquifer system.

DESCRIPTION OF U12n TUNNEL CULTURAL FEATURES

The U12n Tunnel complex consists of two discontinuous areas on the east slope and on top of Rainier Mesa (Figure 120). These are the portal area and the mesa area. Features within the two areas are topographically separate and, generally, functionally different. The topographic distinction is due to an abrupt elevation change for the portal area at 6,020 ft (1,834.9 m) to the mesa area at up to 7,450 ft (2,270.8 m). Functionally, the features at the portal area relate to construction, testing, and general everyday activities within the U12n Tunnel. Many of the features on the mesa area are related to pre- and post-shot drilling from the mesa surface into the tunnel complex. However, some of the features (i.e., cable holes and vent holes) are related to testing and everyday tunnel activities. A total of 202 features, 83 at the portal area and 119 at the mesa area, were recorded, mapped, and photographed for the U12n Tunnel complex project.

The portal area is on the lower slopes of Rainier Mesa and is divided into 10 sub-areas based on their topographic location and function (Figure 121). The portal area extends 4,330 ft (1,319.7 m) east-west by 1,085 ft (330.1m) north-south and encompasses 52.6 acres (21.3 hectares). The sub-areas are the portal pad, telephone pad, cooling tower pad, ventilation pad, water tank pad, muckpile, powder magazines pad, parking area pad, pond area, and miscellaneous features along N Tunnel Road. These sub-areas are within close proximity to each other, 0.75 miles (1.2 km), and within a drainage (canyon) that extends from the east slope of Rainier Mesa to the northern end of Yucca Flat.

The mesa area includes all features found on the steep east face (Features 84-86) and top of Rainier Mesa (Features 87-202) associated with the U12n Tunnel complex. The mesa area extends approximately 1.28 mi (2.1 km) east-west by 1 mi (1.6 km) north-south and encompasses 548.2 acres (221.8 hectares). It varies in elevation from 6,700 ft (2,042.2 m) on the east slope of the mesa to 7,420 ft (2,261.6 m) on the mesa top. Features on the mesa area are related to pre- and post-shot drilling from the mesa surface into the tunnel complex. However, some of the features at the mesa area are related to testing and tunnel activities (i.e., vent hole and cable holes). The features have been divided into 3 sub-areas and are the mesa trailer park, parking area, and the general mesa area. These areas are up to 1.7 mi (2.7 km) in linear distance from the U12n Tunnel portal and up to 1,500 ft (457.2 m) higher in elevation.

Portal Area Feature Descriptions

The portal area contains 83 features that are found within 10 sub-divisions and are listed in Table 4 with locational information in Universal Transverse Mercator (UTM) coordinate system North American Datum (NAD) 27, Zone 11. Fifty-two features are at the portal pad and a description follows. Features 53-83 are described at the various locations near the portal pad. Engineering drawings by Raytheon Services, Nevada, related to U12n Tunnel activities were obtained from the NNSA/NSO Archives and Records Center. Drawings JS-012-U12n.24-C3 (1992) and JS-012-U12n-C123 (1993) were used to determine the function of features at the portal area and drawings JS-012-U12n-C 46.3 (1969), JS 012 N09 E22 (1974), JS 012-U12n.15-C21 (1981), JS-012-U12n.15-C20.3 (1982), JS-012-U12n.15-E45.1 (1982), and JS-12-U12n.19-C1 (1984) were used for features on the top of Rainier Mesa.

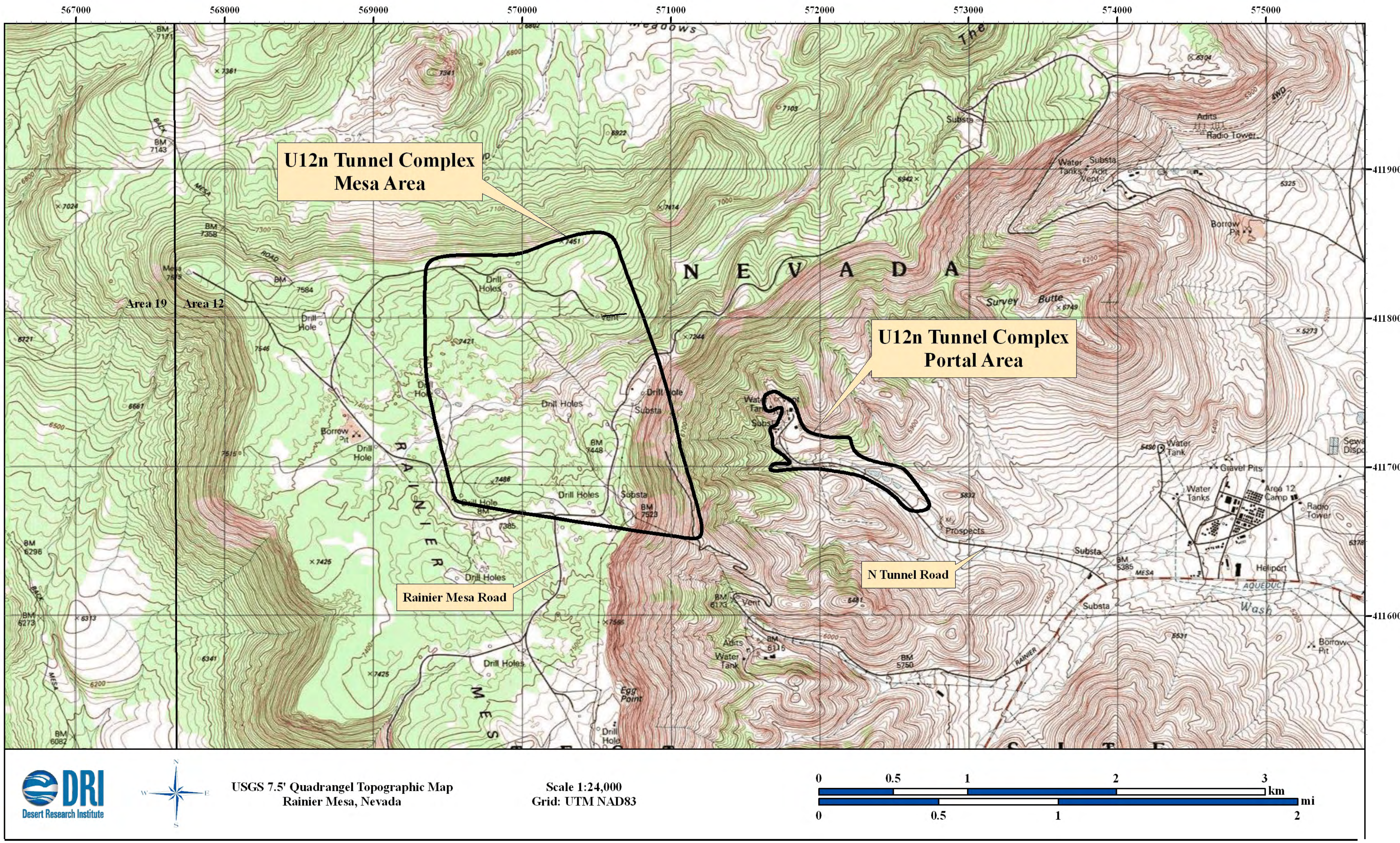


Figure 120. Location of the U12n portal area and mesa area on the NNSS.

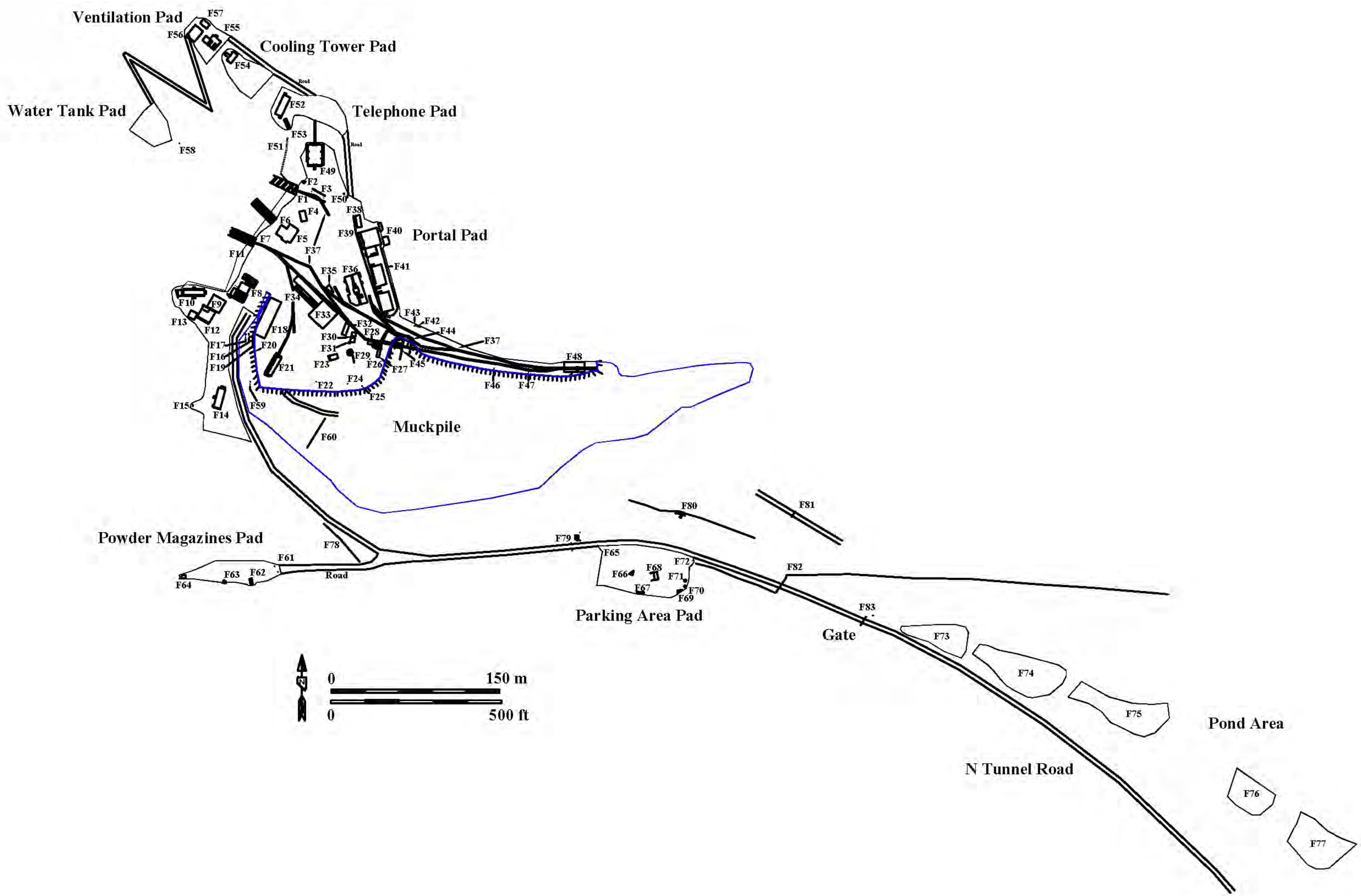


Figure 121. Plan map of the U12n Tunnel complex portal area.

Table 4. List of Features at the Portal Area.

NO.	FEATURE TYPE	ELEVATION (ft-m)	EASTING	NORTHING
	PORTAL AREA			
Portal Pad				
1	U12n Tunnel Portal	6,024 - 1,836.1	571784	4117350
2	Concrete Pad	6,030 - 1,838.1	571789	4117353
3	Sign	6,030 - 1,838.1	571808	4117341
4	Re-entry Substation Foundation	6,020 - 1,834.9	571790	4117328
5	Entry Control Building Foundation	6,020 - 1,834.9	571784	4117310
6	Storage Alcove	6,020 - 1,834.9	571760	4117316
7	U12n Tunnel Extension Portal	6,020 - 1,834.9	571747	4117306
8	Substation 12-5 Foundations	6,020 - 1,834.9	571741	4117267
9	Concrete Foundation	6,000 - 1,828.8	571717	4117250
10	Portal Recording Station Foundation	6,000 - 1,828.8	571700	4117258
11	Cable Trough (south end)	6,040 - 1,841.0	571678	4117257
12	RCMC Facility and Maintenance Shop Foundation	6,000 - 1,828.8	571710	4117237
13	Microwave Tower	6,000 - 1,828.8	571694	4117236
14	Sandia Office Foundation	5,980 - 1,822.7	571719	4117168
15	Electrical Panel	5,980 - 1,822.7	571690	4117217
16	Light Pole	6,015 - 1,833.4	571739	4117217
17	Sign	6,010 - 1,831.8	571737	4117218
18	Storage Pad	6,020 - 1,834.9	571769	4117246
19	Pipe	6,020 - 1,834.9	571743	4117218
20	Electrical Panel Backboard	6,020 - 1,834.9	571745	4117203
21	Tunnel Boring Machine Mechanics Shop Foundation	6,020 - 1,834.9	571769	4117196
22	Water Pipe Manifold and Electrical Junction Box	6,020 - 1,834.9	571800	4117175
23	Loading Ramp	6,020 - 1,834.9	571811	4117198
24	Compressed Air Pipe Manifold	6,020 - 1,834.9	571828	4117173

Continued

Table 4. List of Features at the Portal Area (continued).

NO.	FEATURE TYPE	ELEVATION (ft-m)	EASTING	NORTHING
	PORTAL AREA			
Portal Pad				
25	Light Pole	6,020 - 1,834.9	571841	4117171
26	Light Pole	6,020 - 1,834.9	571848	4117195
27	Lube and Oil Concrete Pad	6,020 - 1,834.9	571857	4117203
28	Concrete Pad	6,020 - 1,834.9	571852	4117210
29	Water Pipeline	6,020 - 1,834.9	571831	4117204
30	Concrete Foundation	6,020 - 1,834.9	571835	4117218
31	Cement Operators Shack Concrete Foundation	6,020 - 1,834.9	571834	4117213
32	Liquid Nitrogen Plant Concrete Foundation	6,020 - 1,834.9	571830	4117221
33	Loading Dock	6,020 - 1,834.9	571819	4117235
34	Experimenter's Holding and Dry Storage Building Foundation	6,020 - 1,834.9	571806	4117256
35	Loading Ramp	6,020 - 1,834.9	571815	4117254
36	Multi-Purpose Building Foundation	6,020 - 1,834.9	571837	4117272
37	Rail Lines (at portal)	6,020 - 1,834.9	571784	4117350
38	Electrical Storage Building Foundation	6,020 - 1,834.9	571838	4117323
39	Storm Drainage Channel (north end)	6,020 - 1,834.9	571833	4117323
40	Electrical Storage Alcoves	6,020 - 1,834.9	571856	4117316
41	Concrete Foundations (north)	6,020 - 1,834.9	571854	4117312
42	Electrical Panel Backboard	6,020 - 1,834.9	571893	4117224
43	Pipe Manifold	6,020 - 1,834.9	571888	4117225
44	Camel Back	6,020 - 1,834.9	571887	4117213
45	Concrete Walls and Rotary Dump	6,020 - 1,834.9	571887	4117204
46	Light Pole	6,020 - 1,834.9	571959	4117187
47	Light Pole	6,020 - 1,834.9	571990	4117184

Continued

Table 4. List of Features at the Portal Area (continued).

NO.	FEATURE TYPE	ELEVATION (ft-m)	EASTING	NORTHING
	PORTAL AREA			
Portal Pad				
48	Wash Area	6,020 - 1,834.9	572040	4117190
49	REECo Office Building Foundation	6,030 - 1,837.9	571808	4117387
50	Fire Hydrant	6,030 - 1,837.9	571827	4117342
51	Wood Walkway	6,060 - 1,847.1	571777	4117429
Telephone Pad				
52	RSN/DNA Office Building Foundation	6,040 - 1,841.0	571775	4117393
53	Telephone Trailer on Concrete Pad	6,040 - 1,841.0	571777	4117402
Cooling Tower Pad				
54	Cooling Tower Concrete Pad	6,080 - 1,853.2	571730	4117467
Ventilation Pad				
55	Concrete Pad	6,120 - 1,865.4	571715	4117479
56	Compressor Pad	6,120 - 1,865.4	571699	4117488
57	Compressor Operator’s Shack Foundation	6,120 - 1,865.4	571705	4117494
Water Tank Pad				
58	Fiberglass Insulated Pipe Connections	6,200 - 1,889.7	571678	4117388
Muckpile				
59	Sign	5,900 - 1,798.3	571741	4117175
60	Fence and Gate	5,900 - 1,798.3	571808	4117142
Powder Magazines Pad				
61	Boxes	6,000 - 1,828.8	571766	4117005
62	Powder Magazine	6,000 - 1,828.8	571743	4116999
63	Powder Magazine	6,000 - 1,828.8	571719	4116997
64	Powder Magazine	6,000 - 1,828.8	571719	4116997

Continued

Table 4. List of Features at the Portal Area (continued).

NO.	FEATURE TYPE	ELEVATION (ft-m)	EASTING	NORTHING
	PORTAL AREA			
Parking Area Pad				
65	Sign	5,880 - 1,792.2	572056	4117023
66	T Posts	5,880 - 1,792.2	572084	4117006
67	Concrete Barriers	5,880 - 1,792.2	572093	4116987
68	Milled Lumber	5,880 - 1,792.2	572105	4117005
69	Concrete Barriers	5,880 - 1,792.2	572127	4116989
70	Cable Spool	5,880 - 1,792.2	572130	4116992
71	Pipe Clamps	5,880 - 1,792.2	572130	4116997
72	Sign and Pipe	5,880 - 1,792.2	572137	4117015
Retention Pond Area				
73	Pond 1	5,780 - 1,761.7	572323	4116956
74	Pond 2	5,760 - 1,755.6	572387	4116931
75	Pond 3	5,740 - 1,749.6	572484	4116906
76	Pond 4	5,720 - 1,743.5	572635	4116800
77	Pond 5	5,700 - 1,737.4	572695	4116760
Miscellaneous Features Along N Tunnel Road				
78	Pipe Line	5,960 - 1,816.6	571807	4117048
79	Traffic Control Building	5,860 - 1,786.1	572034	4117037
80	Tunnel Discharge Monitoring Station and Water Line	5,840 - 1,780.0	572126	4117065
81	Gate and Road	5,840 - 1,780.0	572229	4117059
82	Electrical Panel and Conduit	5,820 - 1,773.9	572221	4117002
83	Barricade	5,800 - 1,767.8	572292	4116965

Portal Pad

The U12n Tunnel portal pad is a large dirt and gravel pad used as a staging area for construction of the U12n Tunnel and testing activities within the tunnel. It is irregular in shape with a sinuous boundary (Figures 122-128) and was constructed along the northern edge of a southeast trending drainage (canyon) on the lower southeast facing slope of Rainier Mesa. The pad is at an elevation of 6,020 ft and is 730 ft (222.5 m) north-south by 1,265 ft (385.5 m) east-west encompassing 7.7 acres (3.1 hectares). The north and west edges abut the steep slope of the mesa face and the east and south edges slope abruptly into the drainage. The pad (upper bench) is between the muckpile (lower bench) to the south and east and the telephone pad to the north. Fifty-one features were recorded on the portal pad (Features 1-51) and include the U12n Tunnel portals, concrete foundations for buildings, communication equipment, rail lines, and electrical supply equipment. All the features on the portal pad are at an elevation of 6,020 ft unless otherwise noted.

Feature 1

Feature 1 (Figure 129) is the U12n Tunnel portal at UTM coordinates 571784 E, 4117350 N at an elevation of 6,024 ft. The portal extends approximately 10 ft (3.1 m) south of the mesa face and is constructed of metal sets, wood lagging, and shotcrete. Visually, the extension is arched with a steel set at the face of the portal opening. The set is 13 ft 5 inches (4.1 m) wide and is 12 ft 9 inches (3.9 m) from top (outside) of the arch to the ground surface. Sets are placed at intervals along the tunnel with wood lagging between the sets to support the surrounding rock. Along the interior of the portal are high voltage panels, insulated pipe, various sized cables, sand bags, and two metal rail lines. The portal is secured with two locked metal gates that are inset within the first set. At the left bottom corner of the right gate is a 3 x 3 ft (91.4 x 91.4 cm) personnel access panel that is locked. On top of the portal are five metal signs. They are labeled: #1 RE-ENTRY VENT, #2 PORTAL UTILITY, #3 TUNNEL UTILITY, #4 INST POWER, and #5 POWER. Below each sign are two lights mounted vertically on galvanized conduit. Below these lights and mounted to the top of the first set are two red (flashing type) lights used, in conjunction with a siren, to warn when a train was coming out of the tunnel. Behind the signs are two orange metal boxes approximately 2 ft 6 inches x 2 ft 6 inches x 1 ft (76.2 x 76.2 x 30.4 cm) labeled LIGHTENING ARRESTER and DANGER HIGH VOLTAGE. To the right of the portal is a 1 ft 8 inch x 2 ft 6 inch x 6 inch (50.8 x 76.2 x 15.2 cm) electrical junction box housing three black insulated cables and one bradded copper ground cable. On the left side of the portal is a 10 ft east-west by 8 ft (2.4 m) north-south rectangular extension covered with concrete. The roof slopes downward to the west from the south side of the portal. It is 9 ft (2.7 m) in height on the north end where it joins the portal and 7 ft (2.1 m) in height on the south end. Expanded metal is exposed through the concrete on the top of the extension. On the east face of the extension is an electrical panel backboard. The backboard is constructed of 3-inch (7.6 cm) channel iron posts and 1 1/2-inch (3.8 cm) channel iron rails. Attached to the rails are four electrical panels with cables that exit the bottom and extend underground and through the top and connect to a series of lights and a siren above the portal. Multiple cables and conduit extend from the vertical mesa face and enter the portal at various locations along the top and sides of the extension.

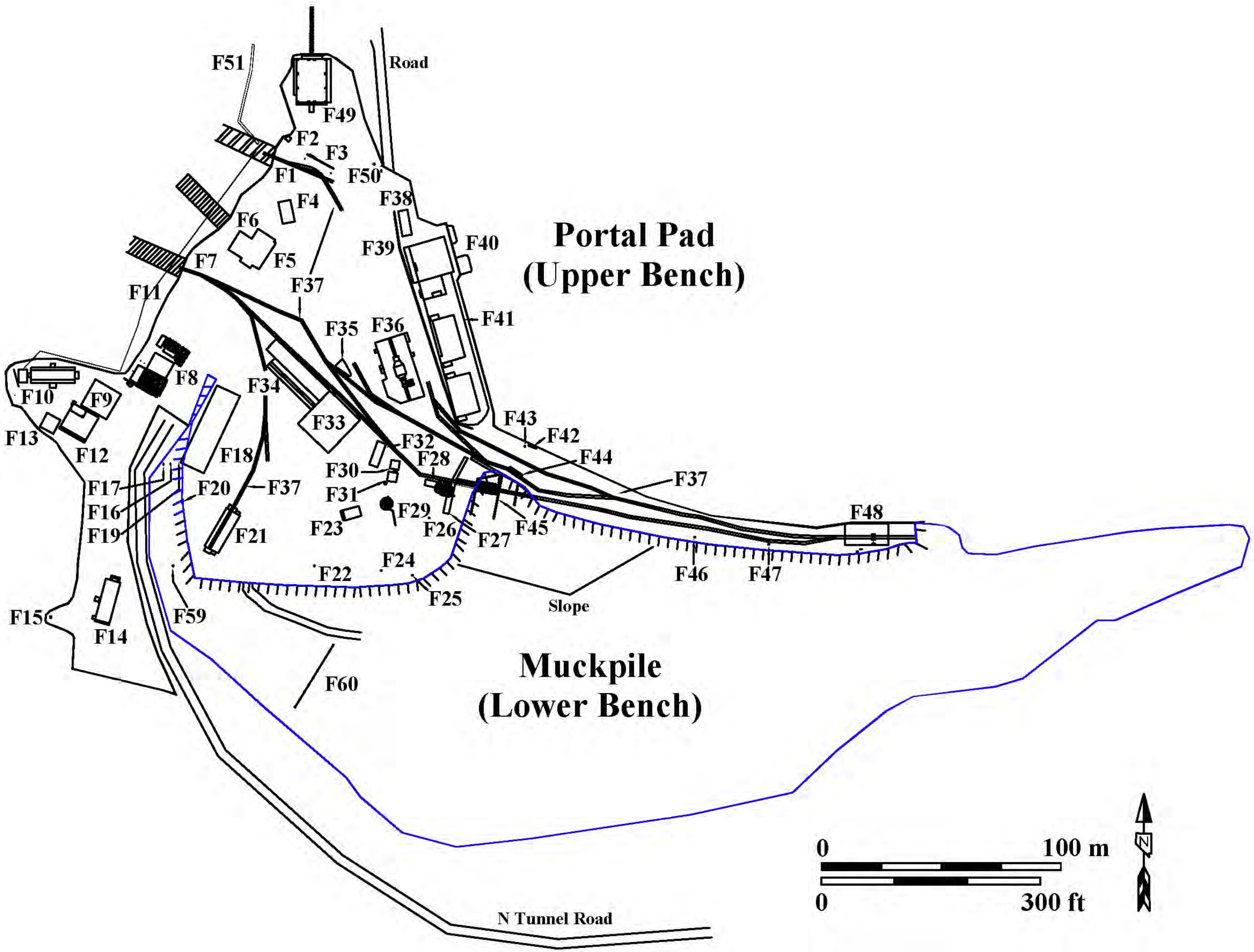


Figure 122. Plan map of the U12n Tunnel complex portal and muckpile.


Figure 123. Overview of the U12n Tunnel complex, portal area (portal not in view), view east (2008).


Figure 124. General area view of U12n Tunnel portal pad (portal not in view), view southeast (2008).

Figure 125. Overview of portal pad upper bench (portal not in view), view south (2008).