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10/01/2007	01	Approved Revision 01 initiated as a result of the biennial document review. Constitutes a total rewrite of document. This revision includes expanded details as to activities and project timeframes at the NTS. General information about access control has been added. New attachments include an enumeration of tests by year, type, and location; a description of nuclear rocket and ramjet tests; an evaluation of exposure potential by contractor job title; and a discussion of post-test drilling technology. Incorporates formal internal and NIOSH review comments. Training required: As determined by the Task Manager. Initiated by Eugene M. Rollins. Approval: Signature on File 09/27/2007 Eugene M. Rollins, TBD Team Leader Signature on File 09/28/2007 John M. Byrne, Task 3 Manager Signature on File 09/27/2007 Edward F. Maher, Task 5 Manager Signature on File 09/27/2007 Kate Kimpan, Project Director Brant A. Ulsh Signature on File for 10/01/2007 James W. Neton, Associate Director for Science
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ACRONYMS AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
Anti-C	anticontamination
BEEF	Big Explosives Experimental Facility
BN	Bechtel Nevada
BOP	blowout preventer
BREN	Bare Reactor Experiment Nevada
cfm	cubic feet per minute
Ci	curie
cm	centimeter
CP	Control Point
cpm	counts per minute
d	day
DAF	Device Assembly Facility
decon	decontamination
DNA	Defense Nuclear Agency
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DSWA	Defense Special Weapons Agency
DTRA	Defense Threat Reduction Agency
EG&G	Edgerton, Germeshausen, and Grier
EIS	environmental impact statement
E-MAD	Engine Maintenance Assembly and Disassembly
EPA	U.S. Environmental Protection Agency
°F	degrees Fahrenheit
FSN	Fenix & Scisson of Nevada
ft	foot
g	gram
GMX	Gadgets, Mechanics, and Explosives (former division of Los Alamos National Laboratory)
H&N	Holmes & Narver
HAZMAT	hazardous material
HE	high explosive
HENRE	High Energy Neutron Reactions Experiment
HLOS	horizontal line of sight
hr	hour
in.	inch
INC	Isotope and Nuclear Chemistry
JASPER	Joint Actinide Shock Physics Experimental Research
°K	degrees Kelvin
keV	kilovolt-electron, 1,000 electron volts
kg	kilogram

km	kilometer
kps	kilometers per second
kt	kiloton (explosive force of 1,000 tons of TNT)
kW	kilowatt
LANL	Los Alamos National Laboratory
LASL	Los Alamos Scientific Laboratory
lb	pound
LLNL	Lawrence Livermore National Laboratory
LOS	line of sight
LRL	Lawrence Radiation Laboratories
LYNER	Low-Yield Nuclear Explosive Research
m	meter
MAD	Maintenance, Assembly, and Disassembly
mCi	microcurie
mi	mile
min	minute
ml	milliliter
mph	miles per hour
mR	milliroentgen
ms	millisecond
Mt	megaton (explosive force of 1 million t TNT)
MW	megawatt
NASA	National Aeronautics and Space Administration
NEAF	Nuclear Explosive Assembly Facility
NERVA	Nuclear Engine for Rocket Vehicle Application
NIOSH	National Institute for Occupational Safety and Health
NNSA	National Nuclear Security Administration
NRDS	Nuclear Rocket Development Station
NSO	Nevada Site Office
NTS	Nevada Test Site
NTTR	Nellis Test and Training Range
NUWAX	Nuclear Weapons Accident Exercise
PPC	personal protective clothing
psi	pounds per square inch
R	roentgen
RAM	remote air monitoring
RCRA	Resource Conservation and Recovery Act
REECo	Reynolds Electrical and Engineering Company
RER	Radiological Emergency Response
RMAD	Reactor Machine Assembly and Disassembly
RSN	Raytheon Services Nevada
RWMS	Radioactive Waste Management Site
s	second
SNM	Special Nuclear Material
SOP	standard operating procedure

t	ton [explosive force of 1 t (2,000 lb) TNT]
TAPS	tunnel and pipe seal
TED	track etch dosimeter
TLD	thermoluminescent dosimeter
TNT	trinitrotoluene
TRU	transuranic
TTR	Tonopah Test Range
U.S.C.	United States Code
WEF	Waste Examination Facility
WIPP	Waste Isolation Pilot Plant
WSI	Wackenhut Services, Inc.
XE	Experimental Engine
yr	year
µCi	microcurie

2.1 INTRODUCTION

Technical basis documents and site profile documents are not official determinations made by the National Institute for Occupational Safety and Health (NIOSH) but are rather general working documents that provide historic background information and guidance to assist in the preparation of dose reconstructions at particular sites or categories of sites. They will be revised in the event additional relevant information is obtained about the affected site(s). These documents may be used to assist NIOSH staff in the completion of the individual work required for each dose reconstruction.

In this document the word "facility" is used as a general term for an area, building, or group of buildings that served a specific purpose at a site. It does not necessarily connote an "atomic weapons employer facility" or a "Department of Energy [DOE] facility" as defined in the Energy Employees Occupational Illness Compensation Program Act [EEOICPA; 42 U.S.C. § 7384l(5) and (12)]. EEOICPA defines a DOE facility as "any building, structure, or premise, including the grounds upon which such building, structure, or premise is located … in which operations are, or have been, conducted by, or on behalf of, the Department of Energy (except for buildings, structures, premises, grounds, or operations … pertaining to the Naval Nuclear Propulsion Program)" [42 U.S.C. § 7384l(12)]. Accordingly, except for the exclusion for the Naval Nuclear Propulsion Program noted above, any facility that performs or performed DOE operations of any nature whatsoever is a DOE facility encompassed by EEOICPA.

For employees of DOE or its contractors with cancer, the DOE facility definition only determines eligibility for a dose reconstruction, which is a prerequisite to a compensation decision (except for members of the Special Exposure Cohort). The compensation decision for cancer claimants is based on a section of the statute entitled "Exposure in the Performance of Duty." That provision [42 U.S.C. § 7384n(b)] says that an individual with cancer "shall be determined to have sustained that cancer in the performance of duty for purposes of the compensation program if, and only if, the cancer … was at least as likely as not related to employment at the facility [where the employee worked], as determined in accordance with the POC [probability of causation[1]] guidelines established under subsection (c) …" [42 U.S.C. § 7384n(b)]. Neither the statute nor the probability of causation guidelines (nor the dose reconstruction regulation, 42 C.F.R. Pt. 82) define "performance of duty" for DOE employees with a covered cancer or restrict the "duty" to nuclear weapons work (NIOSH 2007).

The statute also includes a definition of a DOE facility that excludes "buildings, structures, premises, grounds, or operations covered by Executive Order No. 12344, dated February 1, 1982 (42 U.S.C. 7158 note), pertaining to the Naval Nuclear Propulsion Program" [42 U.S.C. § 7384l(12)]. While this definition excludes Naval Nuclear Propulsion Facilities from being covered under the Act, the section of EEOICPA that deals with the compensation decision for covered employees with cancer [i.e., 42 U.S.C. § 7384n(b), entitled "Exposure in the Performance of Duty"] does not contain such an exclusion. Therefore, the statute requires NIOSH to include all occupationally-derived radiation exposures at covered facilities in its dose reconstructions for employees at DOE facilities, including radiation exposures related to the Naval Nuclear Propulsion Program. As a result, all internal and external occupational radiation exposures are considered valid for inclusion in a dose reconstruction. No efforts are made to determine the eligibility of any fraction of total measured exposure for inclusion in dose reconstruction. NIOSH, however, does not consider the following exposures to be occupationally derived (NIOSH 2007):

- Background radiation, including radiation from naturally occurring radon present in conventional structures

[1] The U.S. Department of Labor (DOL) is ultimately responsible under the EEOICPA for determining the POC.

- Radiation from X-rays received in the diagnosis of injuries or illnesses or for therapeutic reasons

2.1.1 Purpose

The purpose of this section of the NTS Site Profile is to provide background information on the site and its historical activities to the dose reconstructor.

2.1.2 Scope

The scope of this section of the NTS Site Profile is to describe the site in relation to possible sources of radioactive contamination from site activities and facilities (Section 2.2) and site processes (Section 2.3) and provide an overview of radiological access controls (Section 2.4). The attachments include an enumeration of tests by year, type, and location; a description of nuclear rocket and ramjet tests; an evaluation of exposure potential by contractor job title; and a discussion of post-test drilling technology.

2.2 SITE ACTIVITIES AND FACILITIES

The Nevada Test Site (NTS) in southern Nevada has served as the Nation's primary continental test site for the development of nuclear explosives. The NTS currently encompasses approximately 3,500 km^2 (1,375 mi^2); it is surrounded on the east, west, and north by the Nellis Test and Training Range (NTTR; formerly the Nellis Air Force Range), which provides a 24- to 100-km (15- to 64-mi) buffer zone between the NTS border and public lands. Included within the NTTR and to the northwest of the NTS is the Tonopah Test Range (TTR). The U.S. Bureau of Land Management administers Federal lands on the southern and southwestern borders of the NTS. Las Vegas, the major metropolitan center closest to the NTS, is approximately 105 km (65 mi) southeast of the site. Residential locations within 48 km (30 mi) of the NTS boundary are Indian Springs in Clark County and Pahrump and Beatty in Nye County. Other surrounding cities with sparse population within 48 km of the NTS are Rachel, Scotty's Junction, Rhyolite, Amargosa Valley, Johnnie, and Cactus Springs in Nevada; and Furnace Creek Ranch and Death Valley Junction in California.

The U.S. Department of Energy, National Nuclear Security Administration (NNSA), Nevada Site Office (NSO), operates the NTS, which is divided into the following seven zone categories as described in DOE (1996a):

1. **Nuclear Test Zone** – Land area reserved for underground hydrodynamic tests, dynamic experiments, and underground nuclear weapons and weapons effects tests. The stockpile stewardship emplacement hole inventory is in this zone. Part of the mission of the Stockpile Stewardship Program is to reserve land and infrastructure for next-generation nuclear weapons simulators pending programmatic decisions.

2. **Nuclear and High Explosive (HE) Test Zone** – Area designated for additional underground and aboveground HE tests or experiments.

3. **Research, Test, and Experiment Zone** – Area designated for small-scale research, development, and pilot projects and outdoor tests and experiments for the development, quality assurance, or reliability of materials and equipment under controlled conditions.

4. **Radioactive Waste Management Zone** – Area designated for the shallow land burial of low-level and mixed wastes.

5. **Critical Assembly Zone** – Area used for nuclear explosive operations, which generally include assembly, disassembly or modification, staging, repair, retrofit, and surveillance. This zone could also be used for weapons storage.

6. **Spill Test Facility Impact Zone** – A downwind geographic area that would confine the effects of the largest planned tests of materials released at the Hazardous Material (HAZMAT) Spill Center (formerly the Spill Test Facility).

7. **Reserved Zone** – Controlled-access area that provides a buffer between non-defense related research, development, and testing activities. The Reserved Zone includes areas and facilities that provide widespread flexible support for diverse short-term non-defense related research, testing, and experimentation. In addition, this zone is used for short-duration exercises and training, such as Nuclear Emergency Support Team and Federal Radiological Monitoring and Assessment Center training, both part of DOE, and U.S. Department of Defense (DOD) land navigation exercises and training.

Each numbered area on the NTS is associated with one or more of these zones. Figure 2-1 shows the numbered areas, principal facilities, and testing areas. Attachment A shows the NTS tests by year, type, and location and the intervals between NTS tests. The following sections describe these areas and indicate where activities that produced radioactive effluents occurred on the NTS. There is no Area 21 or Area 24 at the NTS: Area 21 simply does not exist, and Area 24 is the support facility in the Las Vegas metropolitan area.

The *Final Environmental Impact Statement for the Nevada Test Site and Off-site Location in the State of Nevada* (DOE 1996a) and the *United States Nuclear Tests, July 1945 through September 1992* (DOE 2000a) provided much of the area-specific descriptions in the following sections. In addition, *Nevada Test Site Contaminated Land Areas Report* (DOE 2000b) provided information about past contamination, its causes, and current practices such as the use of postings and fences for control of contaminated areas. The names of nuclear tests and some programs are in all-capital letters but are not necessarily acronyms with meaning.

DOE was created in 1977. The historical activities described in this document occurred for the most part under the authority of DOE or its predecessor agencies (the U.S. Atomic Energy Commission (AEC) and the Energy Research Development Administration). In addition, DOD and the Defense Special Weapons Agency [DSWA; the Defense Nuclear Agency (DNA) until 1996] supported nuclear weapons testing on the NTS. DSWA, which is a descendent of the Manhattan Project, evolved from the Armed Forces Special Weapons Project in 1947, to the Defense Atomic Support Agency in 1959, to DSWA in 1971.

2.2.1 Area 1 Nuclear Test Zone

Area 1 was the site of five atmospheric nuclear tests between 1952 and 1955 and of three underground nuclear tests, one in 1971 and two in 1990. In 1955, as part of the Nation's Civil Defense Program, various types of homes and buildings were constructed to test the effects of a nuclear blast and blast overpressures on typical urban structures. A few of these "Survival Town" structures still stand. Area 1 is the location of two four-story reinforced concrete structures built for structural response investigations. These structures have allowed study of structural response characteristics applicable to high-rise buildings.

In addition, Area 1 contains the U1a mined underground complex, which is available for dynamic experiments (including subcritical experiments involving special nuclear material) and HE tests that cannot be conducted atmospherically because they could disperse hazardous materials. The vertical

shaft is equipped with a mechanical hoist for personnel and equipment access while another vertical shaft about 1,000 ft away provides cross ventilation, instrumentation, utility access, and emergency egress. On the surface, there are several temporary buildings and instrumentation trailers.

The U1a facility was previously called the Low-Yield Nuclear Explosive Research (LYNER) Complex. The Complex consists of horizontal tunnels about 0.5 mi long mined at the base of a vertical shaft approximately 960 ft beneath the surface mined in the late 1960s for an underground nuclear test that never occurred. In 1988, the shaft was reopened, and a 1,460-ft horizontal tunnel was mined south at the 962-ft level of the shaft. The LEDOUX nuclear test, with a yield of less than 20 kt, was conducted in 1990 in a drift in this tunnel complex.

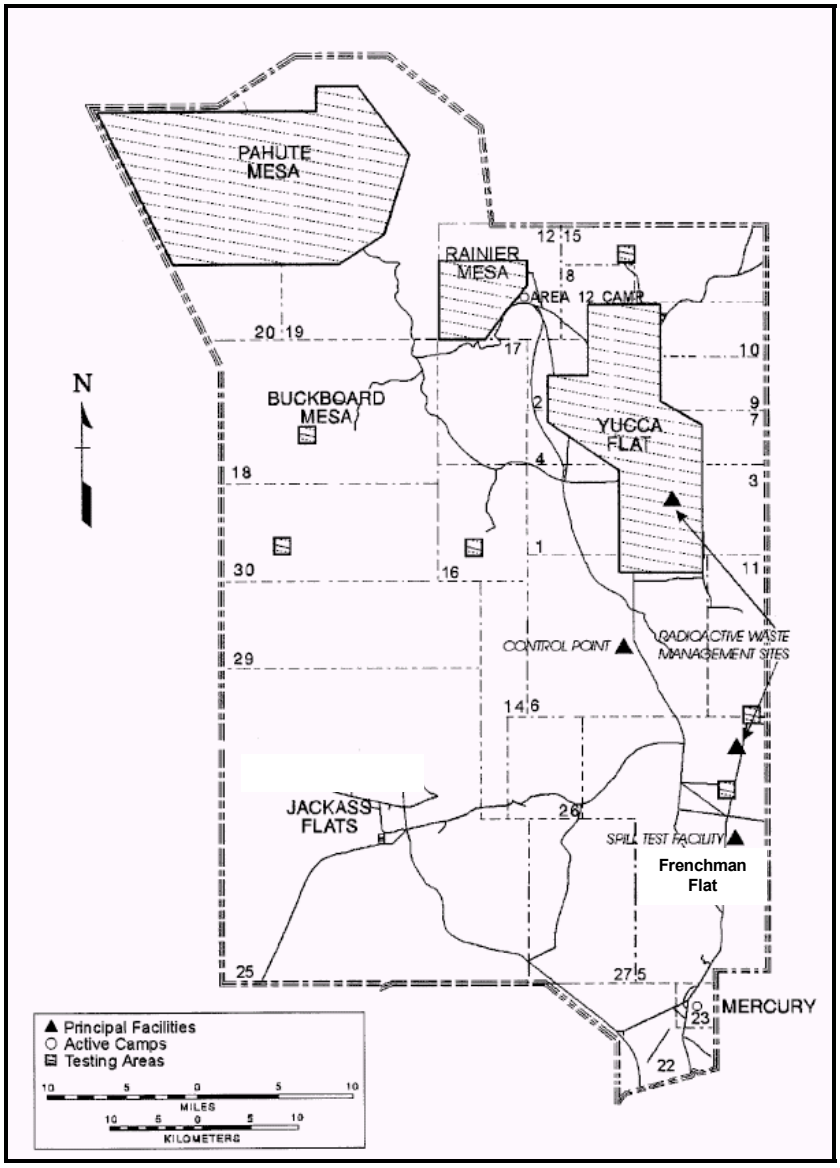

Figure 2-1. NTS areas, principal facilities, and testing area (DOE 1997a).

Further work took place in the 1980s and early 1990s to develop U1a for experiments likely to remain subcritical. The dynamic KISMET experiment, involving HE, tritium, depleted uranium, and other

materials, was conducted in March 1995. Both LEDOUX and KISMET were contained to prevent radiological releases to the rest of the Complex and the surface environment.

The subcritical experiments are integrated systems tests of mock-up nuclear packages calling for explosion of the conventional HE portion and measurement of the resultant motions and reactions of materials and components. These tests obtain diagnostic information on the behavior of a nuclear weapons primary assembly using stockpile material and evaluate the effects of aging on nuclear weapons in the Nation's arsenal. Subcritical experiments began in 1997 and continue today.

2.2.2 Area 2 Nuclear Test Zone

This area in the Nuclear Test Zone occupies approximately 52 km^2 (20 mi^2) in the northern half of the Yucca Flat basin. The eastern portion of Area 2 was the site of seven atmospheric nuclear tests between 1952 and 1957. A series of underground nuclear tests in Area 2 began in late 1962 and continued through 1990. A number of the 137 underground tests were simultaneous detonations of multiple devices in the same emplacement hole; other underground tests involved the firing of two or more devices in separate emplacement holes. Until 1992, Area 2 Camp provided test support for LLNL and consisted of a full complement of craft shops, equipment and material storage yards, and administrative services. In 1992, construction and maintenance operations were consolidated in Area 6.

2.2.3 Area 3 Nuclear Test Zone and Radioactive Waste Management Site

This portion of the Nuclear Test Zone occupies 83 km^2 (32 mi^2) near the center of the Yucca Flat weapons test basin. It was the site of 14 atmospheric tests between 1952 and 1958. There were 252 underground nuclear tests in Area 3 from 1958 to 1992, which was the largest number of tests in any NTS underground test area. A number of these tests consisted of simultaneous device detonations, and nearly all of the simultaneous tests consisted of single devices in separate emplacement holes. Between mid-1957 and late 1958, nine underground nuclear tests in Area 3 occurred in unstemmed holes to minimize, but not eliminate, releases of radioactivity to the atmosphere. Area 3 contains numerous posted areas.

Area 3 contains numerous circular subsidence craters formed by the collapse of deep underground spherical cavities formed by nuclear explosions. The earth collapses as the gases inside the test cavity cool and outward pressures decline. The collapse progresses upward from the cavity to the ground surface, which results in the formation of a subsidence crater. The BILBY test in the fall of 1963 (approximately 249 kt) was one of the largest detonations ever conducted in the Yucca Flat basin, and it was the first underground test to be felt by a large number of Las Vegas residents. BILBY was fired 732 m (2,400 ft) underground in volcanic rock and resulted in one of the largest subsidence craters at the test site, which measures 1,800 ft (549 m) in diameter and 24 m (80 ft) deep. This crater is on a public tour route. The crater bottom contains a capped borehole.

NTS disposes of bulk low-level waste in seven Area 3 subsidence craters that collectively make up the Area 3 Radioactive Waste Management Site (RWMS). This activity began in the mid-1960s with the beginning of removal of scrap tower steel, vehicles, and other large objects subjected to atmospheric testing. From 1979 to 1990, large amounts of contaminated soil and other debris from the NTS were added to the craters.

There are four stockpile stewardship emplacement holes in Area 3. Until 1992, Area 3 Camp provided test support for LANL and consisted of a full complement of craft shops, equipment and material storage yards, and administrative services. In 1992, construction and maintenance operations were consolidated in Area 6.

2.2.4 Area 4 Nuclear Test Zone

This area in the Nuclear Test Zone occupies 41 km^2 (16 mi^2) near the center of the Yucca Flat basin. Area 4 was the site of five atmospheric nuclear tests between 1952 and 1957. From the mid-1970s through 1991, there were 35 underground nuclear tests in Area 4, mainly in the northeast corner. Two of these tests involved the simultaneous detonation of multiple devices in the same emplacement hole. There are four stockpile stewardship emplacement holes in Area 4.

The Big Explosives Experimental Facility (BEEF) in Area 4 was designed as an operational complex for testing large conventional non-nuclear HE charges weighing as much as several thousand or more kilograms. The need for the BEEF site originated when, due to community encroachment near the Lawrence Livermore National Laboratory (LLNL) in Livermore, California, DOE was no longer allowed to perform large HE experiments at that facility's Site 300 under the Shaped Charge Scaling Project. Therefore, DOE looked at the NTS as a location to continue to perform these large HE experiments and chose two earth-covered, 2-ft-thick steel-reinforced concrete bunkers (built to monitor atmospheric tests at Yucca Flat in the 1950s).

The facility consists of a control bunker, a camera bunker, a gravel firing table, and associated control and diagnostic systems. The facility has conducted conventional HE experiments using a test bed that provides sophisticated diagnostics such as high-speed optics and X-ray radiography on the firing table, while operating personnel are present in the bunker.

The 465-m (1,530-ft) Bare Reactor Experiment, Nevada (BREN) Tower was originally erected in Area 4 of the NTS (DOE 2005). Operation BREN, conducted in 1962, was designed to accurately estimate the radiation doses received by selected survivors of the atomic bombings of Nagasaki and Hiroshima. Oak Ridge National Laboratory's Health Physics Research Reactor, a small, unshielded (bare) reactor, was mounted on a hoist car and moved to various heights on the tower. Facsimiles of Japanese houses were built near the base of the tower and were bombarded with various intensities of radiation so the shielding effects of various types of housing materials could be studied in estimating human radiation doses. The reactor was a source of neutrons and gamma rays and was operated in the steady state at a power level of up to about 10 kW (AEC 1962a). During the second phase of the study, the reactor was pulsed, and the spectrum of the fission-product gamma rays was studied as a function of time after burst. The reactor was operated from the end of March through June of 1962. After the reactor was removed from the tower and returned to Oak Ridge National Laboratory, a ^{60}Co source (1200 Ci) was placed on the hoist car to permit measurements of a gamma-radiation field from a "point" source. The ^{60}Co gamma source study was conducted in July of 1962. Due to interferences with the NTS's primary mission of underground testing, the BREN Tower was relocated to Area 25 in 1966 (DOE 2005).

The POPOVER test series was conducted in 1995 to demonstrate that large conventional HE experiments could be safely conducted while operating personnel were present in the control bunker. The test data was used to develop an effects profile that defined the relationship of the HE charge size and detonation point to blast effects such as overpressure, bunker wall strain, dynamic response (acceleration), and noise amplitude.

2.2.5 Area 5 Radioactive Waste Management Site and Spill Test Zones

This area in the Reserved Zone occupies about 246 km^2 (95 mi^2) in the southeastern portion of the site. It includes the Area 5 RWMS, the Hazardous Waste Storage Unit, the HAZMAT Spill Center, the Transuranic (TRU) Pad Cover Building, and the Waste Examination Facility (WEF). The WEF houses a large multilevel glovebox used to examine legacy and national laboratory waste, to separate and segregate Resource Conservation and Recovery Act (RCRA) material, and to repack TRU waste for

shipment to the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico. The original and repacked containers are stored in the TRU Pad Cover Building. Operations in WEF have the potential for internal exposure if a breach in the glovebox barrier occurs.

From 1951 to early 1962, there were 14 atmospheric tests at Frenchman Flat, several of which were weapons effects tests. Among the remains of the structures tested in Frenchman Flat are simulated motel complexes, metal frames that supported a variety of roofing materials, a window test structure, cylindrical liquid storage vessels, reinforced concrete domes, aluminum domes, bridge pedestals, and a bank vault, all of which are of considerable historic interest.

Twenty-four experiments occurred between 1954 and 1956 in the Gadgets, Mechanics, and Explosives (GMX) project site in Area 5 in which small quantities of plutonium materials were subjected to HE detonations (see Section 2.3.2 for additional information on safety tests). Five underground nuclear weapons tests occurred at Frenchman Flat between 1965 and 1971. However, the presence of a carbonate aquifer makes this area less suitable for underground testing than other locations on the NTS.

A simulated test corresponding to the accidental explosion of HE material in an underground bunker (commonly known as a Gravel Gertie) occurred in Area 5 in the 1950s and again in late 1982. This structure satisfied tests for containment of the explosion and associated radioactive material. Similar designs have been used at the Device Assembly Facility (DAF) in Area 6 and at the Pantex Plant near Amarillo, Texas, where DOE has conducted the majority of nuclear weapons assembly and disassembly operations.

Area 5 is the permanent home for the HAZMAT Spill Center. By Congressional mandate, use of the Spill Center is available to private and public sector test sponsors (i.e., chemical processors and oil companies) on a fee basis. The Spill Center (the only facility of its kind in the world) was completed in April 1986 as a place to conduct safety research associated with the handling, shipping, and storage of liquefied gaseous fuels and other hazardous fluids. The facility is used to release hazardous materials for training purposes, field-test detection, plume dispersion experimentation, and equipment and materials testing. The facility consists of a complex of fuel tanks, spill pads, meteorological and camera towers, assorted equipment arrays, control buildings, and a large-scale wind tunnel.

One of the primary NNSA/NSO missions has been to provide an ongoing waste management program that covers all wastes generated on the NTS as well as wastes from other defense-related facilities. Opened in 1961, the Area 5 RWMS is a 296-hectare (732-acre), low-level radioactive waste storage and disposal facility. The developed area at the RWMS consists of 22 landfill cells (pits and trenches) and 13 greater confinement disposal boreholes. DOE has disposed of mixed waste, including transuranic mixed waste, at the NTS in the past and currently stores transuranic wastes in Area 5 pending ultimate disposal at WIPP.

The Hazardous Waste Storage Site in Area 5 is a Nevada-approved NTS-wide accumulation point for the collection of RCRA nonradioactive hazardous materials such as paint residues, miscellaneous chemicals, unused or surplus fuels, and so forth. Hazardous wastes generated at the NTS are periodically sent to licensed offsite commercial facilities for recycling, incineration, or disposal.

2.2.6 Area 6 Nuclear Test Zone

This area occupies a 212-km^2 (82-mi^2) parcel of land between Yucca Flat and Frenchman Flat (straddling Frenchman Mountain). Between 1968 and mid-1990, four underground nuclear tests occurred at this location, one of which involved the simultaneous detonation of multiple devices in two

separate emplacement holes in Area 6 and Area 3. There are two stockpile stewardship emplacement holes in Area 6.

The Control Point (CP) complex serves all NTS user organizations as a centralized point of coordination for administrative, scientific, and technical matters. The CP also serves as the NNSA/NSO command center, air operations center, and timing and firing center. Support facilities include a communications building, several radiological sciences facilities, and technical laboratories. In addition, this area contains the Los Alamos National Laboratory (LANL) Mouse House, which houses the LANL radiation control facilities in support of U1a Complex activities.

The Area 6 Construction Facilities provide craft and logistical support to activities in the forward areas of the NTS. This complex replaces older construction base camps in Areas 2 and 3. Until 1992, construction crafts provided testing support from Area 2, 3, and 12 Camps. In general, Area 2 Camp provided support for LLNL vertical shaft tests, Area 3 Camp provided support for LANL vertical shaft tests, and Area 12 Camp provided support for tunnel tests (DOD/laboratories). Site maintenance support was provided by maintenance crafts located in Areas 6 and 23. In 1992, construction and maintenance operations were consolidated in Area 6.

The elements of the Yucca Lake facilities include a variety of equipment storage facilities, a heavy-duty maintenance and equipment repair facility, and decontamination (decon) facilities. Facilities for laundering radiologically contaminated clothing were operated here. At the Decon Facility, large pieces of equipment were decontaminated. Contaminated liquid waste from decontamination operations was discharged through floor drains to large tanks. The yard below these facilities could be contaminated. Contaminated radioactive waste was also stored in a tent structure adjacent to the Decon Facility. A 3,353-m (11,000-ft) airstrip and nearby weather station are on the dry Yucca Lake bed.

The DAF is approximately 3 mi (4.8 km) south of the CP complex and was designed to serve as a modern, safe, and secure facility for assembling and disassembling nuclear test devices and nuclear weapons. The DAF, which replaced and consolidated facilities elsewhere on the NTS, was designed to limit explosive overpressures and to contain radioactive materials in the event of an accident. Construction began in 1988 and ended in 1990, when equipment installation and related interior work began. The DAF is an operational facility that includes glovebox and downdraft table equipment to support receipt of material from JASPER. LLNL and LANL jointly operate the DAF.

The DAF is a collection of more than 30 individual steel-reinforced concrete buildings connected by a rectangular common corridor. The entire complex, covered by compacted earth, spans an area of 100,000 ft^2. Safety systems include fire detection and suppression, electrical grounding, independent heating, ventilation and air-conditioning systems with high-efficiency particulate air filters, loudspeaker and alarm systems, and warning lights. In operational areas, pairs of blast doors designed to mitigate the effects of an explosion are interlocked so that only one door can open at a time. The operational buildings in the DAF include five assembly cells, four high bays, three assembly bays (one of which houses a glove box and one of which houses a downdraft table), and two radiography bays. Five staging bunkers provide space for staging nuclear components and HE.

All materials packages arrive or depart the DAF through one of two shipping or receiving bays. The support buildings include three small vaults for staging small quantities of HE or special nuclear material, two decontamination areas, and an administration area containing office space, a conference area, personnel changing and shower rooms, and a machine shop. In addition, one building provides laboratory space for conducting instrumentation and environmental testing and another provides for observation of operations in an adjacent assembly cell.

The DAF assembly cells were modeled after the structure at Pantex Plant, where hands-on assembly and disassembly of U.S. nuclear weapons takes place. The cells provide maximal environmental and personnel protection in the event of an inadvertent HE detonation. The cells are designed to absorb the blast pressure from a detonation of up to 192 kg (423 lb) of plastic-based explosives equivalent to 250 kg or 550 lb of TNT. Should a detonation occur, the Gravel Gertie would minimize the release of nuclear material and its spread to other areas of the facility and to outside areas.

The ATLAS pulsed power construction project began in 1995 at LANL, with engineering design and component testing. Full-scale assembly began in November 1999 and construction was completed in August 2000. In 2001, LANL scientists performed the first pulsed-power driven implosion shot. This successful experiment demonstrated the facility's capability to provide materials data to support the certification of the nuclear weapons stockpile. Congress directed that ATLAS be relocated to the NTS in 2002. Construction of the new 14,000-ft^2 high-bay facility in Area 6 was completed in April 2004 and electrical testing was completed in July 2005.

ATLAS consists of high-voltage capacitor banks that discharge electrical energy into a system of parallel-plate transmission lines. Large electrical currents flow through the plates to produce an intense magnetic field, which applies a huge pressure pulse into a cylindrical liner and target containing materials of interest. ATLAS acts as a giant power amplifier, using energy that accumulates slowly at 480 volts and is stored in the machine's capacitor banks for sudden release into the liner and target. As the current surges through ATLAS, it accelerates materials to velocities well in excess of that required to escape Earth's gravity (as high as 22,000 mph), and generates pressures equivalent to millions of times that of Earth's atmosphere. ATLAS can impinge on axial targets with tremendous force to study the shock and compression properties for materials of interest to weapons design, manufacturing, and performance. Highly advanced optical and X-ray diagnostic equipment measures the properties of the imploding materials. The physical environments produced by ATLAS enable a wide range of safe, reproducible, and controllable experiments in areas of basic science and civilian technologies that have no significant effects on the environment in an era that precludes nuclear weapons testing. The extreme conditions of high-energy density, strongly coupled plasmas, and high magnetic fields have potential applications for understanding planetary physics, condensed-matter physics, fusion energy research, and astrophysics. The Hydrocarbon Contaminated Soils Disposal Site in Area 6 is a Nevada-approved Class III landfill for the disposal of all non-RCRA hydrocarbon-contaminated soils and materials from the NTS.

2.2.7 Area 7 Nuclear Test Zone

This area in the Nuclear Test Zone occupies 52 km^2 (20 mi^2) in the northeast quadrant of the Yucca Flat weapons test basin. Thirty atmospheric tests occurred in this area. From late 1964 to the fall of 1991, 62 underground nuclear tests occurred in Area 7, each of which consisted of a single nuclear device in a drilled emplacement hole. There are three stockpile stewardship emplacement holes in Area 7.

2.2.8 Area 8 Nuclear Test Zone

This area in the Nuclear Test Zone occupies 34 km^2 (13 mi^2) in the northeast quadrant of the Yucca Flat weapons test basin. Area 8 was the site of four atmospheric nuclear tests in 1958. From mid-1966 to late 1988, 10 underground nuclear tests occurred at this location. Two of the underground tests involved the simultaneous firing of multiple devices in the same emplacement hole.

French- and German-type underground shelter structures were tested in Area 8 in 1957. In 1964, the University of Florida used these structures for shelter habitability studies. The BANEBERRY test, which vented to the atmosphere, occurred here in 1970. Section 2.3.3 provides a description of the

BANEBERRY test and other tests that resulted in radioactive releases to the environment. The area is geographically complex due to the combination of tests, wide-spread debris, steep slopes, and wastes.

2.2.9 Area 9 Nuclear Test Zone

This area in the Nuclear Test Zone occupies 52 km^2 (20 mi^2) in the northeast quadrant of the Yucca Flat weapons test basin. Fifteen atmospheric tests occurred in this area between 1951 and 1958. Area 9 was used extensively for underground nuclear testing; 100 such tests occurred from late 1961 to mid-1992. Of the dozen underground tests involving the simultaneous detonation of multiple devices, most involved the use of separate emplacement holes (two or more holes, each with a single device). There is one stockpile stewardship emplacement hole in Area 9.

The Area 9 sanitary landfill is in a subsidence crater formed as the result of a subsurface nuclear detonation in the early 1960s. In October 1995, the landfill underwent partial closure as a Class II landfill and reopened as a Class III construction and demolition debris landfill.

2.2.10 Area 10 Nuclear Test Zone

This area in the Nuclear Test Zone occupies 54 km^2 (21 mi^2) in the northeast quadrant of the Yucca Flat weapons test basin. Area 10 was the location for the Nation's first nuclear missile system test, an air-to-air rocket detonated in mid-1957. This was the only nuclear rocket test ever conducted at the NTS. Two of the earliest shallow nuclear cratering experiments at the NTS were detonated in 1951 and 1955 at this location. Resuming with the deeply buried SEDAN cratering experiment in mid-1962 and extending through early 1991, a number of underground nuclear tests occurred in Area 10. Counting both the cratering and contained underground tests, there were 57 nuclear tests. No atmospheric tests were conducted in Area 10. A number of the underground tests were simultaneous detonations of multiple devices in the same emplacement hole, while others involved the firing of multiple devices with each device in a separate emplacement hole.

Area 10 is the site of SEDAN Crater, which was formed by a thermonuclear device detonated in July 1962. It left a large throw-out crater with a diameter of 390 m (1,280 ft) and a depth of 98 m (320 ft). SEDAN was the first in a series of 23 PLOWSHARE tests conducted at the NTS to develop peaceful uses of nuclear explosives. The SCOOTER Crater, also in Area 10, is the result of a 500-t conventional HE experiment in 1960. The area includes underground bunkers and mud pits.

2.2.11 Area 11 Nuclear Test and Reserved Zone

This area, which is divided between the Nuclear Test and Reserved Zones, occupies 67 km^2 (26 mi^2) along the eastern border of the NTS. Project 56 consisted of four atmospheric plutonium-dispersal safety tests in the northern portion of Area 11 in 1955 and 1956 in what is now known as Plutonium Valley (see Section 2.3.2 for additional information on safety tests). Because of the radioactive residue that remains, DOE used Area 11 for realistic training drills in radiological monitoring and sampling operations. Training was discontinued by the current contractor because of concern for plutonium intakes.

Although no full-scale atmospheric tests occurred in Area 11, five underground nuclear weapons tests occurred at this location between the Spring of 1966 and early 1971. A 1950s-era experimental jet was located in Plutonium Valley and later used by the Accident Response Group for training. Contamination was spread throughout the interior. The aircraft was recently removed for decontamination and transported to a U.S. Air Force base.

A number of technical facilities that remain in Area 11 are essentially no longer in use; NNSA/NSO is maintaining some of these in varying states of readiness in case there is a future requirement or need for such facilities. An explosive ordnance disposal facility in the southern portion of Area 11 functions as a RCRA-permitted treatment unit. This site consists of a detonation pit surrounded by an earthen pad, approximately 8 m (25 ft) by 31 m (100 ft), and support equipment including a bunker, electrical shot box, and electrical wiring.

2.2.12 Area 12 Nuclear or HE Test Zone

This area, which is in the Nuclear or HE Test Zone, occupies 104 km^2 (40 mi^2) at the northern boundary of the NTS on Rainier Mesa. No atmospheric nuclear tests occurred at this location; however, Area 12 was the site of the AEC's first fully contained underground nuclear detonation. The RAINIER test took place on September 19, 1957, in a horizontal tunnel mined about 487 m (1,600 ft) into the mesa and 274 m (900 ft) beneath its top.

In the past several decades, a number of tunnels were mined into Rainier Mesa, in which most of the DOD horizontal line-of-sight (LOS) exposure experiments occurred. The N-, P-, and T-tunnel complexes, in particular, were developed extensively during the 1970s and 1980s. The tunnel experiments usually involved complex construction of large-diameter (up to 9 m [27 ft]) LOS pipes and special closure mechanisms, blast and gas seal doors, and stemming plugs. The G-tunnel complex was established for nuclear testing purposes but, since 1971, has been used only as an underground research facility.

Of the 61 underground nuclear tests performed in Area 12 between late 1957 and the fall of 1992, two were detonated in vertical stemmed holes, and the 59 others were detonated in mined tunnels. Several tests in tunnels resulted in containment failures and the release of radioactive material (see Section 2.3.3 for additional information).

In addition to its use for nuclear testing purposes, N-tunnel was the location of a Nonproliferation Experiment involving 1.3 million kg (2.9 million lb) of conventional explosives detonated on September 22, 1993. Observers from the United Nations Geneva Conference on Disarmament were present. The acquired information and data are being used to develop verification requirements to support activities in relation to both the Nonproliferation Treaty activities and the Comprehensive Test Ban Treaty.

DOD operates an HE research and development tunnel in Area 12. This reusable test bed supports programs involving the detonation of conventional or prototype HE and munitions. Because of the remote location, the Area 12 Camp was constructed in the early 1960's to support underground testing for the Area 12 tunnel complexes. Support structures included a major maintenance building, miner's change house, craft and repair shops, a first aid facility, and a supply depot. Billeting was available for underground workers supporting tests. Other facilities in the Area 12 Camp included a cafeteria, motor pool, and recreation hall. The Area 12 Base Camp was used until the testing period ended in 1992.

2.2.13 Area 13 Nellis Test and Training Range Complex

Officially, there is no Area 13 within the NTS boundary; however, there is a land plot on the NTTR Complex, known as NTTR Complex Area 13, which is off the northeast corner of the NTS. This was the location for Project 57, a plutonium-dispersal safety experiment in early 1957 (See Section 2.3.2).

2.2.14 Area 14 Reserved Zone

This Reserved Zone area occupies 67 km^2 (26 mi^2) in the south-central portion of the NTS. Because this area is relatively isolated from major NTS operational and support facilities, no atmospheric or underground nuclear tests have occurred in Area 14.

2.2.15 Area 15 Reserved Zone

This Reserved Zone area occupies 96 km^2 (37 mi^2) at the northeast corner of the NTS. No atmospheric tests occurred at this location, but three underground nuclear tests occurred between early 1962 and mid-1966. There were two major complexes in Area 15, the HARDHAT/PILEDRIVER site and the U.S. Environmental Protection Agency (EPA) Farm Complex. Ongoing environmental remediation activities have taken place at both sites since the mid-1990s.

HARDHAT was conducted on 2/15/62 at the U15a shaft and PILEDRIVER was conducted on 6/2/66 at U15a.01 tunnel. The purpose of the HARDHAT/PILEDRIVER tests was to investigate the simulated effects of a nuclear surface detonation on a deeply buried, super-hard command-and-control center in a granite rock formation.

From 1978 to 1983, the Spent Fuel Test Complex also known as Climax Mine was a separately mined drift at the HARDHAT/PILEDRIVER site. The purpose of this study was to learn more about how granite would react to heat and radiation from spent nuclear fuel. In the test, spent fuel was sealed in protective canisters and lowered underground. An underground emplacement vehicle put the canisters in lined test holes. All equipment used to handle the canisters was operated by remote control. The canisters were stored in the Climax granite stock for 3 yr, then removed and repackaged at the Engine Maintenance Assembly and Disassembly (E-MAD) facility in Area 25 before shipment to the Idaho National Engineering and Environmental Laboratory.

As part of the DOE long-range safety program, the U.S. Public Health Service (and later the EPA) developed and operated an experimental 30-acre dairy farm in Area 15 between 1965 and 1981. Researchers studied the passage of airborne radionuclides through the soil-forage-cow's milk food chain. In addition, cows were fed plutonium-loaded capsules to study the metabolic process and effects of the material. The facilities included irrigated cropland, an irrigation reservoir, and typical structures for a Grade A dairy farm. These facilities were also used for autopsy studies of animals that grazed on the NTS.

2.2.16 Area 16 Nuclear or HE Test Zone

This area, which is in the Nuclear or HE Test Zone, occupies 73 km^2 (28 mi^2) in the west-central portion of the NTS. No atmospheric tests have occurred at this location. Area 16 was established in 1961 for exclusive DOD use in support of a nuclear effects experiment that required a tunnel in an isolated area away from other active weapons test areas. From mid-1962 to mid-1971, six underground nuclear weapons effects tests occurred in the tunnel complex. Several tests breached the tunnel containment systems. Radioactive materials include TRU and fission products. Area 16 Camp was set up in the early 1960's to house the Area 16 tunnel workers. The facilities were residential in nature and included residential (52), dining (2), shower (2), kitchen, and recreation trailers. The camp was dismantled sometime between the mid 1960's and 1972. In the early 1990's, the Defense Threat Reduction Agency (DTRA) began using Area 16 tunnels for HE research and development in support of programs involving the detonation of conventional or prototype explosives and munitions.

2.2.17 Area 17 Reserved Zone

This area, which is in the Reserved Zone, occupies 80 km^2 (31 mi^2) in the north-central portion of the NTS. It has been primarily a buffer between other testing activities. No atmospheric tests or experimental activities of programmatic consequence have occurred in Area 17.

2.2.18 Area 18 Reserved Zone

This area, which is in the Reserved Zone, occupies 231 km^2 (89 mi^2) in the northwest quadrant of the NTS. The inactive Pahute airstrip is in the east-central portion of the area. Area 18 was the site of four nuclear weapons effects tests in early to mid-1962. Two of these tests were atmospheric (slightly aboveground) and the other two were cratering experiments. SULKY, a PLOWSHARE test, in late 1964 was the first nuclear cratering test conducted by the United States after ratification of the Limited Test Ban Treaty. DANNY BOY and JOHNNIE BOY resulted in Trinity glass debris. LITTLE FELLER I and II resulted in TRU and fission product soil contamination and were very low-yield effects tests. The SULKY device was placed fairly deep for its yield and, as a consequence, did not produce a crater, although it did produce a mound of broken rock. In addition, in 1964 this area was used for Project DUGOUT, a PLOWSHARE-sponsored test using chemical HE to investigate the potential use of nuclear explosives for ditch digging in dense hard rock. The resultant crater was 87 m (285 ft) long, 41 m (135 ft) wide, and 11 m (35 ft) deep.

The Pahute CP, now abandoned, is in the northeast corner of the area; it was used until 1971 as the diagnostic and microwave communications monitoring center for nuclear test events on Buckboard and Pahute Mesas (Areas 18, 19, and 20). The deactivated Pahute airstrip, in the east-central portion of Area 18, was used primarily for shipments of supplies and equipment related to Pahute Mesa high-yield underground nuclear test operations.

2.2.19 Area 19 Nuclear Test Zone

This area in the Nuclear Test Zone occupies 388 km^2 (150 mi^2) of the Pahute Mesa in the northwest corner of the NTS. Area 19 was developed for high-yield underground nuclear tests, and no atmospheric nuclear tests occurred there. The geology of Pahute Mesa makes it possible to test devices at much greater depths than in Yucca Flat (down to more than 1,370 m [4,500 ft]). The greater depth and isolation allowed much higher yield tests with minimal levels of ground motion felt in Las Vegas, more than 160 km (100 mi) away. From the mid-1960s to 1992, 36 underground nuclear tests occurred. This area contains underground radioactive material areas because of tests and post-test drilling pads. Soil activity is from fission products. There are five stockpile stewardship emplacement holes in Area 19.

2.2.20 Area 20 Nuclear Test Zone

This area in the Nuclear Test Zone occupies 259 km^2 (100 mi^2) in the extreme northwest corner of the NTS. Area 20, like Area 19, was developed in the mid-1960s as a suitable location for high-yield underground nuclear tests; there were no atmospheric nuclear tests there. A total of 49 tests occurred. Three underground nuclear tests in the 1 Mt and greater yield range occurred on Pahute Mesa between 1966 and 1976. These tests were the well-publicized BOXCAR, BENHAM, and HANDLEY tests. From the mid-1960s to 1992, 46 contained underground nuclear tests occurred in Area 20. All of these tests consisted of the detonation of a single nuclear device in a drilled emplacement hole. Area 20 boundaries were expanded after SCHOONER to incorporate an extensive fission product plume and throw-out debris.

One nuclear test detection experiment and three PLOWSHARE tests occurred on Pahute Mesa. The PLOWSHARE tests included the nuclear cratering experiments PALANQUIN, CABRIOLET, and SCHOONER. PALANQUIN, detonated in the spring of 1965, was the first nuclear test on Pahute Mesa. The PALANQUIN and CABRIOLET tests were low yield. TRU and fission products are present, as is Trinity glass. There are two stockpile stewardship emplacement holes in Area 20.

2.2.21 Area 21

There is no Area 21 on the NTS.

2.2.22 Area 22 Reserved Zone

Area 22, in the southeastern corner, serves as the main entrance to the NTS, with vehicle access from Las Vegas by U.S. Highway 95. The area between Highway 95 and the Mercury town site was annexed to the NTS in 1964. Area 22 was home for Camp Desert Rock during the early days of atmospheric testing. The camp opened in September 1951 as a Sixth Army installation for housing troops taking part in military exercises at NTS; at that time, it was primarily a trailer and tent camp with several semipermanent structures and an airstrip. During the 1955 test series, the camp housed about 9,000 men from the military services, some of whom saw a single test and departed for their home duty stations while others stayed through the entire test series. Camp Desert Rock was not used by the military after 1958, and many of the structures were moved to other parts of the NTS. Essentially all of the remaining facilities except the airstrip were dismantled and destroyed as scrap or salvaged. The AEC resurfaced and enlarged the Desert Rock airstrip in 1969, extending the runway to a length of 2,155 m (7,500 ft). This airstrip served the NTS. At present, the airport provides no services, although it is available for emergency landings.

2.2.23 Area 23 Reserved Zone

This area, which is in the Reserved Zone, occupies 13 km^2 (5 mi^2) in the southeastern portion of the NTS and is the location of the Site's largest operational support complex. Mercury, which was established in 1951, is the main administrative and industrial support center. Permanent structures and services include housing and cafeteria services, laboratory, maintenance, communication and support facilities, computer facilities, warehouses, storage yards, motor pools, and administrative offices. Mercury also houses the NNSA and the health physics, medical, and fire departments. Mercury is approximately 8 km (5 mi) from U.S. Highway 95.

The Area 23 Sanitary Landfill for all NTS organizations is a Class II landfill just west of Mercury. The landfill is an open, rectangular pit with nearly vertical sides. Because of its Class II designation, the landfill is open to receive all types of nonhazardous solid waste. The current capacity of the landfill is approximately 4.5 million m^3 (6 million cubic yards). A RCRA-compliant closed hazardous waste site is next to the landfill. NNSA/NSO conducts periodic monitoring in accordance with State regulations at this location.

2.2.24 Area 24

Area 24 is the designation for the support area in metropolitan Las Vegas. The North Las Vegas Facility (NLVF) includes approximately 80 acres of property and is located on Losee Road in North Las Vegas. The NLVF was used for pre-staging and equipment fabrication in support of nuclear testing. The complex (Buildings A-1, B-1, B-2, and B-3) contained offices, light laboratories, a large machine shop, electrical fabrication shops, chemical etching and plating shops, and a high bay area dedicated to the assembly of instrumentation trailers used for tests at the NTS. Edgerton, Germeshausen, and Grier Corporation (EG&G) technical services and general management occupied

the facility along with support groups for LANL and Sandia National Laboratory. These workers traveled to the NTS as necessary in support of testing. The Reynolds Electrical and Engineering Company (REECo) and NNSA/NVO administrative offices were located in Las Vegas near the Sahara Avenue and Interstate 15 interchange.

A radiological source range area for calibrating instruments is located in the basement of NLVF Building A-1. The facility began operating in 1963 and is still in operation. The range has the following principal sources and associated activities:

^{241}Am	(1.17 E-2 mCi)	^{239}Pu	(1.37 E-6 mCi)
^{133}Ba	(3.14 E-3 mCi)	^{239}Pu	(1.60 E-3 mCi)
^{137}Cs	(5.37 E+1 mCi)	^{239}Pu	(2.60 E-7 mCi)
^{137}Cs	(8.33 E-3 mCi)	^{90}Sr	(1.54 E-5 mCi)
^{252}Cf	(9.42 E-3 mCi)	^{90}Sr	(1.54 E-5 mCi)

When Bechtel Nevada won the NTS operations and management contract in 1995, REECo, EG&G, and Raytheon Nevada operations were consolidated into a single contract. The Bechtel Nevada employees and their subcontractors stationed in Las Vegas were located at the NLVF. NNSA/NVO moved to a new building (Nevada Support Facility) constructed in 1996 at the NLVF campus. The NLVF Buildings B-1 and B-2 were demolished in 2004. NSTec currently manages and operates the test site and its related facilities for the Nevada Site Office. Attachment C contains additional information on NTS contractors.

2.2.25 Area 25 Yucca Mountain Project, Reserved, and Research and Experiment Zones

Area 25, the largest area on the NTS, occupies about 578 km^2 (223 mi^2) in the southwestern corner of the Site and includes an entrance gate. Area 25 has its own direct U.S. Highway 95 access approximately 3 km (2 mi) north of Amargosa. Other than several small and isolated hills of volcanic rock in the west-central portion of Area 25, the interior valley floor encompasses what is commonly known as Jackass Flats. Roughly in the center of Area 25, Jackass Flats was selected for a series of ground tests of reactors, rocket engines, and stages as part of a program to develop nuclear reactors for use in the Nation's space program.

In the early 1960s, the AEC and the National Aeronautics and Space Administration (NASA) negotiated an interagency agreement to establish and manage a test area at the NTS called the Nuclear Rocket Development Station (NRDS). It consists of three widely separated reactor test cells or stands, two Maintenance, Assembly, and Disassembly (MAD) facility buildings, a CP complex, an Administrative Area complex, and a radioactive materials storage area. A standard-gauge railroad system connects the test stands and the MAD buildings. The railroad transported nuclear reactors and engine systems back and forth from the rocket and engine assembly buildings to the test cells and engine test stand. The NRDS operated two shallow-land burial radioactive waste disposal units. An equipment decontamination facility was operated near the MAD facility. Attachment B contains additional information about the NRDS.

During the late 1970s and early 1980s, the E-MAD building was used for high-level radioactive materials handling studies. It contained the world's largest hot cells, which were used to disassemble, examine, and package nuclear reactors. These hot cells are highly contaminated. Thirteen hot spent fuel assemblies were brought to E-MAD and encapsulated in stainless-steel canisters with welded lid closures. Eleven of the canisters were transported to Area 15 in support of the underground Spent Fuel-Climax project. The other two canisters were used in aboveground concrete-shielded storage studies and shallow dry-well storage studies. When the studies were completed in 1983, the canisters were removed from their temporary storage holes and returned to E-MAD. In 1986, all 13 of the spent fuel assemblies were repackaged and shipped to the Idaho National Engineering and

Environmental Laboratory. Due to the destruction of two nuclear reactors and transport of radioactive material, the area was extensively contaminated with enriched uranium, niobium, cobalt, and cesium. Legacy contamination areas include several highly radioactive burial areas, such as the Reactor Machine Assembly and Disassembly (R-MAD) Trolley Dump and leach fields, which have been managed under the DOE environmental remediation program since the mid-1990s.

The former NRDS Administrative Area complex in Area 25, along with much of the land area to the north and west of Lathrop Wells Road, has been rededicated as a Yucca Mountain support site. DOE is preparing a License Application for a U.S. Nuclear Regulatory Commission permit to operate and close a geologic repository under Yucca Mountain. The mountain is just off the western boundary of Area 25 and 160 km (100 mi) northwest of Las Vegas and if approved may contain up to 70,000 metric tons (77,000 tons) of spent nuclear fuel and high-level radioactive waste. About 90% of the waste would be from commercial nuclear power reactors and the rest would be wastes from defense nuclear reactors.

After BREN tower was moved from Area 4 and erected at its new site in Area 25, the tower was used for Operation HENRE (High Energy Neutron Reactions Experiment) which was conducted from 1966 through 1968 (AEC 1962b). Operation HENRE included a series of radiation measurement experiments using a linear accelerator to provide 14 MeV neutrons. A small accelerator developed by Oak Ridge National Laboratory was mounted to the tower and measurements were taken at many distances from the accelerator by radiation dosimetry instruments to determine the distribution of neutrons and gamma rays. In addition, radiation scattering and applied shielding experiments were conducted. The BREN Tower is a versatile facility used intermittently by a number of organizations for sonic boom research, meteorological studies, and free fall or gravity drop tests. The tower was recently used in support of the BRILLIANT PEBBLES program, and in studies to develop technology and measurement techniques for advanced infrared imaging from space satellites. BRILLIANT PEBBLES was a relatively small, computer-operated, rocket-powered, laser-equipped missile designed to detect, track, and intercept ballistic missiles.

The Rock Valley Study Area, south of Jackass Flats Road on the southern boundary of Area 25, was selected in 1960 for studies of radiation on a desert ecosystem. Three study plots were fenced in the early 1960s, and in 1964 a ^{137}Cs shielded source was installed on a 50-ft tower in the center of one of the plots. The cesium source was removed in the fall of 1982. The other two areas were used as control areas. Many research projects have been conducted at the Rock Valley facility in the past three decades by a number of government-sponsored scientists as well as students and others environmental researchers.

The military uses portions of the Area 25 Reserved Zone for land navigation and training exercises. The DOD used portions of Area 25 during the 1980s in conjunction with MX (Peacekeeper) missile siting studies and canister ejection certification tests; all of these facilities have been removed. At present, Area 25 is used by the U.S. Army's Ballistic Research Laboratory for depleted uranium ballistics testing. Two types of tests, open air and X-tunnel, which include hazard classification and system tests, are conducted.

DOE established a Treatability Test Facility in Area 25 several years ago for bench-scale testing of physical processes for decontamination of plutonium- and uranium-contaminated soils. At present, Area 25 is under consideration as a site for a utility-scale research and demonstration solar power project planned for the NTS. As noted in the Final NTS environmental impact statement (DOE 1996a), depending on the technology or technologies being pursued for application at the NTS, the solar power project could affect an area as large as 971 hectares (2,400 acres).

2.2.26 Area 26 Reserved Zone

This area, which is in the Reserved Zone, occupies 57 km^2 (22 mi^2) in the south-central portion of the NTS. The area contains the Horn Silver Mine and a leach field from Building 2201. Radionuclides in the soil are a mixture of fission products and uranium. No nuclear explosive tests occurred at this location. However, the southern portions of the area were used for nuclear-powered ramjet engine tests. Although the tests that began in 1957 were successful, this program was terminated in 1973. The residual test facilities include a CP, test bunker, compressor house and air storage facilities, and a disassembly building. Attachment B contains information about the PLUTO Program.

In recent years, these facilities were used as mock reactor facilities to provide Radiological Emergency Response training for civilian and Federal emergency teams. In 1981 the DOD and the DOE conducted a joint accident nuclear weapons accident training exercise, Nuclear Weapons Accident Exercise (NUWAX)-81, at the PLUTO site. The exercise was designed to put into action a planned emergency response to radioactive material scattered in the vicinity of a fictitious town as a result of the explosion of nuclear weapons. The NUWAX-81 scenario involved a simulated crash of an U.S. Army helicopter transporting nuclear weapons to a storage site. Short-lived radioisotopes were distributed via an agricultural sprayer to simulate contamination by weapons-grade Pu. In 1983, personnel training for emergency response to nuclear weapons accidents was continued with the advent of NUWAX-83. A scenario similar to NUWAX-81 was conducted using short-lived radioisotopes to simulate contamination with Pu and Am.

2.2.27 Area 27 Critical Assembly Zone

This area, which is in the Critical Assembly Zone, occupies 130 km^2 (50 mi^2) in the south-central portion of the NTS. LANL controls this area, which includes five assembly bays, four storage magazines, two combination assembly bay/storage magazines, and three radiography buildings. The critical assembly facilities are an alternative to the DAF. Area 27 was used in the past for the Super Kukla Reactor Facility. As in Area 26, no nuclear explosive tests occurred in this area.

In addition, the Joint Actinide Shock Physics Experimental Research (JASPER) Facility is in Area 27, which became operational in the mid-1990s. In the post-nuclear testing era, JASPER plays an integral role in the certification of the Nation's nuclear weapons stockpile by providing a method to generate and measure data about the properties of materials (radioactive chemical elements) at high shock pressures, temperatures, and strain rates. These extreme laboratory conditions approximate those experienced in nuclear weapons. Data from the experiments is used to determine material equations-of-state and to validate computer models of material response for weapons applications. Experiment results are used for code refinement to permit better predictive capability and to ensure confidence in the U.S. nuclear stockpile. LLNL maintains the responsibility for overall project management, physics definition, engineering, health, and safety.

To achieve the high shock pressures, temperatures, and strain rates similar to that of a nuclear weapon, JASPER experiments use a two-stage gas gun. A gas gun propels a projectile into a target at extremely high velocities, often exceeding 8 kps. The JASPER gas gun is specifically designed to conduct research on plutonium and other surrogate materials as targets. The two-stage gun consists of a first-stage breech containing gunpowder and a pump tube filled with hydrogen gas and a second-stage evacuated barrel for guiding the high-velocity projectile to a radioactive material target. Hot gases from the burning propellant drive a heavy piston down the pump tube, compressing the gas. At sufficiently high pressures, the gas eventually breaks a rupture valve and enters the narrow barrel and propels the projectile, housed in the barrel, toward the target.

When the projectile hits the target, it produces a high-pressure shock wave. In a fraction of a microsecond, the shock wave reverberates through the target. Diagnostic equipment triggered by the initial wave measures the properties of the shocked material inside the target during this extremely brief period. The target is disintegrated by the impact of the projectile and contained within the primary confinement chamber. A second confinement chamber protects workers as a safety precaution in the unlikely event that the primary system fails.

2.2.28 Area 28

Area 28 is no longer in existence. The Area 28 designation applied to a portion of the NTS that has been absorbed into Areas 25 and 27.

2.2.29 Area 29 Reserved Zone

This area, which is in the Reserved Zone, occupies 161 km^2 (62 mi^2) on the west-central border of the NTS. A communications repeater station for the NTS is in the Shoshone Mountains. Area 29 consists of rugged terrain that includes Mid-Valley, Fortymile Canyon, and Shoshone Mountain. Because of its mountainous terrain and relative inaccessibility, limited use has been made of this area. Area 29 has served as a buffer zone between activities in Area 25 and weapons-testing activities elsewhere on the NTS.

2.2.30 Area 30 Reserved Zone

This area in the Reserved Zone occupies 150 km^2 (58 mi^2) on the western edge of the NTS. Area 30 has rugged terrain and includes the northern reaches of Fortymile Canyon. In the past, Area 30 had limited use in support of nuclear testing programs. In the spring of 1968, it was the site of Project BUGGY, the first nuclear row-charge experiment in the PLOWSHARE Program. BUGGY was designed to develop nuclear excavation technology for digging canals or mountain passes. Five small devices were spaced 46 m (150 ft) apart at a depth of 41 m (135 ft) and detonated simultaneously in early 1968. The result was a trench 255 m (835 ft) long, 77 m (254 ft) wide, and 206 m (675 ft) deep. The BUGGY test resulted in large quantities of vitrified glass. This site has limited access.

2.2.31 Nellis Test and Training Range

The NTTR Complex includes the NTTR and the TTR. The more-than-12,000-km^2 (4,700-mi^2) Range buffers the NTS on its north, east, and west boundaries. The TTR, which covers about 1,600 km^2 (620 mi^2), is approximately 40 km (25 mi) southeast of Tonopah in Nye County, and is inside the NTTR boundaries. Further information about the TTR is found in the Sandia National Laboratory site profile (ORAUT 2007). According to DOE (2000a), plutonium dispersal tests were conducted at NTTR/TTR in 1957 (Project 57) and 1963 (DOUBLE TRACKS and CLEAN SLATE I to III). See Section 2.3.2 for additional information. In addition to these events, nuclear tests occurred on the NTS in which atmospheric plumes caused contamination to spread beyond the Site boundary to the NTTR Complex. The plume of SCHOONER in 1968 appeared prominently on the 1994 aerial radiation survey (Hechanova and O'Neill 1998).

2.3 SITE OPERATIONS AND PROCESSES

This section briefly describes the operations and historic nuclear weapons tests that could have resulted in occupational radiation exposure to employees on the NTS site.

Timeline

The sources of radionuclides on the NTS include current and past activities. The Site was the primary location for the testing of nuclear explosives in the continental United States between 1951 and 1992. Historic testing above or at ground surface included (1) atmospheric testing in the 1950s and 1960s, (2) earth-cratering experiments, and (3) open-air nuclear reactor and rocket testing. Since 1961, testing of nuclear explosive devices has occurred mainly in vertical drill holes or in mined tunnels until the end of the testing era in September of 1992. Environmental restoration at the NTS is ongoing through the partnership with the State of Nevada. Status information on remediation projects is available in the *Federal Facility Agreement and Consent Order* documentation (DOE 2004).

The United States entered a unilateral testing moratorium on October 1, 1958, and resumed testing on September 15, 1961. Before the moratorium, most tests occurred in the atmosphere. Following the resumption of testing in 1962, more than 800 nuclear weapons tests occurred with only one identified as an atmospheric test (Small Boy) detonated approximately 10 feet above the ground. No tests have occurred since September 23, 1992. *Radiological Effluents Released from U.S. Continental Tests 1961 Through 1992* (DOE 1996b) provides information on radiological releases that resulted from each test. Table 2-1 summarizes the types of tests by the testing era. Table 2-2 provides a listing of radionuclides of concern for various NTS operations. Table 2-3 presents a listing of radionuclides typically deposited following atmospheric tests for various time intervals (10 d, 1 yr, 20 yr, and 50 yr); the data are calculated gamma radiation exposure rates from fallout and related radionuclides from the BUSTER-JANGLE test in 1951. The ^{233}U, ^{235}U, ^{238}U, and ^{239,240}Pu data were omitted primarily to keep the output unclassified. In addition, the background plutonium in Nevada and Utah soils comes from worldwide fallout (DNA 1982a).

Table 2-1. Nuclear weapons test timeline.[a]

Testing era	Number of tests	Type of tests
Post-World War II to 1951[b]	5	Atmospheric
1951-1958 Atmospheric Testing Period	97	Atmospheric
	2	Cratering (near-surface)
	20	Underground
1958-1961 Voluntary Moratorium		
1961-1992 Underground Testing Period	6[c]	Surface
	1	Tower (atmospheric)
	7[d]	Cratering (near-surface)
	799[e]	Underground (vertical shafts or tunnels)

a. Source: DOE (2000a); 1963 Limited Test Ban Treaty on atmospheric testing; 1992 U.S. cessation of nuclear weapon testing.
b. Excludes TRINITY, July 5, 1945. First nuclear test conducted near Alamogordo, New Mexico, that produced a yield of 21 kt.
c. LITTLE FELLER II, LITTLE FELLER I, CLEAN SLATE I, DOUBLE TRACKS, CLEAN SLATE II, CLEAN SLATE III.
d. Five of the 7 cratering tests were for peaceful purposes as part of the PLOWSHARE Program (1960-1968); DANNY BOY, SEDAN, JOHNNIE BOY, PALANQUIN, CABRIOLET, BUGGY, SCHOONER.
e. Total of underground tests at NTS from 1951 to 1992 was 828.

The following categories summarize NTS operations that could have resulted in radiological releases:

- Atmospheric Weapons Testing
- Safety Tests
- Underground Tests
- Nuclear Reactor Development Tests
- RWMSs
- Laboratories

- Well Logging
- Treatability Test Facility
- Decontamination Facility
- Radiation Instrument Calibration Facilities
- Radioactive Source Storage Areas
- Nuclear Explosives Assembly and Device Assembly Facility

Unless otherwise noted, most of the information in the following sections about the NTS testing program, site operations, and facilities is from *Final Environmental Impact Statement for the Nevada Test Site and Off-Site Locations in the State of Nevada* (DOE 1996a).

2.3.1 Atmospheric Weapons Testing

U.S. aboveground nuclear weapons tests at the NTS began on January 27, 1951, with the detonation of a 1-kt air-dropped weapon over Frenchman Flat and ended with the last tower and surface weapons effects tests in July of 1962. Little Feller I was the last atmospheric test conducted on 7/17/62 at the Nevada Test Site (Area 18) and had a “low” yield (i.e., less than 20 kt). More than 100 atmospheric tests occurred before the signing of the Limited Test Ban Treaty in August 1963. In addition to airdrops, atmospheric testing included detonations from towers at heights from 30 to 213 m

Table 2-2. Radionuclides of concern for various NTS activities.[a,b]

Radionuclide of concern ▼	Atmospheric Weapons Test Areas	Safety Test Areas	Drill-back Opera-tions	Routine Tunnel Opera-tions	Reentry and Mineback Opera-tions	Nuclear Rocket Develop-ment	Low-Level Waste Site	Low-Level Waste Site	Radio-chemistry and Counting Laboratories	Radiograph Operations	Well Logging Operations	Treat-ability Test Facility	Decon-tamination Facility	Radiation Instrument Calibration	Radio-active Source Storage	Nuclear Explosive /Device Assembly
NTS Area ►	**All areas except 22, 23 & 27**	**Areas 5 & 11**	**Areas 1-10 & 18-20**	**Areas 1, 12, 15 & 16**	**Areas 1, 12, 15 & 16**	**Areas 25 & 26**	**Area 3**	**Area 5**	**Areas 6 & 23**	**Area 23**	**Areas 1-10 & 18-20**	**Area 25**	**Area 6**	**Areas 6 & 23**	**Areas 6 & 23**	**Areas 6 & 27**
Period of operation ►	**1951-1963**	**1956-1957**	**1963-1992**	**1957-1992**	**1957-1992**	**1959-1973**	**Mid 1960s-present**	**1961-present**	**1958-present**	**1951-present**	**1963-1992**	**1990s**	**1971-2001**	**1951-present**	**1951-present**	**1951-present**
Ac-227							E,I	E,I					P			P
Al-28[n]	E		E		E											
Am-241	E,I	I					E,I	E,I	E,I		E,I	E,I	P	E,I	E,I	P
Am-243							E,I	E,I	E,I				P			
[241]AmBe											E			E	P	
Ba-133	E,I		P		P			E,I				E	P		E,I	
Ba-140	P		P		P	P	E,I	E,I	P				P		P	
Cd-109									I						I	
Ce-139	P		E[l],I[l]		I[l]	P			E,I				I[l]			
Ce-141	P		E[g],I[g]		I[g]	P	E,I	E,I	P				E[c],I[g]			
Ce-143	P		E[d],I[d]		I[d]	P			P				I[d]			
Ce-144	P		E[c],I[c]		I[c]	P	E,I	E,I	E,I			E	E[c],I[c]			
Cf-252											E			E	E	
Cl-38[n]	E		E		E											
Cm-244									E,I							
Co-57								E,I	E,I				E[c]		E,I	
Co-60	E,I		P		E,I	E,I	E,I	E,I	E,I	E,I	E,I	E	E	E,I	E,I	
Cs-134	E,I		P	P	P	P	E,I	E,I	P			E	P			
Cs-137	E,I		E[j],I[j]	E	E,I[j]	E,I	E,I	E,I	E,I	I	E,I	E	E[k],I[j]	E,I	E,I	
Eu-152	E,I					E,I		E,I	E,I			E			E,I	
Eu-154	E,I					P		E,I	P			E			E,I	
Eu-155	E,I					P		E,I	P			E			P	
Fe-59													E[c]			
H-3			P	I	I	I		I	I					I	P	I
Hg-203									E,I							
I-131			E[f],I[f]		E,I[f]	P			P		P		I[f]			
I-133			E[d],I[d]		E,I[d]	P			P				I[d]			
I-135			E[d],I[d]		I[d]	P			P				I[d]			
Ir-192								E,I		E,I					E,I	
Kr-85			E													
Lu-174	E,I											E				
Mn-54					E		E,I	E,I	P				E[c]		E,I	
Mn-56	E[l]		E[l]		E[l]				E[l]				E[l]			
Mo-99			E[d],I[d]		I[d]	P		E,I	P				I[d]			
Na-22								E,I							E,I	
Na-24									E,I							
Nb-95 (See Zr-95/ Nb-95)																
Ni-63															E,I	
Np-237								E,I								
Np-239	E[l]		E[l]		E[l]				E[l]				E[l]			
Pm-147			E[l],I[l]		I[l]							E	E[c],I[l]			
Pu-238	E,I	I					E,I	E,I			I	E,I	P	I	I	E[l],I
Pu-239	E,I	I					E,I	E,I	E,I			E,I	P	I	E,I	E[l],I
Pu-240	E,I	I					E,I	E,I				E,I	P		E	E[l],I
Pu-241							E,I	E,I					P			E[l],I

Radionuclide of concern ▼	Atmospheric Weapons Test Areas	Safety Test Areas	Drill-back Opera-tions	Routine Tunnel Opera-tions	Reentry and Mineback Opera-tions	Nuclear Rocket Develop-ment	Low-Level Waste Site	Low-Level Waste Site	Radio-chemistry and Counting Laboratories	Radiograph Operations	Well Logging Operations	Treat-ability Test Facility	Decon-tamination Facility	Radiation Instrument Calibration	Radio-active Source Storage	Nuclear Explosive /Device Assembly
NTS Area ►	**All areas except 22, 23 & 27**	**Areas 5 & 11**	**Areas 1-10 & 18-20**	**Areas 1, 12, 15 & 16**	**Areas 1, 12, 15 & 16**	**Areas 25 & 26**	**Area 3**	**Area 5**	**Areas 6 & 23**	**Area 23**	**Areas 1-10 & 18-20**	**Area 25**	**Area 6**	**Areas 6 & 23**	**Areas 6 & 23**	**Areas 6 & 27**
Period of operation ►	**1951-1963**	**1956-1957**	**1963-1992**	**1957-1992**	**1957-1992**	**1959-1973**	**Mid 1960s-present**	**1961-present**	**1958-present**	**1951-present**	**1963-1992**	**1990s**	**1971-2001**	**1951-present**	**1951-present**	**1951-present**
Pu-242							I	E,I	E,I				P			
^{238}PuBe											E^{l},I			E	E	
Ra-226								E,I			E,I			E,I	E,I	
^{226}RaBe											E^{l},I			P	P	
Rh-100												E^{m}				
Rh-101	E^{m},I^{m}											E^{m}				
Rh-102m	E^{m},I^{m}											E^{m}				
Rh-106	P		P		E	P			P							
Ru-103	P		E^{e},I^{e}		E,I^{e}	P	E,I	E,I	P				E^{c},I^{e}			
Ru-106	P		E^{c},I^{c}		E,I^{c}	P	E,I	E,I	P				E^{c},I^{c}			
Sb-124	P				E,I			E,I	P				E^{c}			
Sb-125	E,I				P			E,I	P			E	E			
Sc-46	E^{l}		E^{l}		E^{l}				E^{l}				E^{l}			
Sn-113									I							
Sr-85							E,I	E,I	E,I							
Sr-89	P		E^{e},I^{e}	P	E^{l},I^{e}	P							E^{l},I^{e}			
Sr-90/Y-90	E,I		E^{h},I^{h}	E,I^{h}	E,I^{h}	E,I	E,I	I	E,I			E	E,I^{h}	E,I	E,I	
Ta-182					E			E,I								
Tc-99m			P		P	P		P	P				P			
Te-132			E^{f},I^{f}		I^{f}	P			P				I^{f}			
Th-228							E,I	E,I			E^{l},I			E,I	E,I	
Th-230							E,I	E,I						E,I		
Th-232							E,I	E,I								
U-233							E,I	E,I								
U-234						I	E,I	E,I								E^{l},I
U-235						I	E,I	E,I							E,I	E^{l},I
U-238						I	E,I	E,I								
Xe-133			E		P											
Xe-133m			E		P											
Xe-135			E		P											
Y-88									E,I							
Y-90 (See Sr-90/Y-90)																

Radionuclide of concern ▼	Atmospheric Weapons Test Areas	Safety Test Areas	Drill-back Opera-tions	Routine Tunnel Opera-tions	Reentry and Mineback Opera-tions	Nuclear Rocket Develop-ment	Low-Level Waste Site	Low-Level Waste Site	Radio-chemistry and Counting Laboratories	Radiograph Operations	Well Logging Operations	Treat-ability Test Facility	Decon-tamination Facility	Radiation Instrument Calibration	Radio-active Source Storage	Nuclear Explosive /Device Assembly
NTS Area ►	**All areas except 22, 23 & 27**	**Areas 5 & 11**	**Areas 1-10 & 18-20**	**Areas 1, 12, 15 & 16**	**Areas 1, 12, 15 & 16**	**Areas 25 & 26**	**Area 3**	**Area 5**	**Areas 6 & 23**	**Area 23**	**Areas 1-10 & 18-20**	**Area 25**	**Area 6**	**Areas 6 & 23**	**Areas 6 & 23**	**Areas 6 & 27**
Period of operation ►	**1951-1963**	**1956-1957**	**1963-1992**	**1957-1992**	**1957-1992**	**1959-1973**	**Mid 1960s-present**	**1961-present**	**1958-present**	**1951-present**	**1963-1992**	**1990s**	**1971-2001**	**1951-present**	**1951-present**	**1951-present**
Y-91			E[e],I[e]		I[e]								I[e]			
Yb-169								E,I								
Zr-95/Nb-95	P		E[c],I[c]		E,I[c]	P	E,I	E,I	P			E	E[c],I[c]			
Zr-97			E[d],I[d]		I[d]	P			P				I[d]			

a. Sources: REECo (1993, 1995).
b. E = External hazard per REECo (1995); I = Internal hazard per REECo (1993); P = Possible based on process knowledge and health physics expertise (this designation means the radionuclide was not specifically listed for this facility or process in REECo (1993) or (1995), but should still be considered as a possibility).
c. 1, 10, 100, and 365 d post-test (within first year).
d. 1 d post-test.
e. 10 and 100 d post-test.
f. 1 and 10 d post-test.
g. 10 d post-test.
h. 100, 365, and 10,000 d post-test.
i. 365 d post-test.
j. 10,000 d post-test.
k. After first year only.
l. External was added to this table, but was not included in Allen and Schoengold 1995 for this facility/process.
m. The fission yields for these radionuclides are low and are not considered to have much radiological significance compared to the other radionuclides listed.
n. Activation product important for external gamma dose for armed forces personnel (NRC 1989) added in response to the NTS Site Profile Evaluation (S. Cohen & Associates, 2005). Due to the short half life, this radionuclide would not be a dose factor for reentry personnel.

Table 2-3. Radionuclides typically deposited after atmospheric tests for various time intervals.[a]

Radionuclide	Period				
mCi/m^2	10 d	1 yr	10 yr	20 yr	50 yr
Be-7	2.61E-07	3.46E-07	7.96E-28		
Na-24	1.02E-06				
Mn-54	1.96E-05	1.05E-05	5.69E-09	1.34E-12	1.75E-23
Fe-55	3.57E-05				
Fe-59	2.56E-05	1.89E-06	1.95E-28		
Co-57	3.56E-05	1.62E-05	3.62E-09	3.16E-13	
Co-58	7.68E-02	2.55E-03	3.40E-17	1.30E-32	
Co-60	1.51E-04	1.71E-04	5.20E-05	1.39E-05	2.67E-07
Cu-64	5.29E-06				
Cu-67	7.09E-06				
W-181					
W-185		1.64E-08	1.09E-21		
W-187					
W-188					
Au-198					
Au-199					
Pb-203					
U-237	6.5E-02				
U-240	5.47E-06				
Np-237					
Np-239	1.54E+00				
Np-240m	5.52E-06				
Am-241	7.05E-09	1.11E-06	1.13E-06	1.13E-06	1.11E-06
Cm-242	1.75E-07	3.00E-06	2.55E-12	7.43E-17	6.83E-17
Ge-77	4.45E-09				
As-77	1.50E-04				
Se-77m	4.50E-07				
As-78					
Br-82	3.33E-06				
Br-83	7.74E-30				
Kr-83m	3.40E-29				
Kr-85m	3.18E-16				
Kr-85	9.24E-05	5.37E-05	3.01E-05	1.59E-05	2.32E-06
Kr-87					
Kr-88	4.99E-25				
Rb-88	5.56E-25				
Sr-89	7.87E-02	4.28E-04	4.01E-23	2.91E-44	
Sr-90	6.10E-04	3.57E-04	2.87E-04	2.24E-04	1.07E-04
Y-90	5.67E-04	3.57E-04	2.87E-04	2.24E-04	1.07E-04
Sr-91	5.40E-07				
Y-91m	3.50E-07				
Y-91	9.84E-02	9.89E-04	1.48E-20	2.98E-39*	
Sr-92	1.30E-25				
Y-92	6.70E-19				
Y-93	1.45E-06				
Zr-95	1.13E-01	2.31E-03	1.39E-18	1.70E-35	
Nb-95m	1.97E-03	4.89E-05	2.95E-20	3.61E-37	
Nb-95	2.11E-02				
Zr-97	6.14E-01				

Radionuclide	Period				
mCi/m^2	10 d	1 yr	10 yr	20 yr	50 yr
Nb-97m	5.89E-04				
Nb-97	6.19E-04	4.97E-03	3.01E-18	3.69E-35	
Mo-99	2.55E-01				
Tc-99m	2.43E-01				
Ru-103	1.28/E-01	4.51E-04	4.69E-29		
Rh-103m	1.28E-01	4.52E-04	4.69E-29		
Ru-105	1.03E15				
Ru-105m	1.03E-15				
Rh-105m	2.63E-02				
Ru-106	7.73E-03	1.01E-02	2.04E-05	2.06E-08	2.12E-17
Rh-106	7.73E-03	1.01E-02	2.04E-05	2.06E-08	2.12E-17
Pd-109	2.39E-06				
Ag-109m	2.40E-06				
Pd-111m	5.45E-14				
Pd-111	4.40E-14				
Ag-111m	5.76E-14				
Ag-111	9.54E-03				
Pd-112	5.15E-05				
Ag-112	6.10E-05				
Ag-113	7.23E-15				
Cd-115m	8.97E-05				
Cd-115	1.27E-03				
In-115m	1.38E-03				
Cd-117	5.40E-31				
In-117m	2.76E-30				
In-117	1.86E-30				
Sn-121	1.39E-04				
Sn-123	3.34E-04	9.79E-05	1.19E-12	1.91E-21	7.91E-48
Sn-125	4.57E-03				
Sb-125	1.04E-04	2.48E-04	2.46E-05	1.89E-06	8.56E-10
Sb-126	1.02E-03				
Sn-127	9.86E-35				
Sb-127	2.40E-02				
Te-125m		1.01E-04	1.02E-05	7.81E-07	3.54E-10
Te-127m	8.98E-04	1.68E-04	1.40E-13	1.15E-23	6.43E-54
Te-127	2.17E-02	1.66E-04	1.39E-13	1.14e-23	6.37E-54
Sb-128	7.23E-09				
Sb-129	1.56E-16				
Te-129m	6.84E-03				
Te-129	4.37E-03				
I-130	2.91E-08				
Te-130m	1.85E-03				
Te-131	3.37e-04				
I-131	2.80E-01				
Xe-131m	1.47E-03				
Te-132	2.38E-01				
I-132	2.45E-01				
I-133	3.84E-03				
Xe-133m	7.41E-03				
Xe-133	5.71E-01				
I-135	4.7E-10				

Radionuclide	Period				
mCi/m^2	10 d	1 yr	10 yr	20 yr	50 yr
Xe-135m	1.47E-10				
Xe-135	1.10E-06				
Cs-136	3.15E-03				
Cs-137	7.76E-04	8.99E-04	7.30E-04	5.77E-04	2.90E-04
Ba-137m	7.24E-04	8.43E-04	6.84E-04	5.41E-04	2.71E-04
Ba-139					
Ba-140	3.65E-01				
La-140	4.09E-01				
La-141	1.50E-17				
Ce-141	2.04E-01	9.67E-06	2.82E-35		
La-142					
Ce-143	3.39E-02				
Pr-143	3.49E-01				
Ce-144	2.15E-02	7.87E-03	2.59E-06	3.48E-10	8.51E-22
Pr-144	2.15E-02	7.87E-03	2.59E-06	3.48E-10	8.51E-22
Pr-145	1.69E-11				
Nd-147	1.45E-01				
Pm-147	1.45E-03	2.60E-03	2.41E-04	1.71E-05	6.12E-09
Nd-149	1.60E-39				
Pm-149	3.36E-02				
Pm-150	4.41E-28				
Pm-151	3.03E-03				
Sm-153	1.02E-02				
Sm-156	1.10E-08				
Eu-155	6.33E-04	5.49E-04	1.48E-04	3.46e-05	4.38E-07
Eu-156	9.98E-03				
Eu-157	5.19E-06				
Gd-159	9.39E-06				
Tb-161	7.18E-04				

a. Source: DNA (1982b).

(100 to 700 ft), detonations on the surface of the ground, and the use of helium-filled balloons 137 to 457 m (450 to 1,500 ft) above the ground to loft weapons.

Depending on the proximity of the explosion to the ground surface and the size of the yield, surface disturbances from atmospheric testing varied widely. The greatest surface disturbances typically occurred when an air-dropped weapon penetrated the ground surface to a shallow depth (about 15 m [50 ft]) before detonation. Such a test with a yield of 100 kt would result in a crater about 36 m (120 ft) deep and about 219 m (720 ft) in diameter (DOE 1996a).

Radioactivity from atmospheric tests was dispersed by three primary mechanisms: throwout, base surge, and fallout. *Throwout* occurred at detonation when the fireball propelled large volumes of rock and soil upward. *Base surge* was the settling and outward movement of the throwout. *Fallout* is the portion of material that did not settle, but rose and merged with weapon residues. These materials descended to the ground over the next few hours or more. The extent and distribution of contamination from an atmospheric test was quite variable depending on the height of detonation, the yield and type of device, the nature of the ground surface, the mass of inert material surrounding the device, and weather conditions at the time of and following the test. Typical radionuclides formed during atmospheric testing included isotopes of strontium, cesium, barium, tritium, and iodine. Of these, ^{90}Sr and ^{137}Cs are of concern because of their longer half-lives of 28 and 29 yr, respectively (DOE 1996a)

The vast majority of radioactivity released during atmospheric testing decayed quickly after each test. For example, for a 1-kt atmospheric test, the initial release after 1 min was about 4.1 x 10^{10} Ci. This activity reduced to 1 x 10^{7} Ci just 12 hr after the detonation. If the activity remaining after 12 hr was used as the basis for estimates of total release, about 6 x 10^{10} Ci were released during atmospheric testing between 1951 and 1963 at the NTS (DOE 1996a).

Many of the fission products released during detonations were dispersed into the atmosphere, and much of the residual radioactivity has decayed in the 40 yr since the last atmospheric test. Nonetheless, some of the longer-lived radionuclides remain in the soil and physical structures. The primary radionuclides that remain on the NTS from historic atmospheric testing include americium, plutonium, cobalt, cesium, strontium, and europium.

Residual contamination for atmospheric testing is present in Areas 1, 2, 3, 4, 7, 8, 9, and 10 of the NTS and on Buckboard Mesa in Area 18. All areas except Areas 22, 23, and 27 have some monitoring and restrictions as a result of these tests. The routine device for external exposure monitoring in the atmospheric test areas is the whole-body thermoluminescent dosimeter (TLD) (REECo 1995). Table 2-4 summarizes the major sources of radioactivity on the NTS.

2.3.2 Safety Tests and Contaminated Surface Soils

Safety tests evaluated the safety of nuclear weapons in accident scenarios. Safety experiments that produced no nuclear explosions but created surface contamination were conducted at locations on the NTTR (Area 13) and TTR (DOUBLE TRACKS and CLEAN SLATE I-III), at Plutonium Valley in Area 11, and at the GMX site in Area 5. Contamination from these sites is limited to surface soils. The depth of contamination could vary among sites, but it is not expected to exceed 1 ft at any site (NDEP 2000).

The GMX PROJECT site in NTS Area 4 was used for 24 specific equation-of-state studies or experiments with fissile materials from 1954 to 1956. The purpose of these early GMX experiments was to determine if a nuclear chain reaction could occur after the accidental triggering of conventional HE materials in an assembled weapon.

PROJECT 56 consisted of four discrete surface plutonium dispersal safety tests in 1955 and 1956 in NTS Area 11. The purpose of these safety experiments was to determine whether a weapon damaged in an accident would detonate with a nuclear yield, even if some or all of the HE component burned or detonated. One of these safety tests went partially critical, creating some fission products that contribute to the surface contamination. An enriched uranium safety test cross-contaminated with plutonium took place in Area 11a. Experiments 11b, c, and d were ground-zero detonations. A small underground waste dump is inside the contaminated area boundary. Large metal debris resulted in a Radiation Area near 11c. Area 11 of the NTS is known as Plutonium Valley because of the contaminated soil from the safety experiments and has been used for realistic drills in radiological monitoring and sampling operations.

The PROJECT 57 test area, also known as NTTR Area 13, was a 10- by 16-mi block of land abutting the northeast boundary of the NTS. On April 24, 1957, the safety experiment commenced when the HE charge of a nuclear weapon's warhead destroyed the weapon with no atomic explosion. A radiological survey team entered the experiment area and confirmed there was no beta or gamma radiation hazard from a partial nuclear yield. All personnel entering the area were required to wear full protective suits and respirators to protect from the alpha radiation hazard. The extent and distribution of plutonium contamination was mapped and the area was fenced and posted. Contaminated equipment was disposed in waste burial sites inside Area 13. The PROJECT 57 site lay abandoned

Table 2-4. Residual radioactivity on the NTS, January 1996.[a]

Source of radioactivity	Type of area	Environmental media	Major known elements or waste	Depth range	Approximate activity (curies)
Atmospheric tests[b]	Aboveground nuclear proving area	Surface soils and test structures	Americium Cesium Cobalt Plutonium Europium Strontium	At surface	20
Safety tests[b]	Aboveground experimental areas	Surface soils	Americium Cesium Cobalt Plutonium Strontium	Less than 0.9 m (3 ft)	35
Big Explosives Experimental Facility[b]	Bunkers	Underground	Depleted uranium	N/A	N/A
Deep underground tests[b]	Underground nuclear testing areas	Soils, alluvium, and consolidated rock	Tritium Fission and activation products	Typically less than 640 m (2,100 ft); but may be deeper	Greater than 300 million
Nuclear reactor tests[b]	Nuclear rocket motor, reactor, and furnace testing area	Surface soils	Cesium Strontium	Less then 3 m (10 ft)	1
Shallow borehole tests[b]	Underground nuclear testing area	Soils and alluvium	Americium Cesium Cobalt Europium Plutonium Strontium	Less than 61 m (200 ft)	2,000 at land surface; depth unknown
Shallow land burial of low-level waste[b]	Waste disposal landfills	Soils and alluvium	Dry-packaged low-level and mixed-wastes	Less than 9 m (30 ft)	500,000 at time of disposal; no decay
Crater disposal[b]	Subsidence crater with sidewalls, cover, and drainage	Soils and alluvium	Bulk contaminated soils and equipment	Less than 30 m (100 ft)	1,250 at time of disposal; no decay
Greater containment disposal[b]	Monitored underground waste disposal borehole	Soils and alluvium	Tritium Americium	Less than 30 m (100 ft)	9.3 million at time of disposal; no decay
U1a Complex[b]	Mined underground complex	Underground	(Special Nuclear Material (SNM) Tritium Depleted uranium	To 350 m (1,000 ft)	N/A
Containment ponds[c]	Surface	Water, air, and soil	Tritium	N/A	130
Laboratories[c]	Surface	Air and soil	Tritium	At surface	500 µCi
Joint actinide research (JASPER)[c]	Surface	Air and soil	SNM Actinides	N/A	N/A
Contaminated surface soils[c]	Surface	Soil	Americium Plutonium	0 to 5 cm	Assumed to be included in above totals

a. N/A = not available.
b. DOE (1996a).
c. DOE (1997a).

for nearly 20 yr until 1981 when DOE sought funding for the decontamination and decommissioning of Area 13. Hundreds of thousands of cubic yards of soil were removed from Area 13 during the decontamination efforts and disposed at NTS.

Operation Roller Coaster was an experimental series of plutonium dispersal tests that were conducted in 1963 at the TTR. The purpose of these tests was to evaluate storage and transportation issues. The DOUBLE TRACKS site was remediated in 1995 and 1996 and the CLEAN SLATE I corrective actions were performed in 1997. Contaminated soil was transported to the NTS Area 3 RWMS. Corrective actions for CLEAN SLATE II and III are pending an agreement between the State of Nevada and the Federal government on the level of cleanup. A summary of the plutonium dispersal tests is listed below:

- GMX conducted at NTS Area 5, 1954-1956
- PROJECT 56 conducted at NTS Area 11 (Plutonium Valley), 1955 1956
- PROJECT 57 conducted at NTTR Area 13 in 1957
- DOUBLE TRACKS and CLEAN SLATE I-III (Operation Roller Coaster) conducted at TTR in 1963

The safety tests used mixtures of plutonium and uranium dispersed by conventional explosives. Concurrent with and after these detonations, extensive studies were conducted to understand the dispersal and transport of these radionuclides in the environment including uptake by plants and animals. These studies were documented in a benchmark series of papers by the Nevada Applied Ecology Group, a panel of scientists chartered to investigate the effects of testing at the NTS. The immediate effects of the tests included the dispersal of plutonium and uranium over wide areas. To determine the area affected by these tests, inventories were conducted and later augmented by extensive sampling efforts in the field under the Radionuclide Inventory and Distribution Program. These studies resulted in the definition of affected areas. The GMX PROJECT at Area 5 resulted in the contamination of about 240 acres, and the PROJECT 56 tests resulted in the contamination of about 2,200 acres. On the NTTR Complex, two disturbed areas total slightly less than 1,000 acres. On the TTR, almost 670 acres were contaminated.

At both onsite and offsite locations, the primary radionuclides are plutonium, uranium, and americium, with lesser amounts of cesium, strontium, and europium. These long-lived radionuclides remain in the surface soils in the vicinity of the test areas and are available for transport by wind and uptake by plants and animals. Extensive research into the mobility of the radionuclides has found that wind can transport such contaminants and concentrate them in mounds around desert shrubs, and water can cause plutonium to migrate deeper into the soils with time. At present, the radionuclides are relatively immobile unless the soils are disturbed. Evidence of wind-driven contamination is low. The heat of initial blast, soil bonding and weathering, and the rockiness of native soil prevent deep migration (REECo 1995). DOE (1997b) provides an estimate of the $^{239+240}$Pu inventory at the studied sites.

Surface soils in certain areas on and off the NTS were contaminated with one or more of plutonium, americium, and tritium from nuclear device safety, atmospheric, or cratering tests. Vehicular activity is forbidden in these areas. There is no evidence of significant wind dispersal after initial deposition. Rain and runoff have caused migration in some areas. These areas could become sources of exposures to americium and plutonium if the contaminated soils were to be resuspended during windy conditions, surface cleanup, construction, vehicular travel, or similar activities.

Areas 1 to 12 and 15 to 20 on the NTS, Area 13 on NTTR, and the CLEAN SLATE I to III sites on the NTTR at the TTR contain diffuse sources of radionuclide effluents. Due to occasional high winds, some contaminated soil becomes airborne. Results from air samples in these areas indicate the routine detection of ^{241}Am and $^{239+240}$Pu, but only in concentrations slightly above the minimum detectable concentration. The other predominant isotopes found in NTS soil samples are ^{137}Cs and ^{238}Pu.

MacArthur (1991) contains inventories of americium and plutonium in contaminated surface soils. These areas could become sources of exposure to americium and plutonium if the contaminated soils become resuspended.

2.3.3 Underground Tests

Since 1963, the United States has conducted all of its nuclear weapons tests underground in accordance with the terms of the Limited Test Ban Treaty. Therefore, complete containment of all nuclear weapons tests was a dominant consideration in nuclear test operations.

Various methods were used for emplacing nuclear test devices so the ensuing explosion was contained. The most common method was to place a test device at the bottom of a vertically drilled hole. Another method was to place a test device in a tunnel mined horizontally to a location sufficiently deep to provide containment.

The following paragraphs describe processes associated with nuclear weapons tests in vertical drill holes and mined tunnels. The information is from DOE (1996a).

2.3.3.1 Tests in Vertical Drill Holes and Drill Backs

There were two types of tests in vertical drill holes: Smaller yield devices in relatively shallow holes in the Yucca Flat area (Areas 1 to 10) and higher yield devices in deeper holes on Pahute Mesa (Areas 18 to 20). Tests at the Yucca Flat and Pahute Mesa sites had the same general requirements, but differed in the magnitude of the operations. Deeper hole operations disturbed a larger area, required more onsite equipment, and had higher requirements for electric power and utilities. The distance from NTS facilities and infrastructure was also a factor to minimize the effects of the tests. Pahute Mesa operations were 48 to 81 km (30 to 50 mi) farther away than Yucca Flat.

The following paragraphs describe a vertical drill-hole test:

1. **Site Selection and Drilling** – There were two options in site selection as it applied to a specific event – selection of an existing drill hole or selection of a new drill site from the Nuclear Test Zone. The goal of siting was to optimize the various parameters to attain operational feasibility and successful containment of yields.

   A normal hole was from 1 to 3 m (39 to 120 in.) in diameter and from 213 to 762 m (600 to 2,500 ft) deep. During drilling, samples of drill cuttings were collected at 3-m (10-ft) intervals, and rock cores were taken as required. After drilling was completed, geophysical instruments were run into the hole to evaluate its condition and gain a more thorough understanding of the geology. The drill site was secured by filling the sump and installing specially designed covers over the hole.

2. **Site Engineering and Construction** – An area was cleared and leveled for the surface ground-zero equipment. Another area close by was cleared and leveled for the recording

trailer park. Onsite construction was temporary and abandoned after the test. Concrete pads were poured around the surface at ground zero to provide a stable platform for down-hole operations and a base for the assembly towers. Equipment was moved in to place the nuclear device in the hole, record the data, and provide radiological and seismic monitoring of the site. A circle of radiation detectors was placed back from the surface at ground zero to detect and assess releases from the experiment. A perimeter fence was erected, and access was controlled both to and from the site.

3. **Device Delivery and Assembly** – For safety reasons, the nuclear device was delivered to the NTS unassembled. The device was assembled and inserted in a container in the Area 27 Assembly/Staging Facilities. The device, now encased in the container, was delivered to the event site accompanied by armored convoy. It was attached to the diagnostics canister in preparation for placement in the hole. There was no radiation exposure potential above background environmental levels prior to this stage.

4. **Diagnostic Assembly** – A diagnostic canister or rack was assembled off the site and transported to the test site. A typical canister would have been about 2 m (8 ft) in diameter and 30 m (120 ft) long and would contain all the instrumentation required to receive data at the time of the explosion (real time). On arrival at the site, the diagnostic canister was installed in the assembly tower to be mated with the device.

5. **Emplacement of the Experiment** – The drill hole was opened and the nuclear explosive and measurement devices were moved to the hole and lowered to the detonation position, along with diagnostic materials and instrumentation cables. The assembly was placed on a set of fracture-safe beams that spanned the opening. Any auxiliary equipment was lowered into the hole, and the area was secured. The hole was stemmed to prevent radioactive materials from escaping during or after the experiment. Areas around instrument cables were sealed to prevent a radioactive gas path to the surface.

6. **Test Execution** – Security operations began 2 d before the test to ensure that all non-event-related personnel were evacuated before the test for security and safety. The explosive was armed. Radiation monitors were activated, and aircraft with tracking capability circled the site in case gas and debris unexpectedly vented to the surface. Weather forecasts and fallout pattern predictions were reviewed. When acceptable weather conditions and other criteria were met, the device was detonated.

   When an underground nuclear device was detonated, the energy released almost instantaneously produced extremely high temperature and pressure that vaporized the device and the surrounding rock. Within a fraction of a second after detonation, a generally spherical cavity was formed at the emplacement position. As the hot gases cooled, a lining of molten rock puddled at the cavity bottom.

   After a period of minutes to hours, as the gases in the cavity cooled, the pressure subsided and the weight of the overburden sometimes caused the cavity roof to collapse, producing a vertical, rubble-filled column known as a *rubble chimney*. The rubble chimney commonly extended to the surface, forming a subsidence crater. There are a number of subsidence craters on NTS. These craters generally are bowl-shaped depressions with diameters ranging from about 60 to 600 m (200 to 2,000 ft) and a depth ranging from a few to 60 m (200 ft), depending on the depth of burial and the explosive energy yield. Some deeply buried explosions of low yield formed cavities that did not collapse to the surface and, as a consequence, did not create subsidence craters.

After the test, ground zero remained secure until it was certain that the test had been contained. A reentry crew was dispatched to the site to retrieve data and note the condition of equipment. Reentries had the potential to cause significant external and internal radiation exposures, but a comprehensive radiological control program was in place. After all was secure, normal NTS operations resumed. Ground zero was roped off, outlining an exclusion zone if there was danger of potential cratering.

7. **Post-Shot Operations (Drill back)** – After the temperature of the cavity had cooled, a post-test hole was usually drilled to the point of the explosion to retrieve debris samples. The highly radioactive samples provided important information on the test. The post-test hole was as small in diameter as possible and was drilled at an angle to allow the drill rig to be positioned safely away from the surface at ground zero. The drilling duration depended on multiple factors including the depth of the emplacement, size of device, equipment function, and matrix of the substrate. After drilling and sampling operations were complete, the drill rig and tools were decontaminated. Residual radiation was cleaned up at the site.

   It was possible to encounter high gas pressures in the cavity because the drill back was often performed within 1 or 2 d of the detonation. In 1964, engineering devices were used to prevent the escape of radioactive gases and particulates. However, there was the potential for exposure to gaseous and particulate fission and activation products (REECo 1995).

   The pathways for release of radioactivity and personnel exposure were two-fold. The first scenario was based on a loss of containment in the drilling or coring operation. This occurred during routine drilling operations, or it could be caused by a failure of containment equipment. The radionuclides of concern for dose for this pathway were the fission products ^{85}Kr, ^{131}I, ^{133}I, ^{133m}Xe, and ^{137}Cs. The second scenario was based on particulate fission or activation products in the core samples obtained after an underground test (REECo 1995).

   Although weapons tests have not been conducted since September 1992, in an effort to maintain readiness skills, drill-back operations have been occasionally conducted. Personnel involved in drill-back operations typically wear pocket dosimeters and full personal protection clothing (PPC). Those handling core samples wear extremity monitoring dosimeters (REECo 1995). See Attachment D for additional information about post-test drilling.

2.3.3.2 Tests in Mined Tunnels and Mine Backs

Rainier Mesa in Area 12 was the site of the Nation's first fully contained underground nuclear detonation, called RAINIER, on September 19, 1957, in a horizontal tunnel about 488 m (1,600 ft) into the mesa and 274 m (900 ft) beneath the top of the mesa. Of the 61 underground nuclear tests in Area 12 between late 1957 and 1992, only 2 were in drilled holes; the 59 others were in mined tunnels. By the early 1990s, there was only one active tunnel in use.

The tunnel tests evaluated the effects of nuclear weapons explosions, thermal radiation, blast, shock, X-rays, and gamma rays on military hardware such as communication equipment, rocket nose cones, and satellites. The typical horizontal-line-of sight (HLOS) test was designed to minimize blast and shock effects from the experiments. The large tunnel complex mined under the mesa contained HLOS pipe, which was about 460 to 550 m (1,500 to 1,800 ft) long and tapered from as much as 9 m (30 ft) in diameter at the test chamber to several inches at the working point. Experiments were placed in the pipe test chambers. At zero time, when the nuclear device was detonated, radiation flowed instantaneously down the pipe, creating the necessary radiation environment. To prevent bomb debris and blast from reaching and damaging the experiments, three mechanisms were used to

close the pipe; the first was the Fast Acting Closure, which was slammed shut by HE in about 1 ms; the other two closures followed within 30 and 300 ms.

A number of tunnels were mined into Rainier Mesa, in which most DOD HLOS exposure experiments occurred. In particular, the N-, P-, and T-Tunnel complexes were extensively developed during the past several decades. N-Tunnel was the location for a nonproliferation experiment, detonated in September 1993, which involved 1.3 x 10^6 kg (2.9 x 10^6 lb) of conventional HE. DOD currently operates an HE research and development tunnel in Area 12. This reusable test bed supports programs involving the detonation of conventional or prototype explosives and munitions.

Routine Tunnel Operations – Routine tunnel operations had a potential for personnel exposure to fission or activation products that remained from tests conducted previously in the tunnel complex. These radioactive materials could be carried by water, or could seep through faults and fissures to reenter the working areas. Experience has shown that the external dose levels in routine tunnel work areas were very low. The principal radionuclides of external dose concern were the fission products ^{90}Sr/^{90}Y and ^{137}Cs (REECo 1995).

Containment Ponds – The containment ponds were constructed to catch contaminated runoff from the tunnel complexes. All active containment ponds are fenced and posted with radiological warning signs to prevent human access. Water contaminated with radionuclides seeped from the tunnels in Area 12 and was collected in the containment ponds, resulting in water evaporation and seepage into the soil. The tunnels have been sealed, but water continues to seep from E Tunnel. The only radiological contaminant that produces a measurable air emission from evaporation of the water is ^{3}H (as HTO). In 2001, an estimated 14 Ci of HTO were discharged to the ponds (DOE 2002a). Table 2-4 lists the 1996 estimate.

Reentry and Mineback Operations – Reentry and mineback operations usually took place within days or weeks of an underground test. In some instances, they were conducted as much as decades after a test. These operations took place in a confined underground environment whereby personnel actually entered the test cavity. There were two exposure scenarios during reentry and minebacks. The first scenario was based on a loss of containment in the drilling or coring operation. This could occur during the routine drilling operations or be caused by a failure of containment equipment. The radionuclides of concern for this pathway were ^{54}Mn, ^{90}Sr, ^{90}Y, ^{103}Ru, ^{106}Rh, ^{131}I, ^{133}I, ^{137}Cs, and ^{182}Ta (REECo 1995).

The second exposure scenario was the possibility of fission or activation products entering the working areas of the tunnels by migrating through fissures in the rock, by escaping through LOS pipes when they were opened to remove experiment equipment and samples, or by personnel actually entering the cavity. The radionuclides of concern for dose for this pathway were ^{60}Co, ^{124}Sb, ^{131}I, ^{133}I, and ^{137}Cs. At present, no mineback or reentry operations are likely to be conducted at the NTS unless testing is resumed. If this occurs, personnel would wear whole-body TLDs, pocket dosimeters, and PPC (REECo 1995).

2.3.3.3 U1a Subcritical Experiments

The LEDOUX nuclear test with a yield of less than 20 kt was conducted in 1990 in a drift in this tunnel complex. The dynamic KISMET experiment, involving HE, tritium, depleted uranium, and other materials, was conducted in the complex in March 1995. Both LEDOUX and KISMET were contained to prevent radiological releases to the rest of the complex and the surface environment.

2.3.3.4 Shallow Borehole Tests

Shallow borehole tests occurred between 1960 and 1968. Some of these tests were safety related; others were conducted as part of Project PLOWSHARE to determine if nuclear detonations could be used as a method for excavation. The shallow tests resulted in the development of some large ejection craters, most notably the SEDAN crater in the northern end of the Yucca Flat testing area. SEDAN, a 104-kt nuclear device detonated 194 m (635 ft) underground, displaced about 1.2 x 10^7 t of earth and created a crater 390 m (1,280 ft) in diameter and 98 m (320 ft) deep. The estimated remaining inventory of surface radioactivity at the SEDAN crater is 344 Ci. The total estimate for all releases from shallow borehole tests to the surface soil horizon at the NTS is 2,000 Ci. Radionuclides include isotopes of americium, cesium, cobalt, europium, plutonium, and strontium (DOE 1996a).

2.3.3.5 Radioactive Releases from Nuclear Weapons Testing

The containment of underground nuclear explosions was a process that continually evolved through learning, experimentation, and experience. The record of containment illustrates the various types of releases and their relative effects. Operational releases were small releases of radioactivity from the operational aspects of vertical drill hole tests. Activities that often resulted in operational releases included drilling back down to the location of the explosion to collect core samples, collecting gas samples from the explosion, and sealing the drill-back holes (OTA 1989).

Late-time seeps were small releases that occurred days or weeks after a test when gases diffused through pore spaces in the overlying rock and were drawn to the surface by decreases in atmospheric pressure.

Controlled tunnel purging was an intentional release of radioactive material to recover experimental equipment and ventilate test tunnels. During a controlled tunnel purging, gases from the tunnel were filtered, mixed with air to reduce the concentration, and released over time when weather conditions were favorable for dispersion into sparsely populated areas (OTA 1989).

Successful containment was defined as no radioactivity detectable off the site and no unanticipated release of radioactivity on the site. By definition, there has been containment failure on four occasions since 1970 (OTA 1989). Table 2-5 includes every instance (for both announced and unannounced tests) in which radioactive material reached the atmosphere under any circumstances whatsoever from 1971 to 1988. The lower part of Table 2-5 summarizes underground tests before 1971 and provides a comparison with other releases of radioactive material.

Operational Releases and Tunnel Purging – Past underground tests formed pockets of radioactive contamination around each test site. The source term includes many short- and long-lived radionuclides. For example, for atmospheric testing of a 1-kt nuclear weapon, an initial release of 41 billion Ci decays to about 10 million Ci in just 12 hr. The quantity of radioactivity remaining from a 1-kt underground detonation 180 d after detonation is about 45,000 Ci (including 18,570 Ci of tritium). However, there is considerable uncertainty concerning these estimates. For example, the actual tritium activity after 180 d could range from 5,570 to 55,770 Ci (DOE 1996a).

Purging gases from the tunnel for testing occasionally resulted in releases of radioactivity, and contaminated water drained from the tunnels to containment ponds (DOE 2002a). While the tunnel complex was being secured before detonation of the nuclear device, the ventilation line was disconnected at each containment plug and the penetration through the plug was sealed. Therefore, it was necessary to reenter the tunnel to reestablish ventilation through the various containment plugs. If radioactive gases were present in a portion of the complex, it became necessary to purge these

Table 2-5. Releases from underground tests (normalized to 12 hr after event).[a,b]

Release Events	Ci released
All releases 1971–1988	
Containment failures:	
CAMPHOR, 1971[c]	360
DIAGONAL LINE, 1971	6,800
RIOLA, 1980	3,100
AGRINI, 1984	690
Late-time seeps:	
KAPPELLI, 1984	12
TIERRA, 1984	600
LABQUARK, 1986	20
BODIE, 1986[d]	52
Controlled tunnel purgings:	
HYBLA FAIR, 1974	500
HYBLA GOLD, 1977	0.005
MINERS IRON, 1980	0.3
HURON LANDING, 1982	280
MINI JADE, 1983	1
MILL YARD, 1985	5.9
DIAMOND BEECH, 1985	1.1
MISTY RAIN, 1985	63
MIGHTY OAK, 1987	38,000
MISSION GHOST, 1987[d]	3
Operation releases:	
108 tests from 1980-1988	5,500
Total since BANEBERRY:	54,000
Major pre-1971 releases:	
PLATTE, 1962	1,900,000
EEL, 1962	1,900,000
DES MOINES, 1962	11,000,000
BANEBERRY, 1970	6,700,000
28 others from 1958-1970	3,800,000
Total:	25,300,000
Other releases for reference:	
NTS atmospheric testing, 1951-1963	12,000,000,000
1-kt aboveground explosion	10,000,000
Chernobyl (estimate)	81,000,000

a. Source: OTA (1989).
b. R+12 values apply only to containment failures; others are at time of release.
c. The Camphor failure includes 140 Ci from tunnel purging.
d. BODIE and MISSION GHOST also had drill-back releases.

gases from the tunnel. The major potential for release of radioactive materials to the atmosphere existed during these purging operations. The purging resulted in release of noble gases (^{85}Kr, ^{85m}Kr, ^{86}Kr, ^{131m}Xe, ^{133}Xe, ^{133m}Xe, and ^{135}Xe) and small quantities of ^{131}I and ^{133}I. A release during this phase of the operation was typically of the order of 100 Ci or less of noble gases, with microcurie or millicurie quantities of radionuclides. Reentry drilling produced dust that was removed from the reentry heading by the tunnel ventilation system. This dust contained fission and activation products produced by neutron activation of the HLOS pipe. These releases were in the millicurie range (DOE 1995b).

Unexpected Releases of Radioactivity – Although over 90% of all nuclear weapons tests occurred as predicted, the unexpected sometimes happened. In some cases, the failure resulted in the loss of experimental equipment or required the controlled ventilation of a tunnel system. In even more rare cases (3%), the failure resulted in the unintentional release of radioactive material to the atmosphere. The following information was taken from OTA (1989) unless otherwise noted.

1. BLANCA (October 30, 1958, horizontal tunnel test, 22 kt, radioactivity detected on the site). The test location was NTS U12e.05. Although BLANCA was detonated in a tunnel, it vented through the overburden into the atmosphere. Venting occurred at the edge of Rainer Mesa in Area 12. The ensuing cloud rose 580 ft above the mesa and drifted off in a westerly direction (DNA 1982b).

2. DES MOINES (June 13, 1962, horizontal tunnel test, 2.9 kt, radioactivity detected off the site). The test location was NTS U12j.01. Almost immediately after detonation, venting of radioactive effluents occurred at the surface, then from the vent hole, and finally through the portal. The release lasted approximately 5 min at a velocity of approximately 65 mph. The cloud direction was northeasterly over Queen City, Nevada (unpopulated). The maximum distance radiation was detected was at Ely, Nevada, 163 mi from the detonation site. The cause of the release was attributed to stemming failure around the device (DSWA 1997).

3. BANEBERRY (December 18, 1970, vertical shaft test, 10 kt, radioactivity detected off the site). The test location was NTS U8d. The BANEBERRY test resulted in a prompt massive venting. Radioactive material from BANEBERRY was tracked as far as the Canadian border. The cloud direction was northeasterly and moved over Nevada, Utah, and Wyoming. Another fraction moved toward California. The exact cause of the venting is unknown. The original explanation postulated the existence of an undetected water table, and the explanation assumed that the high temperatures of the explosion produced steam that vented to the surface. Later analysis, however, discredited this explanation and proposed an alternative scenario based on three geologic features of the BANEBERRY site: Water-saturated clay, buried scarp of hard rock, and a nearby fault. It is thought the energy of the explosion was unable to support the containment structure. The hard scarp strongly reflected the energy of the explosion, increasing the force, and the nearby fault provided a pathway along which gases could travel.

4. CAMPHOR (June 29, 1971, horizontal tunnel test, less than 20 kt, radioactivity detected only on the site). The test location was NTS U2g.10. The ground shock produced by the CAMPHOR test failed to close the HLOS pipe fully. After about 10 s, gases leaked through and eroded the stemming plug. As gases flowed through the stemming plug, pressure increased on the closure door behind the experiment. Gases leaked around the cable passageways and eroded a hole in the closure door. Pressure was then placed on the final door, which held but leaked slightly. The releases from the Cable Building lasted 30 min; the releases from the portal lasted 4 d.

5. DIAGONAL LINE (November 24, 1971, vertical shaft test, less than 20 kt, radioactivity detected off the site). The test location was NTS U11g. DIAGONAL LINE was conducted in the northern part of Frenchman Flat. It is speculated that carbonate material released CO_2 gas that forced radioactive material to leak to the surface. The cloud direction was southwesterly toward the Amargosa Desert in Nevada. DIAGONAL LINE was the last test detonated on Frenchman Flat.

6. RIOLA (September 25, 1980, vertical shaft test, less than 20 kt, radioactivity detected off the site). The test location was NTS U2eg. RIOLA exploded with only a small fraction of the expected yield. A surface collapse occurred and the failure of a containment plug resulted in the release of radioactive material.

7. AGRINI (March 31, 1984, vertical shaft test, less than 20 kt, radioactivity detected only on the site). The test location was NTS U2ev. The AGRINI test formed a deep subsidence crater 60 ft west of the emplacement hole. A small amount of radioactive material was pushed through the chimney by noncondensible gas pressure and was detected on the site.

8. MIDAS MYTH (February 15, 1984, horizontal tunnel test, less than 20 kt, no release of radioactive material). The test location was U12t.18. All of the radioactive material produced by the MIDAS MYTH test was contained within vessel 1, with no release of radioactivity to either the atmosphere or the tunnel system. Three hr after the test, however, the cavity collapsed and the chimney reached the surface, forming an unanticipated subsidence crater. Equipment trailers were damaged, personnel were injured, and one person later died due to physical circumstances. There was no radiation exposure.

9. MISTY RAIN (April 6, 1985, horizontal tunnel test, less than 20 kt, no unintentional release of radioactive material). The test location was U12n.17. MISTY RAIN is unusual in that it is the only tunnel test since 1970 that did not have three containment vessels. During the test, an early flow of energy down the HLOS pipe prevented the complete closure of the modified auxiliary closure doors. The doors overlapped, but stopped a couple of inches short of full closure. The tunnel and pipe seal (TAPS) door closed only 20% before the deformation from ground shock prevented it from closing. A small amount of radioactive material escaped down the pipe and then seeped into the bypass tunnel. The tunnel was later intentionally vented so equipment could be recovered.

10. MIGHTY OAK (April 10, 1986, horizontal tunnel test, less than 20 kt, no unintentional release of radioactive material). The test location was U12t.08. During the MIGHTY OAK test, the closure system near the working point was over-pressured and failed. The increased pressure and temperature from escaping gases caused both the MAC and the gas seal auxiliary closure to fail. The loss of the stemming plug near the working point left the tunnel an open pathway from the cavity. Temperatures and pressures on the closed TAPS door reached 2,000°F and 1,400 psi. After 50 s, the center part (approximately 6 ft in diameter) of the TAPS door yielded. With the closures removed, the stemming column squeezed out through the tunnel. Radioactive material leaked from vessel I and vessel II and into vessel III, where it was successfully contained. About $32 million of normally recoverable and reusable equipment was lost. Controlled purging of the tunnel began 12 d after the test and continued intermittently from April 22 to May 19, when weather conditions were favorable. A total of 36,000 Ci were released to the atmosphere during the period.

2.3.4 Nuclear Reactor Development Tests

A number of activities occurred at the NRDS in Area 25. From 1959 to 1973, the area was used for a series of open-air nuclear reactor, nuclear engine, and nuclear furnace tests and for the High Energy Neutron Reactions Experiment. Equipment and facilities remain from some of these activities, and there are some limited areas of contaminated soils. The total estimated inventory of radionuclides remaining in the soils in this area is about 1 Ci (DOE 1996a). The primary soil contaminants are enriched uranium, strontium, cesium, cobalt, and europium. Because of aging and weathering, these materials have become relatively fixed.

The goal of the nuclear rocket engine test program was to develop an operational nuclear-powered rocket for space travel, given that the crew could be adequately protected from radiation produced by the engine. Ramjet exhaust dispersed radioactive material at the core as cladding degraded during operation of the engine. In a somewhat parallel program, the development of a nuclear ramjet engine began in 1957 in Area 26. Because the ramjet was designed as an air-breathing engine, it was visualized as being restricted to relatively low altitudes. The final reactor test was of a nuclear furnace with a replaceable core in a reusable test bed designed to provide an inexpensive approach to testing advanced fuels in full-scale reactor environments. The nuclear furnace was successfully tested in 1972. Reactor-related tests ended in 1973.

Total releases by all rocket and ramjet engine tests amounted to about 834,000 Ci (DOE 1995a). As noted above the radionuclides ^{60}Co, ^{90}Sr/^{90}Y, ^{137}Cs, and ^{152}Eu are of primary concern for dose. When entering into the rocket test areas, personnel wore whole-body TLDs (REECo 1995). Attachment B contains additional information for NRDS activities. Table B-2 identifies off-site releases for nuclear-powered rocket and ramjet engines.

2.3.5 Radioactive Waste Management Sites

2.3.5.1 Crater Disposal – Area 3

DOE disposes of bulk low-level waste in seven selected Area 3 subsidence craters that collectively make up the Area 3 RWMS. This activity began in the mid-1960s when DOE began removing scrap tower steel, vehicles, and other large objects that had been subjected to atmospheric testing. From 1979 to 1990, large amounts of contaminated soil and other NTS debris were added to the craters (DOE 1996a).

Today, Area 3 is used for the disposal of bulk and packaged low-level waste from on- and offsite DOE-approved generators. Waste disposal cells at the Area 3 RWMS consisted of four subsidence craters (U-3ax, U-3bl, U-3ah, and U-3at) with areas between U-3ax and U-3bl and between U-3ah and U-3at excavated to make two oval landfill units. Conventional landfill methods are used to dispose of waste in each cell; each layer of waste is covered with 1 m (3 ft) of fill before additional waste materials are added. The inactive U-3ax/bl disposal cell contains low-level mixed waste. The U-3ah/at cell is used for low-level waste disposal; mixed waste is not accepted. Three additional subsidence craters (U-3bh, U-3bg, and U-3az) have been reserved for use as low-level waste cells. As of 1996, approximately 1,250 Ci had been disposed of in the Area 3 subsidence craters (DOE 1996a).

Because the low-level Area 3 RWMS is in a location where the surrounding surface soil has been contaminated by past nuclear tests, the resuspension of this soil by wind or vehicular activity results in the detection of above-background levels of plutonium in air samples collected inside and outside the perimeter fence (DOE 2002a).

Personnel working inside the RWMS wear whole-body TLDs and pocket dosimetry. Extremity monitoring and multiple dosimetry are required for some waste-handling work (REECo 1995).

2.3.5.2 Shallow Land Burial – Area 5 Low-Level

The Area 5 RWMS uses pits and trenches for shallow land burial of standard packaged low-level waste. The category of low-level waste includes material that is classified because of its physical shape or specific composition. Classification creates a need for the use of separate disposal units controlled with additional security measures.

In 1961, the Area 5 RWMS was established for the disposal of low-level waste, low-level mixed waste, and classified low-level waste from both on- and offsite generators. The waste area at the Area 5 site consists of 23 landfill cells (pits and trenches), 13 greater confinement disposal boreholes, as discussed below, and the transuranic waste storage pad (DOE 2002b). Approximately 500,000 Ci of low-level waste had been disposed of in Area 5 pits and trenches by 1996. High-specific-activity wastes were disposed of in the greater confinement disposal units.

The Area 5 RWMS is a diffuse source of radiological effluents. However, the only emission detected by the various types of samplers surrounding the site in 2001 and attributed to site operations was HTO in atmospheric moisture. Table 2-6 lists the estimated number of curies emitted from the source for 2001 (DOE 2002a). Personnel working inside the site wear whole-body TLDs, track-etch dosimeters (TEDs), and pocket dosimeters. Extremity monitoring is required for some waste-handling work (REECo 1995).

Table 2-6. Estimated curies emitted from the source for 2001.[a]

Event	Estimated Ci
RWMS No. 4	6.5
SEDAN crater	13
E Tunnel pond	11
SCHOONER crater	400

a. Source: DOE (2002a).

2.3.5.3 Greater Confinement Disposal – Area 5

NTS adopted greater confinement burial [21 to 40 m (70 to 120 ft) deep] for wastes that are not appropriate for near-surface disposal due to their radioactive exposure levels. Material was disposed of from 1984 to 1989. The specific types of waste include certain high-specific-activity, low-level waste (for example, fuel rod claddings and sealed sources), TRU waste, and some classified material. The developed waste area in the Area 5 RWMS includes 13 greater confinement disposal boreholes.

As of 1996, approximately 9.3×10^6 Ci of high-specific-activity waste, primarily tritium, had been disposed of in greater confinement disposal units in Area 5 (DOE 1996a).

2.3.6 Laboratories

Radiological analyses were conducted in laboratories in Building 652 in Mercury and Building CP-95A, Building CP-50, and the Device Assembly Facility in Area 6. Because these facilities process environmental samples, very little radioactivity passes through them. However, there is potential for discharges of some radionuclides to the atmosphere from the hood ventilation system during sample processing, particularly of spiked samples, or from loss of radioactive standards in liquid or gaseous form. In the past, evaporation and spills from samples containing HTO, radioiodines, or noble gases were estimated conservatively by assuming all such materials were released even though they were not. In 2001, only actual emissions were reported; 5.6 Ci of tritium gas were used periodically during the year at Area 6 CP-50 to calibrate analytical equipment (DOE 2002a).

Following the closure of the Analytical Services Laboratory in Building 650, all the standards, check sources, and tracer solutions were stored pending proper disposal of all items. Contamination can still be found in the fume hoods. An inventory of standards, check sources, and tracer materials indicates that three of them are volatile and could become a source of air emissions (DOE 2002a):

^{3}H – 3.0×10^{-4} Ci
^{85}Kr – 8.7×10^{-2} Ci
^{129}I – 5.4×10^{-7} Ci

Table 2-4 lists the 1996 estimates.

The Los Alamos National Laboratory maintained standards of radioactivity containing ^{133}Xe, ^{131}I, and ^{3}H in Building 701 at Mercury. Due to the test moratorium that began in 1992, the need for standards was reduced (DOE 2002a).

Sealed and uncontained radioactive sources are used for radiochemistry and sample-counting operations at the NTS. These low-level radioactive sources used as tracers and for instrument calibration present very little external dose potential. Laboratory personnel wear whole-body monitoring TLDs (REECo 1995).

2.3.7 Radiograph Operations

Sealed radioactive sources are used for radiography at the NTS. The potential for external exposure is most likely to occur when the source is removed from the shield for radiography. The radionuclide currently used for radiography at the NTS is ^{192}Ir, although ^{60}Co can be used. Radiographers are required to wear whole-body TLDs, pocket dosimeters, and electronic alarming dosimeters (REECo 1995).

2.3.8 Well-Logging Operations

Sealed radioactive sources are a potential source of external exposure during well-logging operations at the NTS. Well logging is used to characterize drill holes and water movement. The radionuclides ^{60}Co, ^{131}I, ^{137}Cs, ^{226}Ra, ^{228}Th, ^{241}Am, and ^{252}Cf are used for well logging, and are of concern for dose. Well loggers routinely wear whole-body TLDs and pocket dosimeters when working with sources and sometimes wear extremity dosimeters. They also wear TEDs when working with neutron sources (REECo 1995).

2.3.9 Treatability Test Facility

The Treatability Test Facility is a pilot project to bench-test technologies for decontamination of soils that contain TRU materials. Techniques used to separate the radionuclides from the soil include both gravimetric separation and separation based on other properties of the material. The concentrations of radionuclides in the soil are unlikely to exceed a few picocuries per gram of soil. Therefore, external exposures to personnel are not likely to represent any unusual exposure control requirements (REECo 1995).

2.3.10 Decontamination Facility

Equipment, materials, PPC, and devices used in nuclear weapons testing operations can become contaminated with radioactive material. These items are decontaminated on location or are transported to the decontamination facility in Area 6 where the contamination is removed from the material or equipment. Decontamination methods include washing with high-pressure water, submersion in chemical dip tanks, and use of other nonhazardous material solvents. Many different radionuclides can be present at the decontamination facility because contaminated items can come from any operations at the NTS. Decontamination of material is normally delayed until after decay of short-lived radionuclides (REECo 1995).

2.3.11 Radiation Instrument Calibration Facilities

Sealed radioactive sources are used to calibrate instruments that detect radioactive materials. The sources are controlled and leak-tested as required by standard DOE radiological control practices. The potential for external exposure comes from the use of the sources during calibration and testing operations. In general, the sources are operated remotely, and personnel are removed from the calibration range during source exposure periods. The radionuclides ^{60}Co, ^{90}Sr, ^{90}Y, ^{137}Cs, ^{226}Ra, ^{227,228}Th, ^{241}Am, and PuBe (neutron) could contribute to the external dose at these facilities. The routine method of monitoring the external radiation exposure at the instrument calibration facilities is with the whole-body TLD and pocket dosimeter. Neutron TEDs are required for personnel using neutron sources (REECo 1995).

2.3.12 Radioactive Source Storage Areas

Sealed radioactive sources, in addition to the radiography, well-logging, and instrument calibration sources are stored in a few buildings at the NTS. These sources belong to other organizations, and NTS stores them for future use. Because only a few are currently in use, the potential for external exposure is of very short duration during source inventory (REECo 1995).

2.3.13 Nuclear Explosive Assembly and Device Assembly Facility

The Nuclear Explosive Assembly Facility (NEAF) was built for the assembly of nuclear weapons components. The DAF was completed in 1992 and was built for future assembly or disassembly of nuclear weapon components. The potential external exposure at these facilities is high because significant quantities of radionuclides of concern for external exposure could be present. When the NEAF is in operation, personnel wear whole-body monitoring TLDs, (track-etch dosimeters (TEDs), and extremity dosimeters when appropriate.

2.4 RADIOLOGICAL ACCESS CONTROLS

NTS training material from the 1950s included the following basic radiation protection rules:

- Personnel metering equipment will be worn at all times.
- Appropriate protective clothing and equipment will be worn when working in contaminated areas or with contaminated material.
- All radioactive material will be monitored by the Radiological Safety Division before shipped from the NTS.
- Personnel monitoring will be performed following exit from any contaminated area.
- Eating or storing of food or beverages will not be allowed in a contaminated area.
- Smoking is prohibited in contaminated areas.

Personnel exposures were minimized by the basic principles of time, distance, and shielding with access controls developed to support these rules and principles. RADEX areas were defined, a limited RADEX area required personnel protective clothing and monitoring support, and contaminated areas required access permits issued by Rad-Safe. Areas with radioactive materials or contamination were posted and access to such areas was controlled. Radiological Work Permits were issued to

establish controls for work activities within radiological areas. Permits included a review of the radiological conditions, personnel dosimetry requirements, training and protective equipment requirements for entry, allowable stay times, and the level of Rad-Safe coverage required. Training programs were developed at NTS to include General Employee Radiological Training, Radiological Worker I, Radiation Worker II, and Radiological Control Technicians (monitors).

Initially, the limits were those published in the National Bureau of Standards (NBS) Handbook # 59, Permissible Dose from External Sources of Ionizing Radiation (1954) and NBS Handbook # 52, Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water (1953). Following the NBS Handbooks, various other programmatic documents governed the radiation protection program at NTS (e.g., AEC 1961, DOE 1988, and REECo 1994). While the limits have changed over the years, the basic principles for posting areas, issuing work permits, completing training programs, and use of personal protective equipment have remained. The radiation protection program at the NTS is currently regulated under 10 CFR 835. Additional details for radiological access controls are found in the environmental, internal, and external sections of this site profile.

2.5 ATTRIBUTIONS AND ANNOTATIONS

All information requiring identification was addressed via references integrated into the reference section of this document.

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GLOSSARY (DOE 2000a)

atmospheric
A test conducted aboveground or above water (i.e., in the open air). The last atmospheric test at NTS was in 1962.

borehole number
The alpha-numeric designation is given to the nuclear weapon test or detonation. The uppercase alpha designator refers to the type of location: S = surface, U = underground. The numeric designator refers to the geographical area of the Nevada Test Site. The remaining letters refer to the sequential ordering of the test or detonation. In the case of most atmospheric tests, only the geographical area of the Nevada Test Site is given.

cementback
Operation in which the drill hole is sealed with a plug and cemented to the surface after a shaft drill back.

containment failure
Unintentional release of radioactive material to the atmosphere due to a failure of the containment system. Called *venting* if it is a prompt, massive release; or *seep* if it is a slow, small release that occurs soon after the test.

controllable area
An area in which remedial actions are feasible. The DOE criteria for a controllable area are "… areas where trained rad-safe monitors are available, where communications are effective (where the exposure of each individual can be documented), where people can be expected to comply with recommended remedial actions, and where remedial actions against uptake of radionuclides in the food chain are practicable." This equates to a zone of approximately 125 mi from the test CP.

controlled release
A planned, filtered release performed to reduce airborne radiation levels in the tunnel working environment.

controlled tunnel purging
An intentional release to allow recovery of experimental data and equipment or reuse of part of the tunnel system.

crater
A nuclear device placed shallowly enough underground to produce a throw-out of earth when exploded.

detonation
A single nuclear device explosion; a test or test series consists of one or more detonations.

drill back
Directional drilling operation performed after a shaft test to sample fission product materials in the test cavity. Drill back operations after a shaft test were often performed within 1 or 2 d of the detonation.

gas sampling
Operation usually performed after test activities have ceased to determine levels of noble gases present.

Gravel Gertie
A round room with 2-ft-thick concrete walls and a staging area with two staging bays connected to the round room. Tests were conducted in the Gravel Gertie with HE and uranium devices to measure fallout. Gravel Gerties are located in A-5 (GMX) and A-6 (DAF).

greater confinement boreholes
From 1984 to 1989, DOE conducted intermediate-depth disposal operations at the NTS. These operations emplaced high-specific-activity, low-level radioactive wastes and limited quantities of classified TRU wastes in greater confinement boreholes. The boreholes are about 3 m (10 ft) in diameter and 36 m (120 ft) deep. The bottom 15 m (50 ft) of each borehole was used for waste emplacement and the upper 21 m (70 ft) was backfilled with native alluvium.

gross beta
Measure of the total beta activity.

h
A code that indicates *Hour Detonation time* (zero hour), which is the time a device was detonated.

kiloton (kt)
In relation to a nuclear detonation, an amount of energy equivalent to the explosive power of 1,000 tons of TNT.

late-time seeps
Small releases that occur days or weeks after a test when gases diffuse through pore spaces in the overlying rock and are drawn to the surface by decreases in atmospheric pressure. From DOE (1996b): A slow release of gases from test detonation sites that could exist from a few hours to even weeks after all other operations in the area have ceased.

megaton (Mt)
In relation to a nuclear detonation, an amount of energy equivalent to the explosive power of 1 million tons of TNT.

operational release
Small consequential releases that occur when core or gas samples are collected or when the drill back hole is sealed.

PLOWSHARE Program
Application of nuclear explosives to develop peaceful uses for atomic energy at NTS and other locations. REECo provided support to the program, including offsite locations. The PLOWSHARE tests were:

1. GNOME 12/10/61 Carlsbad, NM (shaft)
2. SEDAN 07/06/62 NTS (crater)
3. ANACOSTIA 11/27/62 NTS (shaft)
4. KAWEAH 02/21/63 NTS (shaft)
5. TORNILLO 10/11/63 NTS (shaft)
6. KLICKITAT 02/20/64 NTS (shaft)
7. ACE 06/11/64 NTS (shaft)
8. DUB 06/30/64 NTS (shaft)

9. PAR 10/09/64 NTS (shaft)
10. HANDCAR 11/05/64 NTS (shaft)
11. SULKY 12/18/64 NTS (shaft)
12. PALANQUIN 04/14/65 NTS (crater)
13. TEMPLAR 03/24/66 NTS (shaft)
14. VULCAN 06/25/66 NTS (shaft)
15. SAXON 07/28/66 NTS (shaft)
16. SIMMS 11/05/66 NTS (shaft)
17. SWITCH 06/22/67 NTS (shaft)
18. MARVEL 09/21/67 NTS (shaft)
19. GASBUGGY 12/10/67 Farmington, NM (shaft)
20. CABRIOLET 01/26/68 NTS (crater)
21. BUGGY-A to E 03/12/68 NTS (crater)
22. STODDARD 09/17/68 NTS (shaft)
23. SCHOONER 12/08/68 NTS (crater)
24. RULISON 09/10/69 Grand Valley, CO (shaft)
25. FLASK-GREEN, YELLOW, and Red 05/26/70 NTS (shaft)
26. MINIATA 07/08/71 NTS (shaft)

Radex areas

During the testing era in a Full Radex Area, radiological contamination was greater than or equal to 100 mR/hr (gamma) measured 3 ft from the ground (more than 1×10^4 cpm/55 cm^2) (alpha surface contamination measured by portable alpha survey meter). No one was allowed into a Full Radex Area unless accompanied by a certified monitor who remained with or near the personnel during the entire period. In a Limited Radex Area, radiological contamination is greater than or equal to 10 mR/hr but less than 100 mR/hr (gamma) measured 3 ft from the ground (greater than or equal to 1×10^3 and less than or equal to 1×10^4 cpm/55 cm^2) alpha surface contamination measured by portable alpha survey meter). No one was allowed into a Limited Radex Area unless accompanied by a certified monitor who would initially survey the area and return periodically to check radiological conditions.

reentry

In the context of NTS operations over the entire period of weapons testing, the first entry into an area or tunnel following a nuclear detonation (which usually occurs as soon as safety limitations will permit). Reentry to retrieve experimental data was under the control and responsibility of the Technical Director assigned by the Test Manager and was performed by workers previously identified in the test documentation. Reentry does not cover cleanup operations or preparation for a detonation. Tunnel reentry and mineback operations usually took place within days or weeks of an underground test.

safety experiment

Experiment designed to confirm a nuclear explosion will not occur in case of an accidental detonation of the explosive associated with the device.

seep

Uncontrolled slow release of radioactive material with little or no energy. Seeps are not visible and can be detected only by radiation monitoring.

shaft test

A nuclear device exploded at the bottom of a drilled or mined vertical hole. The hole depth and diameter were dictated by the projected yield and diagnostics. Typical hole depths ranged from 600 to 2200 ft and typical hole diameters ranged from four to 10 ft.

Special Nuclear Material

Plutonium or enriched uranium.

stemming
Placement of materials such as grout, magnetite, bentonite, sand, and other materials to contain the nuclear explosion in a tunnel or shaft.

surface test
A nuclear device placed on or close to the Earth's surface.

test
A test is defined in the Threshold Test Ban Treaty as either a single underground nuclear explosion at a site or two or more underground nuclear explosions within a circle having a diameter of 2 km and within 0.1 s.

ton
In relation to a nuclear detonation, an amount of energy equivalent to the explosive force of 1 ton (2,000 lb.) of TNT.

tower test
A nuclear device mounted at the top of a steel or wooden tower and exploded in the atmosphere.

Trinity glass debris
Vitrified material created during a test that contains radioactive material. In general, there is no removable radioactive contamination, but the material can represent an external hazard. At NTS, this material usually looks like a rough piece of black charcoal or perhaps like the outcrop of a lava flow; it is usually *not* glassy in appearance.

tunnel test
A nuclear device exploded at the end of a long horizontal drift mined into a mountain or mesa in a way that places the burst point deep within the earth.

uncontrolled release
A spontaneous release occurring after a test but before post-test drilling operations commence. For DOE (1996b), this term is used when referring to tunnel tests.

underground test
Underground nuclear test conducted in a tunnel or at the bottom of a drilled hole or shaft. Some underground nuclear tests were not designed to contain all radioactivity (e.g., cratering tests or safety experiments).

venting
Prompt, massive, uncontrolled releases of radioactive material. Ventings are characterized as active releases under pressure, such as when radioactive material is driven out of the ground by steam or gas.

weapons effects
A nuclear test to evaluate the civil or military effects of a nuclear detonation on various targets such as military hardware.

weapons related
A nuclear detonation conducted for the purpose of testing a nuclear device intended for a specific type of weapon system.

yield

The total effective energy released in a nuclear explosion. It is usually expressed in terms of equivalent tonnage of TNT required to produce the same energy release in an explosion.

ATTACHMENT A
TESTS BY YEAR, TYPE, AND LOCATION

Table A-1. Tests by year, type, and location.

YEAR	TYPE	A-1*	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9	A-10	A-11	A-12*	A-15*	A-16*	A-18	A-19	A-20	A-30	TOTAL
1951	Atmospheric	-	-	-	-	5	-	5	-	1	-	-	-	-	-	-	-	-	-	**11**
	UG-Crater	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	**1**
1952	Atmospheric	1	2	1	1	1	-	3	-	-	-	-	-	-	-	-	-	-	-	**9**
1953	Atmospheric	1	-	2	2	2	-	4	-	-	-	-	-	-	-	-	-	-	-	**11**
1955	Atmospheric	2	1	2	1	1	-	4	-	2	-	3	-	-	-	-	-	-	-	**16**
	UG-Crater	-	-	-	-	-	-	-	-	-	1		-	-	-	-	-	-	-	**1**
1956	Atmospheric	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	**1**
1957	Atmospheric	1	4	5	1	1	-	6	-	7	1	-	-	-	-	-	-	-	-	**26**
	UG-Shaft	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**3**
	UG-Tunnel (B,C)	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	**2**
1958	Atmospheric	-	-	4	-	3	-	9	3	5	-	-	-	-	-	-	-	-	-	**24**
	UG-Shaft	-	-	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**6**
	UG-Tunnel (B,C,D,E,F)	-	-	-	-	-	-	-	-	-	-	-	9	-	-	-	-	-	-	**9**
1961	UG-Shaft	-	-	5	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	**6**
	UG-Tunnel (B,E)	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	**3**
1962	Atmospheric	-	-	-	-	1	-	-	-	-	-	-	-	-	-	2	-	-	-	**3**
	UG-Shaft	-	1	26	-	-	-	-	-	23	1	-	-	1	-	-	-	-	-	**52**
	UG-Tunnel (12G,12J,12K,16A)	-	-	-	-	-	-	-	-	-	-	-	3	-	1	-	-	-	-	**4**
	UG-Crater	-	-	-	-	-	-	-	-	-	1	-	-	-	-	2	-	-	-	**3**
1963	UG-Shaft	-	7	20	-	-	-	-	-	14	1	-	1	-	-	-	-	-	-	**43**
	UG-Tunnel (B)	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	**1**
1964	UG-Shaft	-	7	18	1	-	-	2	-	13	7	-	-	-	-	1	-	-	-	**49**
1965	UG-Shaft	-	7	12		3		2		10	1		-	-	-	-	-	1	-	**36**
	UG-Tunnel (15E,16A)	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	**2**
	UG-Crater	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	**1**
1966	UG-Shaft	-	8	13	-	1	-	5	1	4	6	2	-	-	-	-	2	3	-	**45**
	UG-Tunnel (12G,15A,16A)	-	-	-	-	-	-	-	-	-	-	-	1	1	1	-	-	-	-	**3**
1967	UG-Shaft	-	8	13	1	-	-	3	-	1	11	-	-	-	-	-	1	1	-	**39**
	UG-Tunnel (G,N)	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	**2**
1968	UG-Shaft	-	17	21	-	1	1	-	-	5	8	1	-	-	-	-	4	3	-	**61**
	UG-Tunnel (12E,12N,16A)	-	-	-	-	-	-	-	-	-	-	-	2	-	1	-	-	-	-	**3**
	UG-Crater	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	5	**7**
1969	UG-Shaft	-	20	20	-	-	-	4	-	4	4	1	1	-	-	-	-	3	-	**57**
	UG-Tunnel (E,G)	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	**2**
1970	UG-Shaft	-	10	16	-	-	-	3	2	19	3	-	-	-	-	-	-	1	-	**54**
	UG-Tunnel (12E,12N,12T,16A)	-	-	-	-	-	-	-	-	-	-	-	3	-	1	-	-	-	-	**4**
1971	UG-Shaft	1	5	12	-	-	-	-	-	4	2	1	-	-	-	-	-	-	-	**25**
	UG-Tunnel (12G,16A)	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-	**2**

ATTACHMENT A
TESTS BY YEAR, TYPE, AND LOCATION

YEAR	TYPE	A-1*	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9	A-10	A-11	A-12*	A-15*	A-16*	A-18	A-19	A-20	A-30	TOTAL
1972	UG-Shaft	-	8	12	-	-	-	2	-	5	2	-	-	-	-	-	-	-	-	**29**
	UG-Tunnel (N,T)	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	**2**
1973	UG-Shaft	-	6	8	-	-	-	2	-	2	2	-	-	-	-	-	1	-	-	**21**
	UG-Tunnel (E,N)	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	**2**
1974	UG-Shaft	-	8	9	3	-	-	1	-	-	3	-	-	-	-	-	-	-	-	**24**
	UG-Tunnel (N)	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	**2**
1975	UG-Shaft	-	4	4	1	-	-	2	-	2	2	-	-	-	-	-	3	3	-	**21**
	UG-Tunnel (E,T)	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	**2**
1976	UG-Shaft	-	5	2	1	-	-	5	-	-	1	-	-	-	-	-	3	3	-	**20**
	UG-Tunnel (N)	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	**1**
1977	UG-Shaft	-	5	8	2			5		2	2	-	-	-	-	-	-	-	-	**24**
	UG-Tunnel (E)	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	**1**
1978	UG-Shaft	-	3	2	3	-	-	4	2	1	1	-	-	-	-	-	4	1	-	**21**
	UG-Tunnel (N)	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	**1**
1979	UG-Shaft	-	4	4	3	-	-	2	-	-	1	-	-	-	-	-	1	1	-	**16**
1980	UG-Shaft	-	3	5	-	-	-	2	1	1	-	-	-	-	-	-	1	3	-	**16**
	UG-Tunnel (N)	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	**1**
1981	UG-Shaft	-	3	3	2	-	-	4	2	1	1	-	-	-	-	-	1	-	-	**17**
1982	UG-Shaft	-	1	4	3	-	-	2	1	1	1	-	-	-	-	-	2	2	-	**17**
	UG-Tunnel (N)	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	**2**
1983	UG-Shaft	-	7	4	1	-	-	2	-	1	1	-	-	-	-	-	1	1	-	**18**
	UG-Tunnel (N)	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	**2**
1984	UG-Shaft	-	4	5	4	-	-	2	-	1	2	-	-	-	-	-	1	2	-	**21**
	UG-Tunnel (T)	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	**1**
1985	UG-Shaft	-	1	4	2	-	-	2	1	-	-	-	-	-	-	-	1	3	-	**14**
	UG-Tunnel (N)	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	**3**
1986	UG-Shaft	-	2	2	2	-	-	1	-	-	-	-	-	-	-	-	3	4	-	**14**
	UG-Tunnel (T)	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	**1**
1987	UG-Shaft	-	1	4	-	-	1	1	-	-	4	-	-	-	-	-	1	2	-	**14**
	UG-Tunnel (N,P,T)	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	**3**
1988	UG-Shaft	-	3	3	2	-	3	-	2	-	-	-	-	-	-	-	2	2	-	**17**
	UG-Tunnel (N)	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	**1**
1989	UG-Shaft	-	3	2	4	-	-	2	-	-	-	-	-	-	-	-	1	3	-	**15**
	UG-Tunnel (P)	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	**1**
1990	UG-Shaft	2	1	1	-	-	1	-	-	-	-	-	-	-	-	-	1	2	-	**8**
	UG-Tunnel (N)	1	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	**3**
1991	UG-Shaft	-	-	1	4	-	-	1	-	-	-	-	-	-	-	-	1	2	-	**9**
	UG-Tunnel (P)	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	**1**
1992	UG-Shaft	-	-	2	-	-	-	-	-	3	-	-	-	-	-	-	1	-	-	**6**
	UG-Tunnel (N,P)	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	**2**
	TOTAL	**9**	**169**	**288**	**44**	**19**	**6**	**92**	**15**	**133**	**71**	**9**	**62**	**3**	**6**	**5**	**36**	**49**	**5**	**1,021**

ATTACHMENT A
TESTS BY YEAR, TYPE, AND LOCATION
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Table A-2. NTS testing intervals.

Year	Number of NTS test intervals	Maximum interval between tests	Minimum interval between tests	Average interval between tests	Standard deviation	Mode	Median
1951	11	258	1	28	76	4	4
1952	8	124	4	24	41	7	8
1953	11	285	5	33	84	7	7
1954	No NTS tests	N/A	N/A	N/A	N/A	N/A	N/A
1955	16	624	1	55	157	6	6
1956	1	74	74	74	N/A	N/A	74
1957	30	496	1	23	90	3	4
1958	26	182	1	13	38	2	2
1959	No NTS tests	N/A	N/A	N/A	N/A	N/A	N/A
1960	No NTS tests	N/A	N/A	N/A	N/A	N/A	N/A
1961	9	1051	1	0	0	0	0
1962	58	28	1	6	5	6	6
1963	32	56	1	12	12	8	8
1964	42	32	1	9	9	7	7
1965	35	56	1	10	11	1	7
1966	44	31	1	8	8	6	6
1967	37	29	1	10	8	6	7
1968	47	34	1	8	6	5	7
1969	31	34	1	11	7	8	8
1970	29	109	1	13	20	1	7
1971	19	180	1	19	40	1	7
1972	22	43	2	16	11	22	14
1973	18	96	1	18	23	15	14
1974	22	48	1	16	11	11	15
1975	20	72	1	18	19	7	11
1976	18	68	2	21	19	8	13
1977	17	56	3	21	15	8	20
1978	17	61	5	22	15	14	15
1979	16	64	2	23	19	15	17
1980	16	76	6	23	19	6	17
1981	17	64	1	21	15	20	20
1982	16	64	1	22	18	8	18
1983	17	71	1	22	22	8	14
1984	19	46	1	19	12	15	15
1985	16	85	3	23	21	41	17
1986	15	84	2	23	20	29	19
1987	15	52	1	22	18	8	16
1988	14	75	1	27	21	N/A	24
1989	12	79	5	26	24	N/A	15
1990	9	80	7	37	26	N/A	33
1991	8	121	5	47	45	N/A	30
1992	6	121	4	50	46	N/A	43

ATTACHMENT B
NUCLEAR ROCKET AND RAMJET ENGINE TESTS

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B.1 Introduction

Nuclear rocket and ramjet engine tests were conducted at the Nuclear Rocket Development Station (NRDS, now the Nevada Research and Development Area) in Area 25 and Area 26, about 80 mi northwest of Las Vegas, Nevada. One section of the Jackass Flats Area was designated as the 400 Area for Los Alamos Scientific Laboratory (LASL; now known as LANL) operations associated with the ROVER and the Nuclear Engine for Rocket Vehicle Application (NERVA) tests, while the other was designated as the 401 Area for Lawrence Radiation Laboratory (LRL) operations associated with the PLUTO Ramjet Engine Tests (Figure B-1). The ROVER nuclear rocket test program began with Project KIWI—a reactor test on July 1, 1959—and culminated with the Nuclear Furnace (NF-1) test June 1 1972. In January 1973, the ROVER nuclear engine project was terminated due to changing priorities even though it was judged a technical success.

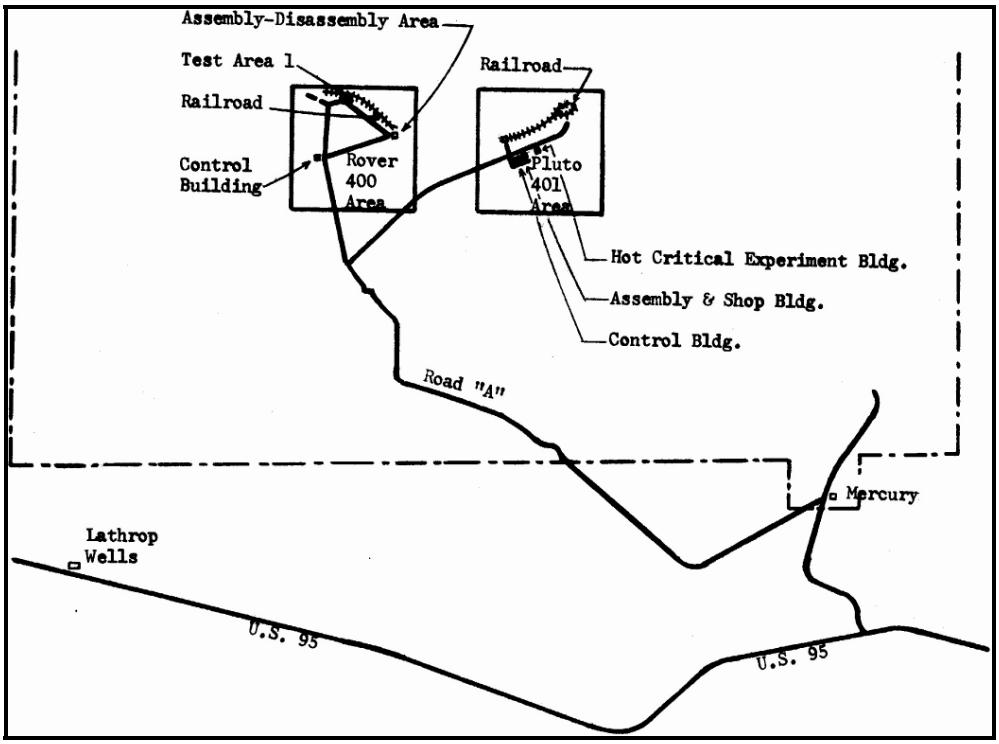

Figure B-1. Details of nuclear propulsion sites (AEC 1958).

B.2 Area 400 Major Facilities

The 400 Area had three major groups of buildings and facilities with supporting roads, water wells and lines, smaller buildings, railroad tracks, electric power supply lines and transformers, and a tank farm (Figure B-2). The three major building groups were (AEC 1958):

Control Building Area – The reinforced concrete Control building, with a floor area of about 9,700 ft^2, housed the controls and instruments for operating and recording tests performed in the Test Cell area. Other buildings in the same area included a generator station for standby power, an administration building, two warehouses, a cafeteria, and a small guardhouse. These were constructed of steel and aluminum components so they could be moved elsewhere if needed. They were built by J. A. Tiberti Construction Company of Las Vegas.

Maintenance Assembly and Disassembly Building – This massive concrete structure has 30,000 ft^2 of floor area where work was performed assembling and disassembling reactors and their components before and after tests. A small office and warehouse building and a guard station are

ATTACHMENT B
NUCLEAR ROCKET AND RAMJET ENGINE TESTS

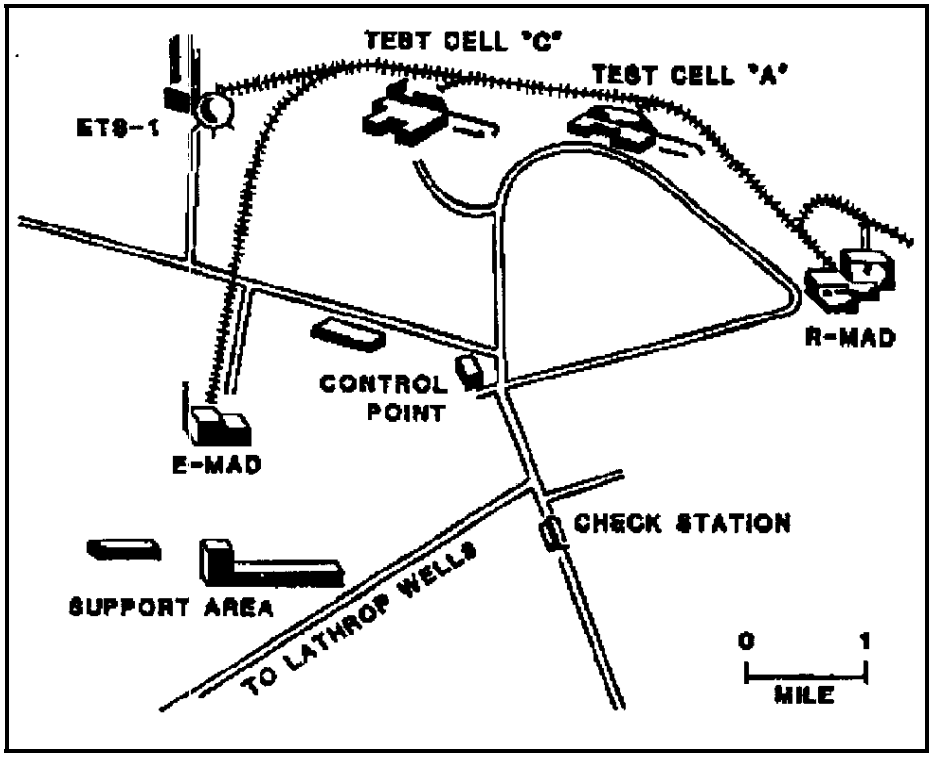

Figure B-2. Nuclear Rocket Development Station (LANL 1986).

nearby. Sierra Construction Company, Inc. of Las Vegas was the contractor for the building. J. A. Tiberti Construction was contractor for a hot cell addition.

Test Cell Area – The Test Cell (A and C, later ETS-1) was constructed of reinforced concrete with a floor area of 1,680 ft^2. Reactors and reactor systems to be tested were housed in the cell but were mounted on a railcar backed up to the cell. The reactor was connected to receiving instruments inside the Test Cell that transmitted needed information to recording instruments in the Control building about 2 mi away. The railcar bearing the reactor was moved by a remotely controlled locomotive over a rail line to and from the MAD building. In addition, there were water storage and other facilities constructed in the Test Cell area. The contractor for the Test Cell and tank farm was the Petroleum Combustion and Engineering Company of Los Angeles. Pittsburgh-Des Moines Steel Company of El Monte, California, was the contractor for the water storage tanks.

Other contractors were as follows:

1. Mercury-Jackass Flats access road, Fred Galante and L. B. Wells of Visalia, California.

2. Water supply wells, Perry Brothers Drilling Company, Flagstaff, Arizona.

3. Roads within the area, J. L. Croft and Sons, Inc., Saugus, California.

4. Water distribution system, Hansen Plumbing and Heating Company, San Bernardino, California.

5. Railroad facilities, A. D. Schader Company, San Francisco, California.

6. Technical Services building, J. A. Tiberti Construction Company, Las Vegas, Nevada.

7. Road H, J. L. Croft and Sons, Saugus, California.

B.3 ROVER

In 1955, the United States embarked on a program to develop a nuclear rocket engine under joint sponsorship of the U.S. Air Force and AEC. The program known as Project ROVER was initiated at LASL. LASL was responsible for developing reactor technology for the Project ROVER nuclear rocket engine based on the concept of a solid hydrogen-cooled core in which the existing gas expanded through a rocket nozzle and discharged into space. The motivation for the development of such a nuclear rocket engine was that it could provide about twice the specific impulse (thrust) of the best chemical rockets corresponding to a reduction of a factor of five in the ratio of take-off mass to final mass at Earth escape velocity. Approximately 120 of the LASL staff worked full time on Project ROVER.

The U.S. Air Force was responsible for the non-nuclear portion of the project. The other key players were the Aerojet-General Corporation, the prime contractor to develop the complete rocket engine system, and the Astronuclear Laboratory of the Westinghouse Electric Corporation, the principal subcontractor to LASL, which was given the role of establishing a basic reactor design and of leading the effort to develop nuclear fuels for the project.

The engine development test program was part of the technology demonstration. Its objectives were to test non-nuclear system components, determine system characteristics during start-up, full-power, and shut-down conditions, evaluate control concepts, and qualify the engine test-stand operations in a downward-firing configuration with simulated altitude and space conditions. These objectives were met or exceeded in the NERVA Reactor Experiment (NRX)/Engine Systems Test (EST) and Experimental Engine (XE) programs. XE, a prototype flight engine system, which consisted of a flight-type reactor with non-nuclear flight components, was tested in a simulated space environment, over some 28 starts and restarts. Figure B-3 shows the chronology of ROVER Program tests. Figures B-4 and B-5 are schematic representations of the reactors for ground-based systems tests and nuclear rocket engine configurations, respectively.

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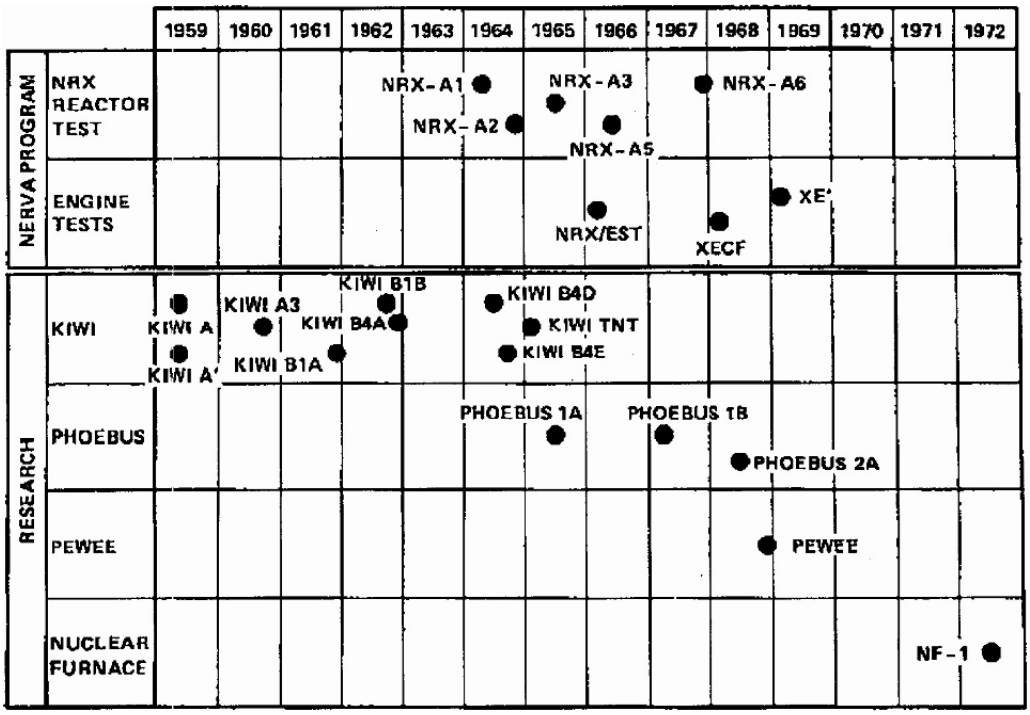

Figure B-3. Chronology of major nuclear rocket tests (LANL 1986).

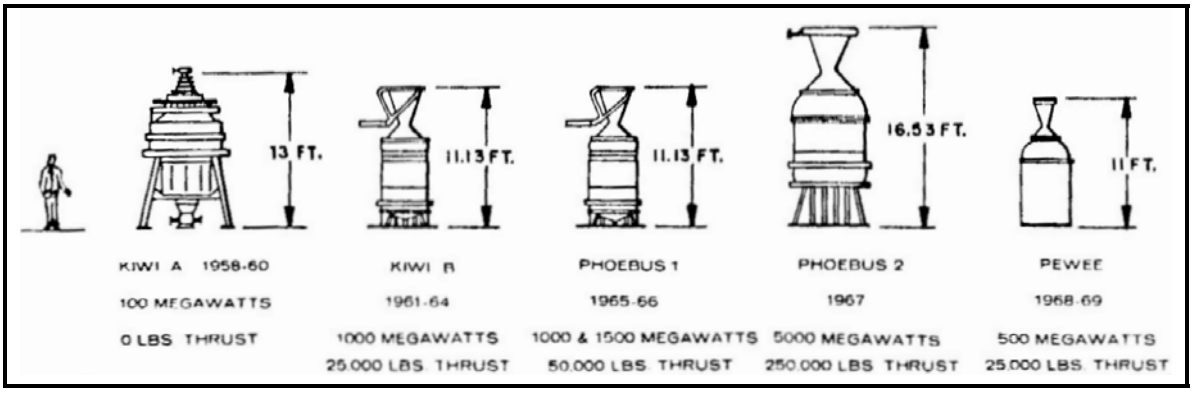

Figure B-4. Reactors for ground-based systems tests (NASA 1991).

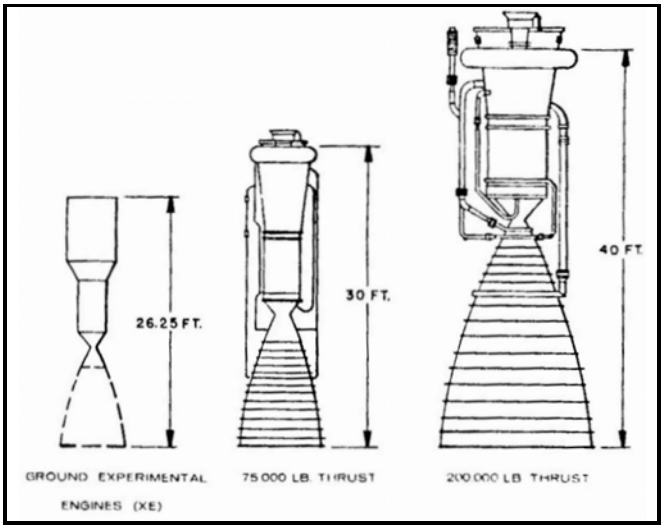

Figure B-5. Nuclear rocket engine configurations (NASA 1991).

In 1960, the AEC and NASA formed the Space Nuclear Propulsion Office (later the Space Nuclear Systems Office) to administer the NERVA program to develop an operational nuclear rocket engine. Such a nuclear-powered rocket was visualized for use in space travel, given that the crew could be adequately protected from radiation produced by the engine. The ROVER program consisted of the NRX and EST programs; the Research Reactor tests program consisted of the KIWI, PHOEBUS, PEWEE, and the Nuclear Furnace tests.

B.3.1 Project Reactor and Engine Tests

A series of reactor and engine tests were conducted in the 400 Area of NTS where major testing facilities were built for the ROVER program (Figure B-1). These included an assembly and disassembly facility and two testing facilities for the research and engine reactors. The test series was initiated with a family of research reactors named KIWI (for the flightless bird of New Zealand). The program objectives were first to demonstrate the proof of principle, then to establish the basic reactor technology and to develop defensible design concepts. These reactors were the first to demonstrate the use of high-temperature fuels and to operate with liquid hydrogen. These tests led to the NRX series of developmental reactors from 1964 to 1969.

KIWI Reactor Tests

July 1, 1959: The first reactor test, KIWI-A, was conducted successfully at the Nevada Test Site. The reactor operated for 5 min at 70 MW and provided important design and materials information. The fuel was hot enough (2,683°K) to melt carbide fuel particles. Vibrations in the core produced structural damage in the graphite elements. The reactor employed uncoated, UO_2-loaded, plate-type fuel elements and was cooled with gaseous hydrogen.

July 8, 1960: KIWI-A PRIME was tested for nearly 6 min at 85 MW to demonstrate an improved fuel element design. The reactor used short, cylindrical, UO_2-loaded fuel elements in graphite modules.

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October 10, 1960: KIWI-A3 reactor operated in excess of 5 min at 100 MW. The fuel was similar to that used in the previous test. This experiment was the third and last in the KIWI-A series of proof-of-principal tests conducted by LASL.

December 7, 1961: KIWI-B1A reactor, first of a new series, was tested by LASL. KIWI-B reactors were designed for 1,100 MW and used reflector control and a regeneratively cooled nozzle. This test was the last to be run with gaseous hydrogen coolant. After 30 s, a hydrogen leak in the nozzle and the pressure vessel interface forced termination of the run. However, the planned maximum power of 300 MW was achieved. The core consisted of cylindrical UO_2-loaded fuel elements.

September 1, 1962: KIWI-B1B reactor test was the first to operate with liquid hydrogen. The test met its primary objective of demonstrating the ability of the system to start up and run using liquid hydrogen. Following a smooth, stable start, the run was terminated after a few seconds at 900 MW when portions of several fuel elements were ejected from the reactor.

November 30, 1962: KIWI-B4A, the first design intended as a prototype flight reactor, was tested. The power run was terminated at about the 50% level when bright flashes in the exhaust (caused by ejection of core material) occurred with increasing frequency. The core consisted for the first time of full-length, 19-hole, hexagonal fuel elements loaded with UO_2.

In **1963-1964**, several cold-flow tests of KIWI-B-type reactors were carried out to determine the solutions for the severe structural damage observed in the previous tests. These tests were performed with gaseous nitrogen, helium, and hydrogen, and they demonstrated that the structural core damage was due to flow-induced vibrations. Based on results of these tests and analyses, design changes were successful in eliminating vibrations.

May 13, 1964: KIWI-B4D, the first test at full design power, was carried out with no indication of core vibration. This was also the first time a completely automatic start was accomplished for a nuclear rocket reactor. The test was terminated after 60 s at full power when several nozzle tubes ruptured.

August 28, 1964: KIWI-B4E, the eighth and final KIWI reactor, was tested by LASL. The reactor operated for more than 12 min, of which 8 min were at nearly full power. The reactor operation was smooth and stable. On September 10, the reactor was restarted and ran at nearly full power for 2.5 min. This was the first demonstration of the KIWI reactor's ability to restart.

January 12, 1965: The KIWI-Transient Nuclear Test reactor test was successfully completed by LASL. In this flight safety test, a KIWI-B-Type reactor was deliberately destroyed by placing it on a fast excursion to confirm the analytical models of the reactor behavior during a power excursion.

PHOEBUS Reactor Tests

June 1965: The aims of PHOEBUS-1A, the first test of a new class of reactors, were to increase the specific impulse, the power density in the core, and the power level. On June 25, 1965, the test was run successfully at full power (1,090 MW) and core exit temperature (2,370°K) for

10.5 min. The reactor was subsequently damaged when the facility's liquid hydrogen supply was exhausted. The event was not the result of a reactor defect.

February 23, 1967: PHOEBUS-1B operated for 45 min of which 30 min were at the design power level of 1,500 MW. The primary purpose of the test was to determine how the higher power operation affected the reactor. This fuel was the same as that used in PHOEBUS 1-A.

June 26, 1968: PHOEBUS-2A, the most powerful nuclear rocket reactor ever built, ran for 12.5 min above 4,000 MW. The duration of the test was determined by the available coolant supply. Designed for 5,000 MW, the test was limited to 80% of full power because the aluminum segments of the pressure vessel clamp band overheated prematurely.

PEWEE Reactor Test

December 4, 1968: PEWEE reactor testing was successfully completed. PEWEE, designed to be a small test-bed reactor, set records in power density and temperature by operating at 503 MW for 40 min at a coolant exit temperature of 2550°K and a core average power density of 2,340 MW/m^3. This power density was 50% greater than that required for the 1,500-MW NERVA reactor. The core contained the same type of fuel elements as PHOEBUS-1A.

Nuclear Furnace Test (NF-1)

June 1, 1972: NF-1 was successfully accomplished in Test Cell C at the NRDS. The reactor operated for 109 min at the full design power of 44 MW, which demonstrated fuel performance at a coolant exit temperature up to 2,500°K and a near-record peak power density in the fuel. Seven reactor runs were conducted with the longest test running nearly 2 hr at design power on July 27, 1972. NF-1 was designed with a remotely replaceable core in a reusable test bed and was intended as an inexpensive approach to multiple testing of advanced fuel materials and structures. Another special feature of this test series was evaluation of a reactor effluent clean-up system. The system performed as expected in removing radioactive contaminants from the effluent reactor gas. Two types of fuel elements, (UC-ZrC)C composite fuel and the pure (U, Zr)C carbide fuel, were tested in NF-1.

The Nuclear Furnace (NF-1) core was replaceable and the test bed reusable, which was unique to the NF-1 program. The NRDS had facilities designed for replacement of the core materials in NF-1. During operation, the nuclear furnace was well shielded, operated from a remote location, and observed by closed-circuit television. This essentially eliminated the potential for external exposure of personnel during the test runs. However, the maintenance performed between runs required hands-on manipulation that could have resulted in significant exposure to the photon fields from fresh, and in many cases decayed, fission products.

NERVA NRX Reactor Tests

September 24, 1964: The NRX-A2 reactor was the first NERVA reactor tested at full power by Westinghouse. The reactor operated in the range of half to full power (1,100 MW) for about 6 min, the time limited by the available hydrogen gas supply. The test was successful and demonstrated an equivalent specific impulse of 760 s in vacuum.

April 23, 1965: The NRX-A3 reactor operated for about 8 min with about 3.5 min at full power. The test was terminated by a spurious trip from the turbine overspeed circuit. The reactor was restarted on May 20 and operated at full power for over 13 min. It was started again on May 28 and operated for 45 min in the low-to-medium-power range to explore the limits of the operating map. The total operating time was 65 min with over 16.6 min at full power.

February 3 to March 25.1966: The NRX/EST, the first NERVA breadboard power plant, was operated during 5 different days for a total of 1 hr and 50 min, of which 28 min were at full power (1,100 to 1,200 MW). These times were by far the greatest achieved by a single nuclear rocket reactor as of this date.

June 8, 1966: NRX-A5 reactor operated successfully at full power for 15.5 min. It was restarted and operated again at full power (1,100 MW) on June 23 for 14.5 min to bring the total operating time at full power to 0.5 hr.

December 15, 1967: The NRX-A6 reactor test exceeded the NERVA design goal of 60 min at 1,100 MW in a single run.

XE PRIME Test

March 1968: The XE PRIME test, the first down-firing prototype nuclear rocket engine, successfully operated at 1,100 MW. The reactor operated at various power levels for a total of 115 min that included 28 restarts. This test series was a significant milestone in the nuclear rocket program and demonstrated the feasibility of the NERVA concept. In this year, the production of the Saturn V chemical rocket was suspended. It would have been the prime launch vehicle for NERVA.

January 1973: The ROVER nuclear rocket program was terminated. It was judged a technical success, but changing national priorities resulted in the decision to cancel the program.

B.4 PLUTO

In 1957, LRL began the PLUTO program to develop a nuclear ramjet engine (AEC 1972). Two tests were conducted in Area 401 of the TORY II-A reactor on May 14, 1960, and the TORY II-C reactor on May 16, 1964. As the reactor design was for an air-breathing engine, high-pressure air (about 3,800 psi) from onsite storage tanks was passed through the core for cooling during the tests.

B.4.1 <u>Area 401 Major Facilities</u>

The main facilities in the 401 Area (Figure B-1) were:

1. Critical Assembly Building of approximately 4,000 ft^2, steel frame and aluminum siding.

2. Control Building with 2,900 ft^2 of floor area, steel and aluminum construction.

3. Assembly and shop building with 2,900 ft^2 of floor, steel and aluminum construction.

4. Disassembly Building constructed of concrete where shielding was required and concrete block elsewhere. This facility, with an area of 16,100 ft^2, was used for the disassembly of hot reactors following tests.

5. Check Station and Emergency Shelter, total area about 2,000 ft^2, concrete block construction. The emergency shelter was a partially-buried Quonset building.

6. Railroad - Two mi of railroad connecting the Disassembly Building with the test bunker.

7. Inter-plant roads, approximately 2 mi long.

8. Tank Farm (High-Pressure Air Storage), Rupert Plumbing.

Project Pluto buildings included a Control Room (Building 2101), Assembly Building (2102), Data Reduction Building (2107), Hot Critical Facility (2103), and the Check Station (2105). The testing area included the Test Bunker (2203), the Disassembly Building (2201) and the Railcar Washdown (2202). The Disassembly Building was constructed in 1959-60. It was used from 1961 to 1964 during Project PLUTO to decontaminate the Tory II-A and Tory II-C reactors. Significant quantities of radioactive material were produced during the Tory reactor testing program, some of which was disposed in the disassembly area radioactive leachfield. Building 2201 was used again in 1972 to repackage PLUTO solid fuel elements for shipment from Area 26 (DOE 2002c).

B.4.2 TORY Reactor Tests

The TORY II-A and TORY II-C reactors were mounted on a special railroad flat car (Figure B-6) that could be moved after operation into a shielded inspection and disassembly facility. This test vehicle assembly was 44 ft long, 14.5 ft wide and 12 ft high. The reactor and duct system, as well as the railcar, each weighed about 20 tons for a total of 40 tons. Because the PLUTO reactor concept involved the use of an air-breathing engine, high-pressure air from storage tanks was passed through the core for cooling. The duct system consisted of five flanged cylindrical sections and a nozzle bolted together and mounted on the flat car. One duct contained the reactor core and the others contained control systems. The reactor duct was 57 in. in diameter and 103 in. long and weighed over 9 tons.

The TORY II-A and II-C cores consisted of homogenous beryllia and uranium oxide extruded into hollow hexagonal rods about the diameter of a pencil and 4 in. long. There were a total of 464,595 rods of which 293,328 were fueled with 63.5 kg of 93% enriched uranium. This bundle was held together by 32 bards of peripheral springs that exerted compressive force radially and 121 tie rods with compression springs that exerted compressive force axially. Eighteen of these rods contained hafnium control rods.

The TORY II-A reactor was designed with two graphite shells that clamped around the outside of the reactor; deuterium was passed through the core for moderation to sustain criticality. The graphite shell around the outside of the reactor could be retracted and the deuterium flow terminated to control reactor power. Control rods were also available to remotely control reactor power.

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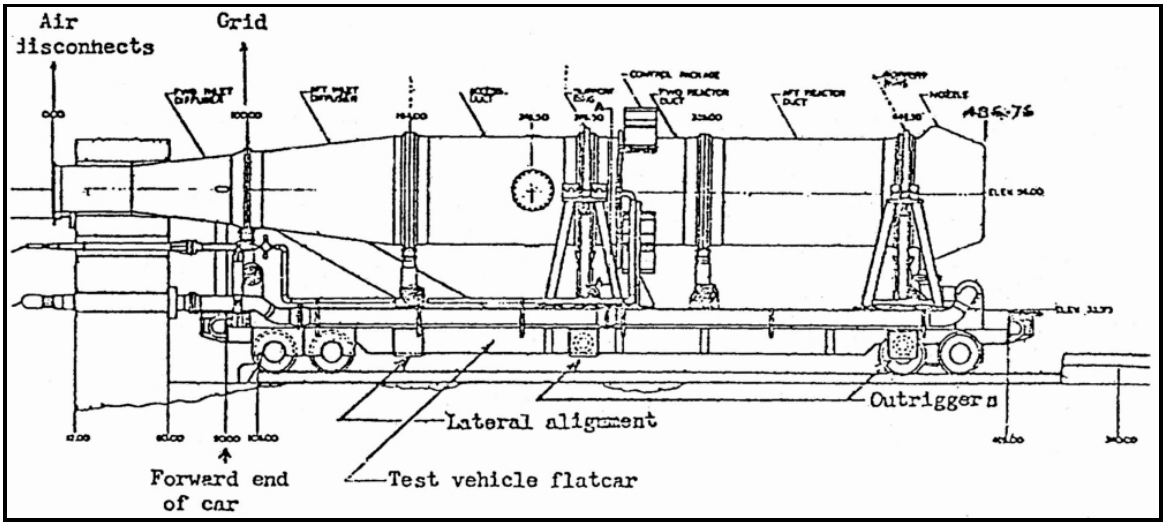

Figure B-6. Schematic diagram of TORY II-C reactor on vehicle flatcar.

The PLUTO Project reactor concept envisioned reactor-powered aircraft that would be restricted to flights at relatively low altitudes. During the two PLUTO Project tests, the reactor sloughed off the fuel and debris as high-pressure air was passed through the reactor core at very high velocity. This would spread significant amounts of radioactive debris in its path of travel and potentially cause health hazards from exposure to the radioactive contamination.

During the test of TORY II-A, a visible cloud was emitted from the reactor that extended north into the forward area past CP-2. Most of the radioactive particles fell within about 1 mi downwind of the reactor, but the noble gases and tritium were contained in a cloud carried in a northerly direction. Based on downwind sampling, no radioactivity was released off the site.

The TORY II-C test was the second and last test performed under the PLUTO Program. The reactor fuel had the same configuration as TORY II-A and used high-pressure air for core cooling. Again, the core sloughed off particulates and gaseous materials during the run that produced a visible cloud that moved northward over the CP-2 complex. Like the Tory II-A test, the particulates fell out within about 1 mi of the reactor, while the gaseous materials continued northward. Downwind sampling did not detect any release activity off the site.

Radiation readings on the reactor surfaces were reported as being above 1,000 R (Shockley 2005). Pocket ion chambers (PICs) were used when reentries were made. Two PICs were used for each worker and were compared for dose determination. Following the test runs, the reactor was moved remotely from the test stand for storage and inspection using the railroad system to a shielded vault with a 5-ft-diameter opening. This vault had 4-ft-thick walls for shielding. Entries were made under the control of REECo Rad Safe Monitors and LRL health physicists along with a very small contingent of the PLUTO technical staff.

The PLUTO project was terminated after TORY II-C for study and partial dismantling. There were no additional tests under the PLUTO Project during 1970 and 1971. The overall Nuclear Rocket Engine Test series was discontinued after 1971.

B.5 Summary of Radiological Hazards

The hazards associated with the nuclear rocket and ramjet engine tests relate to the operation of test reactors. Mobile radiation survey teams entered the area at a designated time after a test run to collect measurements that would define the isodose rate contours. Maps were prepared and posted at the control points. Reentry and stay times varied and were calculated so that personnel radiation exposure limits could be met. Radiation monitors accompanied each group of personnel entering the radiation area to monitor and provide information regarding radiation levels at work locations. Radiation measurements were obtained at station, equipment, and structure location and published in the on-site radiological safety reports that were prepared for each test.

B.5.1 External Exposure

External exposures were primarily due to the decay of fission products. The reactors were operated remotely. Because of the distance between the operating reactors and personnel, external exposures during tests were, at most, a few millirem. Following the tests, the reactors were returned to heavily shielded cells by rail. Usually several hours to several days elapsed between reactor operation and the need for personnel to enter the cells for maintenance. However, even then the dose rates could have been several roentgen per hour. This required that the work be performed very rapidly with short residence times, often as little as 30 s. There were also exposures to H-8 plume-tracking teams, although they were generally less than those for hands-on work with the reactors.

Conventional dosimetry was used for monitoring the external fields and exposures. These included the survey instruments and film dosimeters employed by REECo, LASL, and LRL at that time. Standard film dosimeters and PICs were used for personnel monitoring. Section 6 of the NTS site profile contains more detail on the external dosimetry used at the NTS.

B.5.2 Internal Exposure

The primary source of internal exposure was the fission products released during reactor operation. Table B-1 lists the radionuclides identified in the effluent clouds during reactor operation (DOE 1995a). Several of the tests released radioactive effluent of sufficient magnitude that it could be detected off the site (DOE 1995a). Table B-2 summarizes these releases.

B.6 Onsite Radiological Support for Reactor Tests

The REECo Rad-Safe Division had three objectives in providing support for reactor tests (REECo 1961a):

- Radiological safety support on the NTS in accordance with the NTS standard operating procedure (SOP) as outlined in detail in the REECo Rad-Safe Division's SOP Manual (REECo 1961b). This support includes monitoring and sampling at all NTS work locations.

- Low-level radiation monitoring, sampling, and analyses within a 10-mi radius of each reactor site excluding the user-controlled area. This data is obtained for dissemination to the user

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Table B-1. Radionuclides found in effluent clouds from nuclear rocket and ramjet engine tests (DOE 1995a).

Radionuclide	Half life	Radionuclide	Half life	Radionuclide	Half life
Ni-57	35.6 hr	Ru-103	39.6 d	Xe-135	9 hr
Kr-85m	4.5 hr	Ru-105	4.4 hr	Cs, Ba-137	30.1 yr[a]
Kr-87	76 min	Ru, Rh-106	369 d[a]	Cs-138	32 min
Kr-88	2.8 hr	Te-129	70 min	Ba-239	1.4 hr
Sr, Y-89	50.5 d[a]	Te-131	24 min	Ba, La-140	13 d[a]
Sr, Y-90	29 yr[a]	1-131	8 d	Ce-141	32 d
Sr-91	9.5 hr	Te-132	3.25 d	La-142	1.5 hr
Sr-92	2.7 hr	1-132	2.3 hr	Ce-143	34 hr
Yr-93	10 hr	Te-133m	55 min	Ce-144	284.4 d
Zr-95	64 d	I-133	21 hr	Nd-147	11 d
Nb-95	3.5 d	Xe-133	5.2 d	U-234	244,000 yr
Zr-97	17 hr	I-134	53 min	Np-249	2.3 d
Mo-99	2.75 d	I-135	6.6 hr		

group, the U.S. Weather Bureau, the U.S. Public Health Service, and other interested agencies.

- Monitoring and sampling within the user-controlled area as requested.

Gamma radiation iso-dose rate contours of 0.1, 1, 10, 100, and 1,000 mR/hr were determined with portable hand-carried instruments held approximately 3 ft above surface level. Measurements were referenced to stakes and fallout tray holders beyond the arc roads on existing trails and roads. The initial surveys were performed as soon as possible after initial fallout deposition and were followed by a resurvey in approximately 8 hr. Subsequent surveys were performed to determine the 1, 10, 100,

and 1,000 mR/hr iso-dose rate contours at intervals timed to provide evenly spaced points on the projected decay curve. The instruments used were:

- Precision Model 111 (scintillation) instruments with six ranges between 0 and 5 mR/hr and calibrated at 12 points with a ^{60}Co source.

- Low-range beta-gamma instruments calibrated at 2 points on each range with a ^{60}Co source.

- Ion chamber instruments with five ranges between 0 and 50 R/hr calibrated at 12 points with a ^{60}Co source.

Radioactive fallout was collected on adhesive surface trays. The trays were positioned on stakes surrounding the test cell at approximately 5- and 10-mi radii. The fallout trays were supplemented by collectors placed on existing lateral and radial roads at distances between 5 and 10 mi from the test cell. Fallout trays that showed a beta activity of more than 5 x 10^{-2} µCi/m^2 were assayed for alpha activity using a thin-window gas-flow proportional counter. This method could detect alpha at 9 x 10^{-6} µCi/m^2 with an error of ±3 x 10^{-6} µCi/m^2 at a 90% confidence level. Fallout trays were collected as soon as possible after initial effluent deposition, and sent to the REECo Rad-Chem Laboratory where they were assayed for beta activity with a large area, thin-window (0.85 mg/cm^2) gas-flow proportional counter. Additional fallout trays were collected on D + 1 and assayed in the

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Table B-2. Summary of tests of nuclear-powered rocket and ramjet engines which generated radioactive effluent detected off the site (DOE 1995a).

Test name	Date	Time of day (PST)	Integrated power (MW-s)	Release curies[a]
KIWI A	07/01/59	0900-0905	21,000	840
KIWI A PRIME	07/08/60		60,000	2,500
KIWI A-3	10/19/60		60,000	2,500
TORY II-A	10/06/61	1254	31,300	635
KIWI B-IA	12/07/61	1415-1417	30,000	1,300
KIWI B-1B	09/01/62	1130	10,000	420
KIWI B-4A	11/30/62	1207	40,000	1,700
TORY II-C	05/12/64	1215		256
KIWI B-4D	05/13/64	0945	110,000	4,600
TORY II-C	05/20/64	1250		741
KIWI B-4E	08/28/64	1139-1147	500,000	21,000
KIWI B-4E	09/10/64	1055-1057	180,000	7,600
NRX-A2	09/24/64	0955-1005	300,000	1,100
NRX-A2	10/15/64	1110-1130	300,000	1,100
KIWI	01/12/65	1058	9,000	15,000
NRX-A3	04/23/65	1254-1258	320,000	530
NRX-A3	05/20/65	0932-0946	840,000	2,400
NRX-A3	05/28/65	0930-1000	500,000	1,200
PHOEBUS 1A	06/25/65	1215-1226	740,000	22,000
NRX-A4/EST	02/03/66	1116-1123[3]	390,000	12
NRX-A4/EST	03/03/66	1310-13163	880,000	100
NRX-A4/EST	03/16/66	1004-1020	1,000,000	27,000
NRX-A4/EST	03/25/66	0933.0948	1,100,000	28,000
NRX-A5	06/08/66	1302-1318	1,200,000	1,200
NRX-A5	06/23/66	0935-0950	1,000,000	80,000
PHOEBUS 1B	02/10/67	1130	140,000	34,000
PHOEBUS 1B	02/23/67	1400-1430	2,600,000	240,000
NRX-A6	12/15/67	1059-1159	4,500,000	53,000
PHOEBUS 2A	06/08/68	1014-1025	643,000	7,100
PHOEBUS 2A	06/26/68	1137-1209	4,500,000	51,000
PHOEBUS 2A	07/18/68	1210-1222	660,000	2,100
PHOEBUS 2A	07/18/68	1350-1408	2,000,000	
PEWEE 1	12/04/68	1332-1435	1,530,000	230,000
XE PRIME	06/11/69	0942-0953	425,000	820
XE PRIME	08/28/69	1518-1551	338,000	530

a. As calculated for 12 hr after the time of release (R+12 hr). Short-lived radionuclides have decayed to stable forms by this time.

same manner. This assay method was capable of detecting beta activity at 9 x 10^{-5} μCi/m^2 with error limits of ±3 x 10^{-5} μCi/m^2 at a confidence level of 90%. The fallout trays collected on the 5- and 10-mi perimeters were agglomerated according to distance, and a gamma spectrum was obtained with a 4- by 4-in. NaI crystal.

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Intensity, decay rates, and time of arrival of the effluent cloud with radiation levels above 0.3 mR/hr were determined from telemetered data from Geiger-Muller detectors. The detectors were at the Area 12 Mesa, Area 12 Camp, Security Station 700, BJY, CP-2, Sugar Bunker, Well 5, and Camp Mercury.

Arrival times of the fallout cloud at two locations within a 10-mi radius from the test reactors were determined with Staplex air samplers using 4-in.-diameter glass fiber prefilters followed by 4-in.-diameter by 1-in.-thick charcoal cartridges. As soon as the fallout was deposited, all filters were sent to the Rad-Chem Laboratory for analysis. Arrival times on the 5 and 10 mi area was determined by vehicle-borne monitors using low-range Geiger-Muller and scintillation instruments. Staplex air samplers were operated at Area 12 Mesa, Area 12 Camp, Security Station 700, Yucca Flats, (BJY), CP-2, Frenchman Flat (well 5), Mercury, and at the ROVER and PLUTO administration areas. Filters were collected after possible fallout deposition, and then on a daily basis for several days following each major reactor test.

Particle size samples were obtained at approximately 5 and 10 mi from the reactor during the fallout period by vehicle-borne monitors operating portable generator-powered five-stage cascade impactors.

The gamma activity pattern from cloud passage and fallout was determined with film badges positioned approximately 1 ft above the ground at each fallout tray location and protected from the heat by a reflective cover as well as with trailer mounted air-samplers and hand-held instruments.

The REECo Rad-Chem Laboratory was used to assay all collected samples. Special techniques were used to discount natural emitter activities.

Charcoal cartridges were assayed with gamma scintillation detectors using the ^{131}I - 0.36 MeV photopeak. Because the spectra were often dominated by contribution of other nuclides (^{133}I, ^{135}I, etc.) spectrum-stripping was frequently required at early times to quantify the ^{131}I. The sensitivity of this technique was such that a 5×10^{-5} µCi/sample could be detected with an error of $\pm 1.4 \times 10^{-5}$ µCi at a 90% confidence level.

Selected air samples and fallout trays were analyzed for specific fission products such as ^{89}Sr, ^{90}Sr, ^{137}Cs, ^{95}Zr, and ^{95}Nb.

Special monitoring instruments attached to criticality alarms were used to detect possible inadvertent critical assembly of fissionable material, if requested. Trained emergency radiation monitoring personnel were standing by for emergency support.

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C.1 REECo

REECo job titles that probably had some potential for workplace external or internal exposures (Table C-1) include field workers participating in post-event activities (i.e., drill backs and mine backs) or workers who directly handled radiological materials (laboratory analysis, sample collection, and workers assigned to areas that had the potential to be radiologically controlled or contaminated). Most of these workers were RadWorker-II trained, which included the qualification to wear a respirator and don anticontamination (Anti-C) clothing. Supervisors of field personnel are generally included because they are by definition backups for their personnel. Some select managers are also included for the same reason.

REECo job titles that possibly had some potential for workplace external or internal exposures (Table C-2) include field workers who could have worked underground, on drill rigs, in downhole shafts, or have entered radiologically controlled or contaminated areas during the performance of their tasks. The positions could have required the worker to qualify for a respirator and don Anti-C clothing (i.e., be RadWorker-II trained) depending on the job assignment. Based on the position description, these workers could have worked underground in tunnels or at downhole shaft sites, performed emergency response duties, or had other indications of potential entry into contaminated areas (e.g., respirator use or Anti-C requirements). Managers and supervisors of field personnel are generally included because they are by definition backups for their personnel. Other REECo job titles were administrative, support service (janitorial, cafeteria), or clerical in nature with no access to or assignment in radiological areas. These workers did not have similar exposure potential and are not listed in the tables.

The column descriptions for Tables C-1 and C-2 for REECo job titles are:

- DAILY TUNNEL WORKER INCLUDING REENTRY & MINE BACK SUPPORT– Workers and support personnel assigned work underground.
- OCCASIONAL TUNNEL WORK POSSIBLE – Workers with the potential to work underground who were assigned as needed.
- DAILY DRILL CREW INCLUDING DRILL-BACK SUPPORT- Workers and support personnel assigned to drilling operations.

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- OCCASIONAL DRILL RIG/DOWNHOLE WORK POSSIBLE - Workers with the potential to work on a drill rig or at a downhole (vertical shaft) site who were assigned as needed.
- LAB WORKER/FIELD SAMPLER
- NEUTRON EXPOSURE POTENTIAL
- FIELD WORK WITH POTENTIAL FOR RADIOLOGICAL EXPOSURE – This category is included because some position descriptions list “radiological hazard” with no other descriptors.
- EMERGENCY RESPONSE/MINE RESCUE TEAM
- RESPIRATOR QUALIFICATION REQUIRED
- ANTI-C CLOTHING USE

C.2 Other Contractors (EG&G Energy Measurements, H&N, and RSN)

Position descriptions were supplied for these contractors. Table C-3 lists job titles that could have had the potential for exposure to radionuclides. The potential for neutron exposure is specifically noted in the table. There were additional contractors, but no position descriptions are available for these contractors.

C.3 Current and Former NTS Contractors

NSTec currently manages and operates the test site and its related facilities for the Nevada Site Office. Wackenhut Services (WSI) continues to provide security services at NTS. Previous major contractors for the NTS included the team of Bechtel Nevada (BN) Corporation (1995-2007), REECo (1953-1995), Holmes & Narver, (H&N) (1956-1990), Fenix & Sisson of Nevada (FSN) (1963-1990), and Edgerton, Germeshausen, and Grier (EG&G) Corporation (1951-1995).

C.4 Job Title References

1. REECo Job Title Indices and Position Descriptions (dated 1992 to 1993 for crafts, 1989 to 1994 for exempts, 1983 to 1993 for technical, and 1995 for nonexempts).
2. EG&G Job Title Index and Position Descriptions (various dates from 1976 to 1992).
3. H&N Position Descriptions (various dates from 1975 to 1982).
4. RSN Position Descriptions (various dates from 1976 to 1992).

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Table C-1. REECo job titles that probably had some potential for workplace external and/or internal exposures.

		Tunnel work		Downhole work		Lab	Neutrons	Other field work		Qualifications	
Job title	**Job category**	**Daily tunnel worker including reentry & mine back support**	**Occasional tunnel work possible (as needed)**	**Daily drill crew including drill-back support**	**Occasional drill rig/ downhole work possible (as needed)**	**Lab worker/ field sampler**	**Neutron exposure potential[c]**	**Field work w/potential for radio-logical exposure**	**Emergency response/ mine rescue team**	**Respirator qualifica-tion required**	**Anti-contami-nation clothing use**
Bull Gang Foreman Bull Gang Worker	Craft	x						x	x	x	x[b]
Calibration Lab Supervisor	Exempt					x	x			x[b]	x[b]
Chemist I - IV Sr. Chemist Principal Chemist Analytical Chemistry Section Chief	Exempt					x	x			x[b]	x[b]
Derrickman	Craft			x				x		x	x[b]
Dinkey Locomotive Operator Swamper (signal man/load attendant)	Craft	x						x		x	x[b]
Dosimetry Supervisor	Exempt					x	x			x[b]	x[b]
Driller Drill Helper Drilling Support Superintendent or Tool Pusher	Craft			x				x		x	x[b]
Drilling Support Superintendent or Tool Pusher Drill Rig Superintendent (drilling post shot support)	Exempt			x				x		x[b]	x[b]
Environmental Analyst	Exempt					x		x		x[b]	x[b]
Environmental Compliance Officer I-IV	Exempt		x		x			x		x[b]	x[b]
ES&H Technical Trainee	Nonexempt					x					
Health Physicist I-IV Sr. Health Physicist Principal Health Physicist	Exempt	x[a]	x	x[a]	x		x	x	x	x[b]	x[b]
Health Protection Technician I-IV	Technical		x		x			x	x	x	x[b]
Industrial Hygienist I-IV Sr. Industrial Hygienist Principal Industrial Hygienist Industrial Hygienist Field Ops Section Chief	Exempt	x[a]	x	x[a]	x			x	x	x[b]	x[b]
Lab Technician I-IV	Technical		x		x	x	x	x		x	x
Lab Technician Trainee	Nonexempt					x		x		x	x[b]
Miner Miner-Welder	Craft	x						x	x	x	x[b]
Motorman-Oilfield	Craft			x				x		x	x[b]
Mucking Machine Operator	Craft	x						x		x	x[b]
Nonradioactive Waste Disposal Section Chief	Exempt							x			
Operations Superintendent (event work)	Exempt		x	x	x			x		x[b]	x[b]
Pipefitter/Plumber-Welder	Craft	x[a]	x		x					x[b]	x[b]
Quality Control Technician I & II-Physical Standards & Calibration Lab Sr. Quality Control Technician-Physical Standards & Calibration Lab	Technical					x	x	x			
Quality Control Technician I & II-Cable Ops Sr. Quality Control Technician-Cable Ops	Technical		x		x			x		x	x[b]
Radioactive Waste Section Chief	Exempt							x		x[b]	x[b]
Radioanalytical Section Chief	Exempt					x	x			x[b]	x[b]
Radiological Analysis Supervisor (Hot Lab work)	Exempt					x	x	x	x	x[b]	x[b]

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		Tunnel work		Downhole work		Lab	Neutrons	Other field work		Qualifications	
Job title	**Job category**	**Daily tunnel worker including reentry & mine back support**	**Occasional tunnel work possible (as needed)**	**Daily drill crew including drill-back support**	**Occasional drill rig/ downhole work possible (as needed)**	**Lab worker/ field sampler**	**Neutron exposure potential[c]**	**Field work w/potential for radio-logical exposure**	**Emergency response/ mine rescue team**	**Respirator qualifica-tion required**	**Anti-contami-nation clothing use**
Radiological Control Technician I-IV (Monitor)	Technical	x[a]	x	x[a]	x		x	x	x	x	x[b]
Radiological Engineering Technician	Technical		x		x			x		x	x[b]
Radiological Field Operations Branch Chief Radiological Field Operations Section Chief (Decon Facility Operations)	Exempt		x		x		x	x	x	x[b]	x[b]
Radiological Field Operations Supervisor (event support, reentry monitoring, hot line/base station operations for post shot drilling and tunneling)	Exempt	x	x	x	x		x	x	x	x[b]	x[b]
Radiological Instrument Technician I-IV	Technical		x		x			x		x	x[b]
Respiratory Equipment Specialist Respiratory Equipment Technician	Technical	x[a]	x		x			x		x	x[b]
Sample Management Section Chief	Exempt					x	x				
Shifter	Craft	x						x	x	x	x[b]
Tunnel Walker	Exempt	x						x	x	x[b]	x[b]
Waste Control Section Chief	Exempt							x		x[b]	x[b]
Waste Management Specialist I-IV Sr. Waste Management Specialist Principal Waste Management Specialist Waste Certification Specialist	Exempt		x		x			x		x[b]	x[b]
Waste Operations Special Projects Section Chief (Areas 3 & 5) Waste Operations Technical Support Section Chief	Exempt							x		x[b]	x[b]

a. Not ALL workers with this job title were assigned to a tunnel or drilling operation, but they could have been.
b. These qualifications were not specifically stated in the position descriptions but were assumed based on duties.
c. Monitored with Neutron Track Emulsion, Type A film or TLD depending on the timeframe.

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Table C-2. REECo job titles that possibly had some potential for workplace external and/or internal exposures.

Job title	Job category	Occasional tunnel work possible (as needed)	Occasional drill rig/ downhole work possible (as needed)	Field work w/ potential for radiological exposure	Emergency response/mine rescue team	Respirator qualification required	Anti-contamination clothing use
Carpenter Carpenter Foreman General Foreman Carpenter Welder	Craft	x	x	x		x	
Combination Heavy-Duty Repairman/Welder Combination Heavy-Duty Repairman/Welder Foreman Combination Heavy-Duty Repairman/Welder General Foreman	Craft	x		x			
Compliance & Monitoring Section Chief (Occupational Safety)	Exempt	x		x	x		
Department ES&H Coordinator Director, Emergency Management Office	Exempt			x	x		
Ecologist	Exempt	x	x	x			
Electronic Technician I-IV	Technical	x	x	x			
Engineering and Analysis Section Chief	Exempt	x		x	x		
Engineering Intern	Nonexempt	x	x	x			
Engineering Technician I & II	Nonexempt	x	x	x		x	
Environmental Compliance Officer Director Environmental Program Section Chief Environmental Remediation Section Chief Environmental Restoration & Technology Develop Dept. Manager Environmental Section Chief	Exempt			x			
Environmental Compliance Officer I-IV	Exempt	x	x	x			
Equipment Operator	Craft		x	x			
ER Superintendent ESH&Q Division Manager	Exempt			x	x		
Fire Captain Fire Fighter	Craft			x	x	x	
Fire Engineer	Craft			x	x	x	
Fire Protection Services Section Chief	Exempt			x	x		
Forklift Operator	Craft	x		x		x	
Grade Checker	Craft		x	x			
Heavy-Duty Repairman (Construction)-Equipment Heavy-Duty Repairman Foreman Heavy-Duty Repairman General Foreman	Craft	x		x			
Heavy-Duty Welder	Craft	x		x		x	
High-Voltage Electrical Mechanic High-Voltage Line Mechanic	Craft	x		x		x	x
Hoist Operator	Craft	x		x		x	x

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Job title	Job category	Occasional tunnel work possible (as needed)	Occasional drill rig/ downhole work possible (as needed)	Field work w/ potential for radiological exposure	Emergency response/mine rescue team	Respirator qualification required	Anti-contamination clothing use
Industrial Control Wireman	Craft			x		x	x
Inventory Specialist	Technical	x		x			
Ironworker/Ironworker Foreman	Craft			x		x	
Ironworker General Foreman	Craft			x		x	x
Laborer	Craft			x		x	x
Laborer Foreman Laborer General Foreman	Craft			x		x	
Lineman	Craft	x		x		x	
Lineman Foreman Lineman General Foreman	Craft	x		x			
Locksmith	Craft	x		x		x	
Millwright Millwright Foreman	Craft	x	x	x		x	
Motor Patrol Operator	Craft		x	x		x	
Occupational Safety & Fire Protection Dept. Manager	Exempt	x		x	x		
Occupational Safety Professional I-III	Exempt			x	x		
Occupational Safety Specialist I-II	Exempt	x		x			
Painter Painter Foreman	Craft	x	x	x		x	
Paramedic	Technical	x		x	x		
Plumber/Refrigeration Mechanic	Craft	x	x	x		x	x
Plumber/Refer Mechanic Foreman Plumber/Refer Mechanic General Foreman	Craft	x	x	x		x	x
Principal Ecologist Principal Environmental Scientist	Exempt	x	x	x		x	
Principal Occupational Safety Professional	Exempt	x	x	x	x		
Property Inspector	Nonexempt	x		x			
Property Specialist	Technical	x		x			
Radiological Assessor Radiological Evaluation Section Chief	Exempt			x			
Sanitarian	Technical	x		x			
Scientific Intern	Technical 1983-1993	x	x	x			
Security Assistant	Nonexempt	x		x			
Sheetmetal Foreman Sheetmetal General Foreman Sheetmetal Worker	Craft	x	x	x		x	
Sr. Ecologist Sr. Environmental Compliance Officer	Exempt	x	x	x			
Waste Operations Dept. Manager	Exempt			x			
Wireman Wireman Foreman Wireman General Foreman	Craft	x	x	x		x	x

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Table C-3. Other contractor job titles with some potential for workplace internal and/or external exposure.

EG&G Energy Measurements, Inc. 1951-1995	**Neutron exposure potential?**
Engineer	x
Engineering Coordinator	
Environmental Scientist	
Exercise Planner	
Health Physicist	x
Industrial Hygienist	x
Safety Administrator Safety Assistant Safety Engineer Safety Specialist	
Technician	x
Raytheon Services Nevada (RSN) 1990-1995	
Engineer	x (well logging)
Geologist	x (well logging)
Supervisor, Construction Services	
Supervisor, Drilling	x (well logging)
Supervisor, Field Operations	
Supervisor, Field Operations	
Supervisor, Material Testing Lab	x
Technician	x
Holmes & Narver (H&N), Inc. 1956-1990	
Chief, Materials Testing Lab	x
Chief, Safety Programs	
Engineer	x (well logging)
Supervisor, Construction Services	
Supervisor, Field Operations	
Supervisor, Field Surveys	
Supervisor, Material Testing	x

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POST-TEST DRILLING TECHNOLOGY AND RADIATION EXPOSURE POTENTIAL

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D.1 Post-Test Drilling Techniques

Following the detonation, the cavity cools and a collapse occurs that usually forms a subsidence crater (Figure D-1). Post-test drilling operations were often conducted as soon after detonation as possible to obtain information from the short-lived fission products. These operations were performed to obtain essential diagnostic data on the results of the underground tests (Johnson et al. 1966; Butler 1984). Post-test drilling was used to obtain samples from the zone of interest for radiochemical analysis. In addition, it provided important information on cavity size, chimney dimensions, effects of the explosion on the surrounding material, and distribution of radioactivity in the test zone.

Three approaches to post-test drilling were used at NTS for both LLNL and LANL (Figure D-1):

- **Directional hole** – A standard vertical drill rig was set up on undisturbed ground outside the collapsed area and the hole was started vertically. Directional drilling techniques (whipstocking) were then used to slant the borehole to the zone of interest.

- **Angle hole** – A special rig designed to drill on a slant (Hycalog 1 and 2 at LLNL and a similar drill rig at LANL) was set up on undisturbed ground outside the collapsed area, and the hole was drilled on a slant directly to the zone of interest.

- **Vertical hole** – A vertical rig was set up directly above the working point and the hole was drilled straight down to the zone of interest.

Method 3 was most commonly used at the NTS until late 1963. After that, Methods 1 and 2 were more commonly used by both LLNL and LANL. Cost and time studies showed that Method 1 was superior for holes 1,500 ft or deeper because of the greater speed with which round trips to remove the drill pipe (string) and replace the bits could be made. Method 2 was superior for shallower holes. The Hycalog drill rig used a similar angle-type drill rig for the post-test drilling program. Methods 1 and 2 share the advantage over Method 3 that the drill rig was outside the collapsed zone. These rigs allowed preparations to be made before the test, which speeded up the post-test drilling. The Hycalog drill rig could be set up before the test, the surface casing set and spudded in, and other cellar preparations made. Then the drill rig could be quickly removed before test time depending on the expected motion intensity. After the test, the drill rig could be set up again quickly and the drilling could get under way with a minimum delay. LANL used the same process for Methods 1 and 2 in

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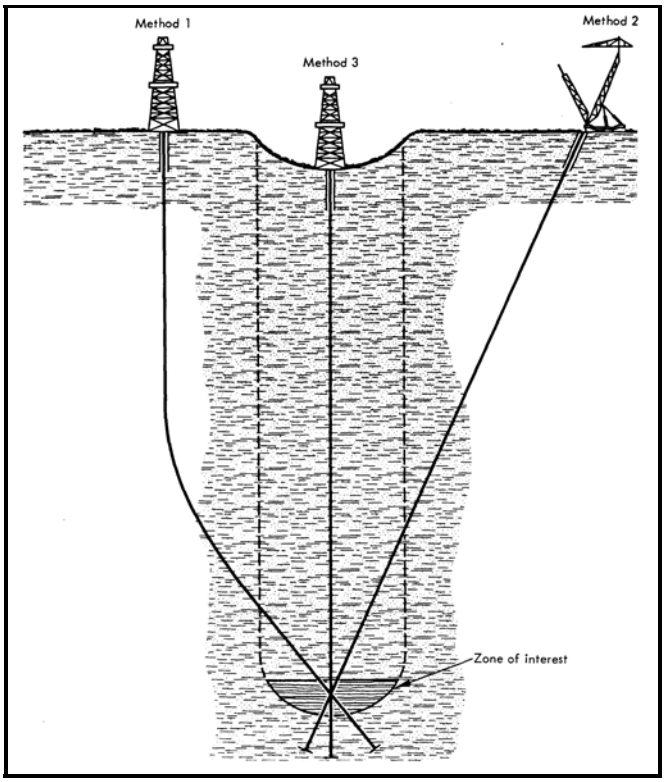

Figure D-1. Three methods of post-test drilling (Johnson et al. 1966).

which the cellar could be prepared and the surface casing installed either before or after the test depending on the expected motion intensity.

At first, drilling was performed using drill rigs of the oil field type. The standard drill rig (Figures D-2 and D-3) basically consists of the drilling platform with a small structure (dog house) to shelter the drillers at some distance from the drill pipe (string) entry point and a separate pipe-racking platform (known as the monkey board, Figure D-3, item 24) several feet above the drill platform. As the drilling progresses, one drilling laborer (roughneck) stood on the monkey board, and usually two stood on the platform to add new sections of pipe.

In rotary drilling, the hole is made by rotating a bit that chews or grinds its way through soil and rock. Because the turning force is usually applied by the drill rig, a rigid connection extending from the surface down to the bit is necessary. This rigid connection must be lengthened as the depth of the hole increases by adding drill pipe. These rigid connections are made using the derrick on the drill rig (Figure D-2). The derrick is a tall, strong structure, and its main function is to support the crown block, which holds all the weight of the drill pipe and associated equipment.

When drilling angle holes (Method 2), LLNL used a Hycalog slant drilling rig (Figure D-4; Table D-1 provides the Hycalog nomenclature for the numbered elements). The rigs were specially built for the DOE by Hycalog, Inc. of Shreveport, Louisiana. These rigs could drill at any angle between the vertical and 30 degrees off the vertical. The rig could therefore be set up some distance from the

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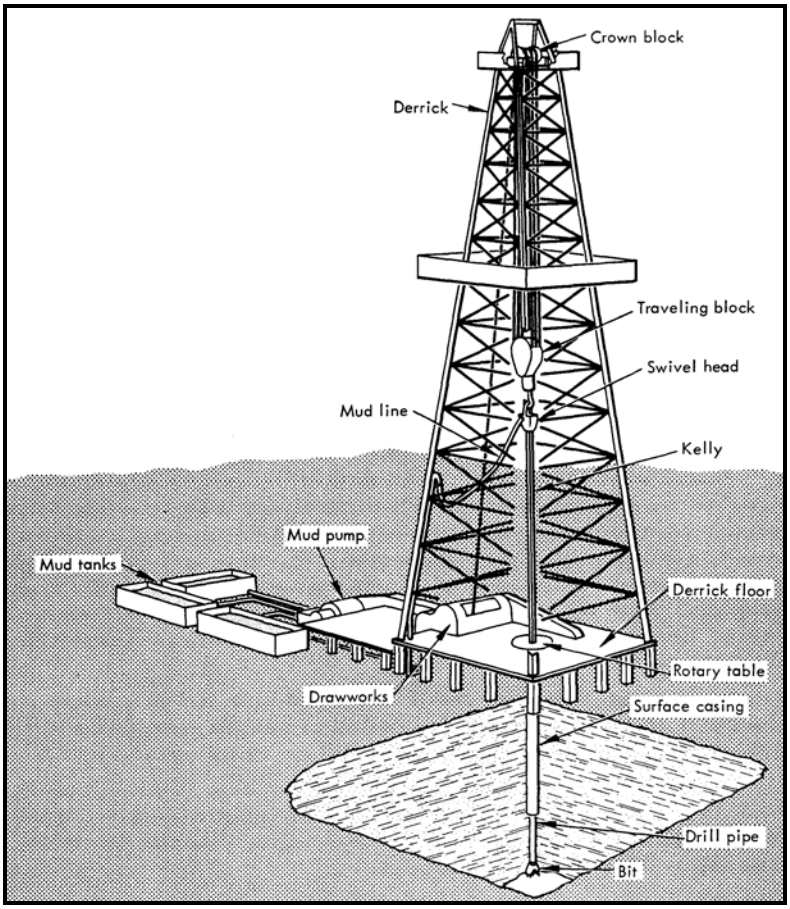

Figure D-2. Schematic of a rotary drilling rig (Johnson et al. 1966).

surface above the detonation point at a distance safely beyond the anticipated range of surface collapse following the test (based on sampling depth). Most of the post-test holes at the NTS were drilled using the angle method after late 1964 because it decreased the drilling time.

In addition to the ability to drill on an angle, the Hycalog-type drill rig differed from the standard vertical rig in another very important way. A power swivel turned the drill pipe rather than a rotary-table-and-kelly arrangement. The swivel was driven by hydraulic power, and the drill pipe fastened directly to the swivel. Because the swivel drive allowed continuous drilling when the bit was being raised in the hole as well as when it was lowered, the problem of the drill pipe sticking in the hole was eliminated. This is a major advantage that the Hycalog-type rig has over the standard vertical rig. In addition, it improved the safety of the drilling operation.

A third advantage of the Hycalog was the ease of moving the rig on and off the preset casing before and after testing. This speeded up the post-test drilling process, and allowed cavity sampling to occur much sooner. LANL used a slant drill rig that was similar to the Hycalog rig, and it provided essentially the same benefits.

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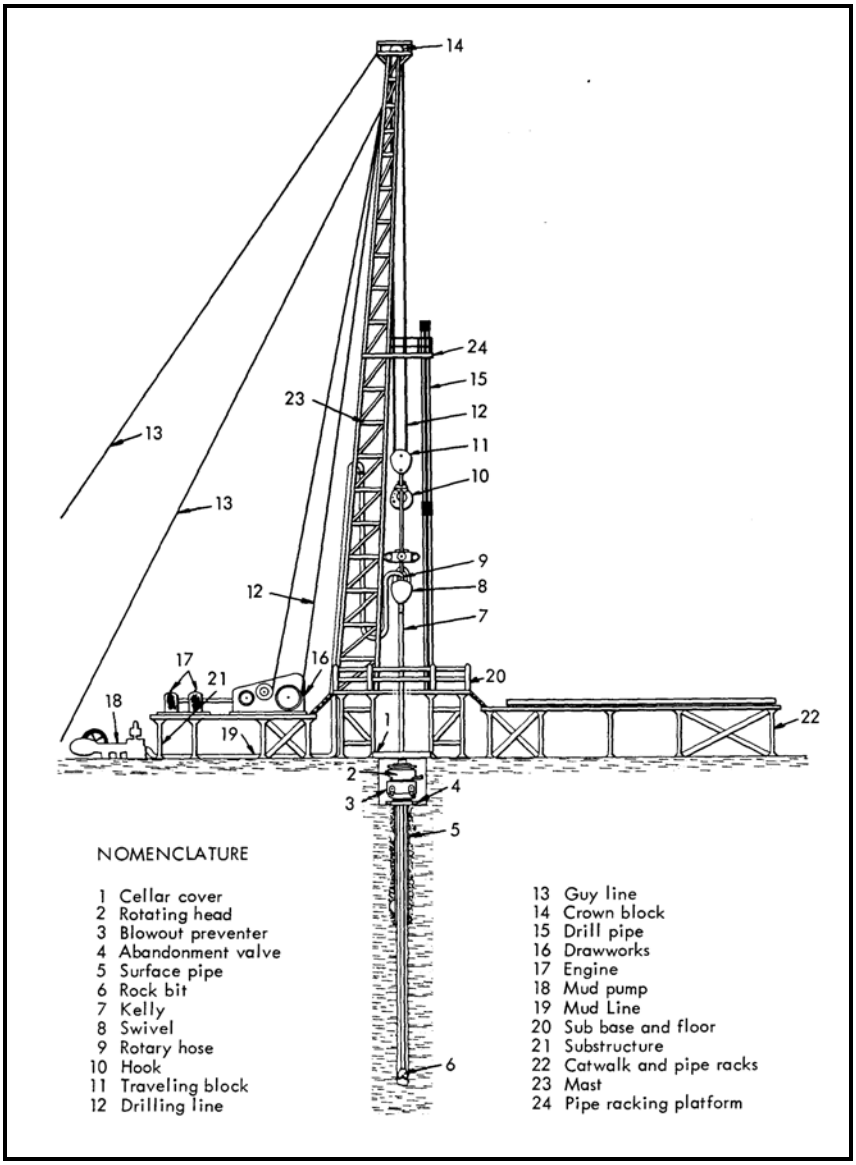

Figure D-3. Schematic of a standard vertical test rig (Johnson et al. 1966).

REECo provided drilling support to both LLNL and LANL, so the drilling operations were very similar. The LLNL post-test drilling group provided the onsite representation for the Test Group Director and determined the drilling depths, the type of drill rig, and the location of the drill site in reference to the placement of the test and expected ground motion. Las Alamos again used essentially the same process where the J-6 Event Engineer determined the location, placement of the drill rig, and the sampling depth. This then became the responsibility of the J-6 NTS engineer for oversight of these protocols (Eberhart 1993).

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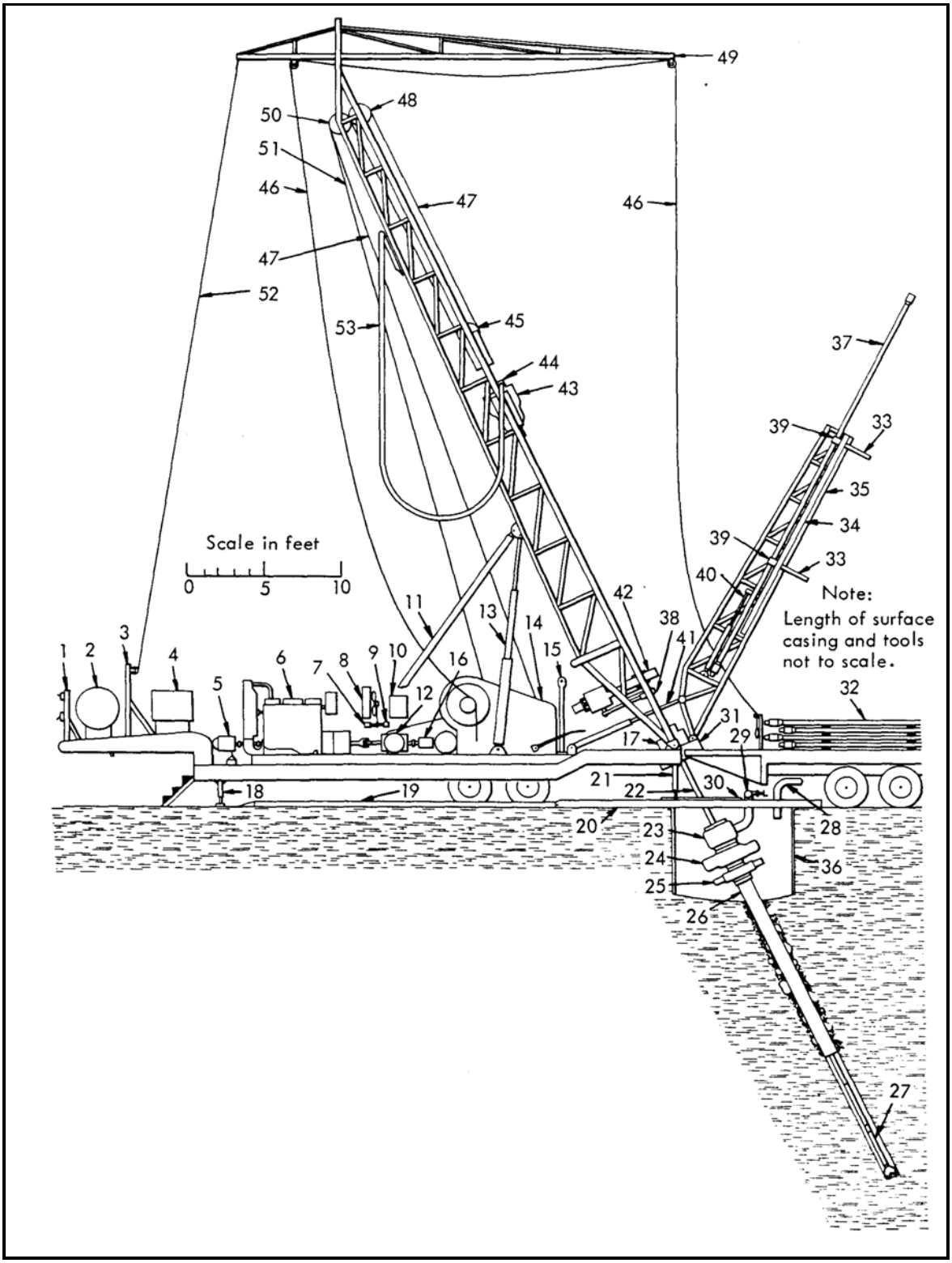

Figure D-4. Hycalog drill rig.

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Table D-1. Hycalog nomenclature.

1 Electrical panel	28 Vacuum vent line
2 Fuel tank	29 Mud return line and valve
3 Derrick lay-down support	30 Sliding cellar doors
4 Main hydraulic reservoir	31 Derrick base
5 Main hydraulic pump	32 Drill pipe and trailer
6 Diesel engine	33 Pipe clamp hydraulic cylinder
7 Hydraulic motor	34 Pipe handler carriage
8 Oil cooler	35 Pipe handler frame
9 Transfer hydraulic pump	36 Cellar casing
10 Auxiliary hydraulic reservoir	37 Drill pipe
11 Derrick stiff leg	38 Backup tongs
12 90° angle drive	39 Pipe clamp
13 Derrick lift cylinder	40 Carriage travel hydraulic cylinder
14 Draw works	41 Pipe handler hydraulic cylinder
15 Derrick lay-down frame	42 Hydraulic-powered pipe breakout tongs
16 Auxiliary hydraulic pump	43 Power swivel assembly
17 Spider assembly, pipe slips	44 Power swivel hydraulic motors
18 Trailer support	45 Traveling blocks
19 Wheel guides	46 Cat line
20 Cellar containment cover	47 Drilling line
21 Rig stabilizer leg	48 Crown blocks
22 Drill string	49 Cat line boom
23 Rotating head	50 Secondary crown blocks
24 Blowout preventer	51 Sand line
25 Abandonment valve	52 Boom guy line
26 10-3/4-in. surface casing	53 Represents mud hose and hydraulic pressure return and drain lines
27 Applicable tools	

D.2 Radioactivity Releases and Personnel Exposure

The drill bit must be cooled and lubricated to operate efficiently, the rigid connection between surface and bit is made up of sections of pipe (called joints) that carry fluid (drill mud) to the bit. The drill mud cools and lubricates the drill bit and the fluid performs an additional important function of carrying the cuttings made by the bit up to the surface and out of the hole. The drill mud is forced down the inside of the pipe and out through the bit to return to the surface in the annular space between the outside of the pipe and the sidewalls of the hole, washing the bit cuttings to the surface. Circulation is lost when the bit penetrates a porous zone, which allows the drill mud to leak away into the surrounding formation. As drill mud was released around the drill bit, it was made up from the mud pit as the drilling continued.

The drilling process continued after the drill bit had entered the fracture zone, with the continuing flow of drill mud around the drill bit. The mudflow helped to absorb radioactive particulates and the radioiodines, but the noble gases were not absorbed. Because the noble gases did not attach to the drill mud, they could be released up through the fracture zone around the drill string on to the drill platform area. This potentially resulted in a cloud of noble gases. The workers could have been in the noble gas clouds for several hours at a time over several days during the post-test drilling and core-sampling process. The possibility of long residence times for noble gases in the lungs is based

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on the length of the exposure time. This situation continued until the introduction of blowout preventers (BOPs) in late 1964 (see Section D.4). Table D-2 lists the characteristics of the most common radioactive noble gases. Of these, ^{133,133m}Xe were the most prevalent at times greater than 2 to 3 d after detonation.

Table D-2. Primary fission product noble gases with half-lives greater than 1 hr (for yields equal to or greater than 0.01 photon or beta per disintegration).

Nuclide	X-ray emission[a]		Gamma emission		Beta emission	
	Energy (keV)	Yield (X-rays/dis[b])	Energy (keV)	Yield (γ/dis)	Energy (keV)	Yield (β/dis)
Kr-85 (10.7 yr)	-	-	-	-	687	0.996
Kr-85m (4.5 hr)	-	-	151	0.75	841	0.783
			305	0.14		
Kr-87 (76.3 m)	-	-	403	0.496	924	0.044
			674	0.019	1,330	0.094
			845	0.073	1,470	0.055
			1,175	0.011	3,040	0.073
			1,740	0.020	3,482	0.41
			2,012	0.029	3,885	0.305
			2,555	0.092		
			2,558	0.039		
Kr-88 (2.84 hr)	-	-	27.5	0.019	366	0.026
			166	0.031	522	0.670
			196	0.260	682	0.091
			362	0.022	1,199	0.020
			835	0.130	1,732	0.010
			986	0.013	2,052	0.013
			1,141	0.013	2,718	0.021
			1,251	0.011	2,914	0.140
			1,370	0.015		
			1,518	0.022		
			1,530	0.109		
			2,030	0.045		
			2,035	0.037		
			2,196	0.132		
			2,232	0.034		
			2,392	0.346		
Xe-133 (5.24 d)	30.6	0.144	81	0.380	346	0.99
	31.0	0.265				
	34.9	0.025				
	35.0	0.048				
	35.8	0.015				
Xe-133m (2.19 d)	29.5	0.162	233	0.10	-	-
	29.8	0.299				
	33.6	0.080				
	34.4	0.016				
Xe-135 (9.14 hr)	30.6	0.015	250	0.90	543	0.031
	31.0	0.028	608	0.029	901	0.96

a. X-rays with energies greater than 15 keV.
b. dis = disintegration

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Figure D-5 shows the flow of the drill mud. From the pump (A), the fluid goes to the swivel (B) down through the Kelly (C) through the drill stem (D) to the bit (E). At the bit, the drilling fluid washes the cuttings from the bit and the bottom of the hole and carries them back to the surface through the annulus (F). At the surface, a pipe carries the cuttings in suspension through a shale shaker (G), which removes the cuttings from the drilling fluid. From the shaker, the drilling fluid goes to the mud pit (H) and then down to the drill bit to the drilling area (Butler 1984).

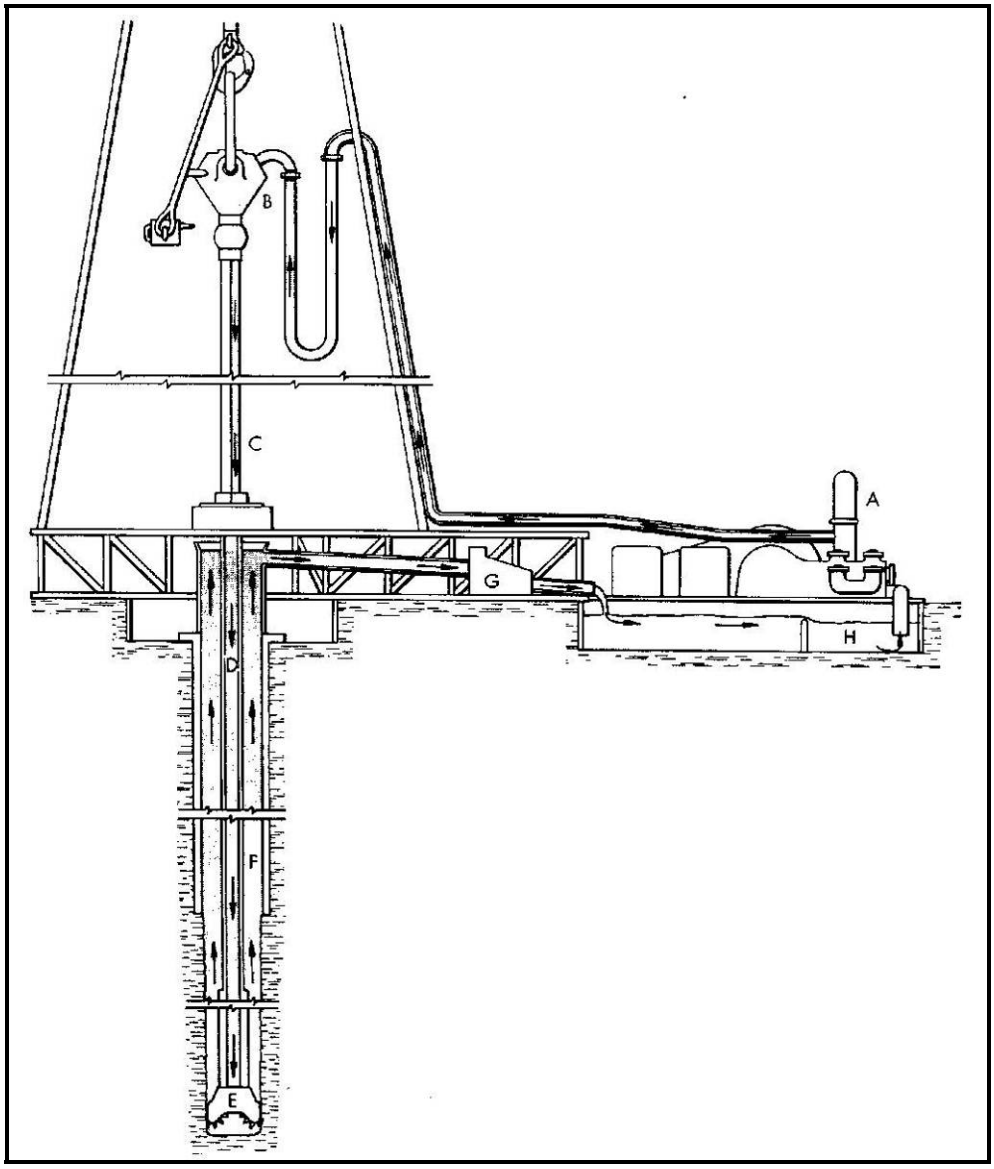

Figure D-5. Circulation of drilling fluid.

The radioiodines that escaped were considered primarily an internal thyroid organ exposure hazard, while the noble gases were of concern for immersion dose (external exposure) and lung dose. In addition, the drill mud trapped most of the radioiodines, which limited the release.

D.3 Core Sampling

When the post-test hole had been drilled through the target zone as determined by the LLNL drilling engineers and the LANL J-6 NTS engineer, preparations were made to take puddle glass samples. The radionuclides present would be based on the time interval from test to sampling. A gamma-logging instrument was lowered inside the drill pipe to survey the puddle glass region. The laboratory drilling representative examined the gamma log and determined where the samples should be taken. When the decision to begin coring was made, the drill string had to be removed so that the Otis and coring subs could be placed in the drill string. The drill string (which now contained the sidewall sampler near its lower end) was pulled up the hole to place the sampling port in position for the first sample, the sidewall tool plug was pulled, and the sampling operation began.

LLNL and LANL used very similar sampling processes. The LLNL onsite representative (usually a radiochemist) along with an NTS Health and Safety representative provided direction on the hygrading, packaging, survey, and shipment. For LANL, the J-6 NTS representative was responsible for the coring operation and the LANL safety representative provided radiological safety operations coverage of the sampling. The LANL Isotope and Nuclear Chemistry (INC) Representative was responsible for providing sampling and downhole radiological monitoring and core sampling requirements including hygrading. The LANL INC representative was also responsible for packaging, onsite storage, and shipping of the core samples to Las Alamos for analysis through the J-3 NTS warehouse (Eberhart 1993).

For both laboratories the samples were taken with a sidewall sampling tool (Figure D-6), which cut into the wall of the hole to obtain cores about 1.5 in. in diameter by 6 in. long (LLNL used the Hunt Tool or Homeco Tool, LANL used the Hunt Tool). Several core samples up to as high as a few dozen could normally be taken in a hole. The best samples were hygraded, selected, and put into a plastic container that was corked and placed in a lead pig. The samples were then prepared for shipment to the laboratory for analysis either through Warehouse No. 7 for LLNL (Butler 1984) or Warehouse J-3 for LANL (Eberhart 1993). Both laboratories used tongs and extended tools for core hygrading. Although these samples, which read several roentgens per hour, were handled quickly, core-handling operations were a major exposure component.

D.4 Radioactivity Control Measures

The use of BOPs to contain the radioactive gases began in 1964. The containment equipment then consisted of three major components: the abandonment valve at the top of the preset casing, the ram unit (BOP) above it, and the rotating head (Figure D-7).

The ram unit contained two sets of rams for shutting off flow: 1) blind rams that sealed the hole when the drill pipe was withdrawn (as when a bit or a tool was being changed), and 2) pipe rams that sealed off the space between the casing and the drill pipe when the drill pipe was in the hole. These rams could withstand pressures of 6,000 psi. The rotating head was lined with a thick rubber gasket that surrounded the drill pipe or Kelly and turned with it, which provided a low-pressure seal against escaping gas or fluid while drilling was in progress.

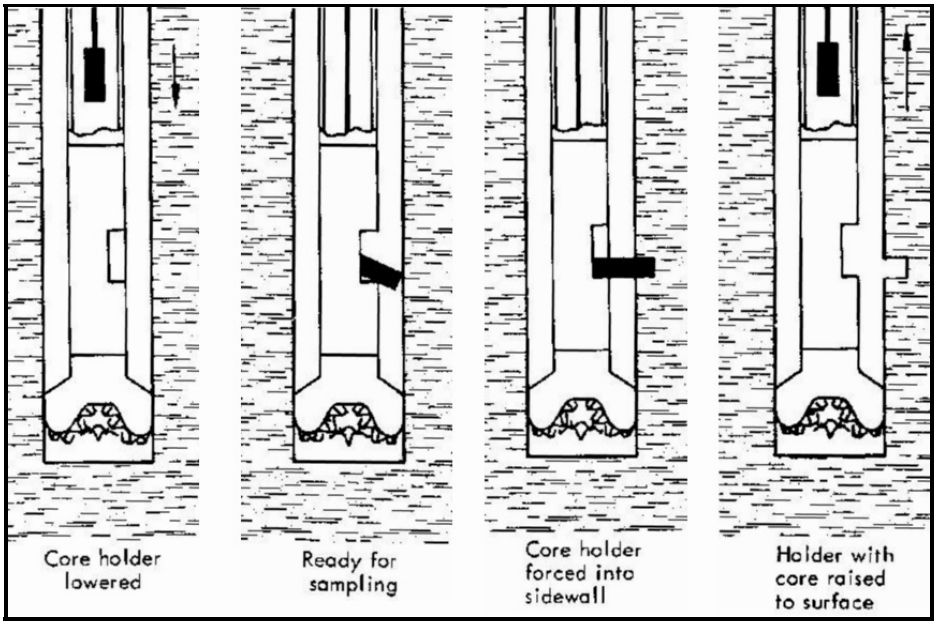

Figure D-6. Four steps in taking a sidewall sample (Butler 1984).

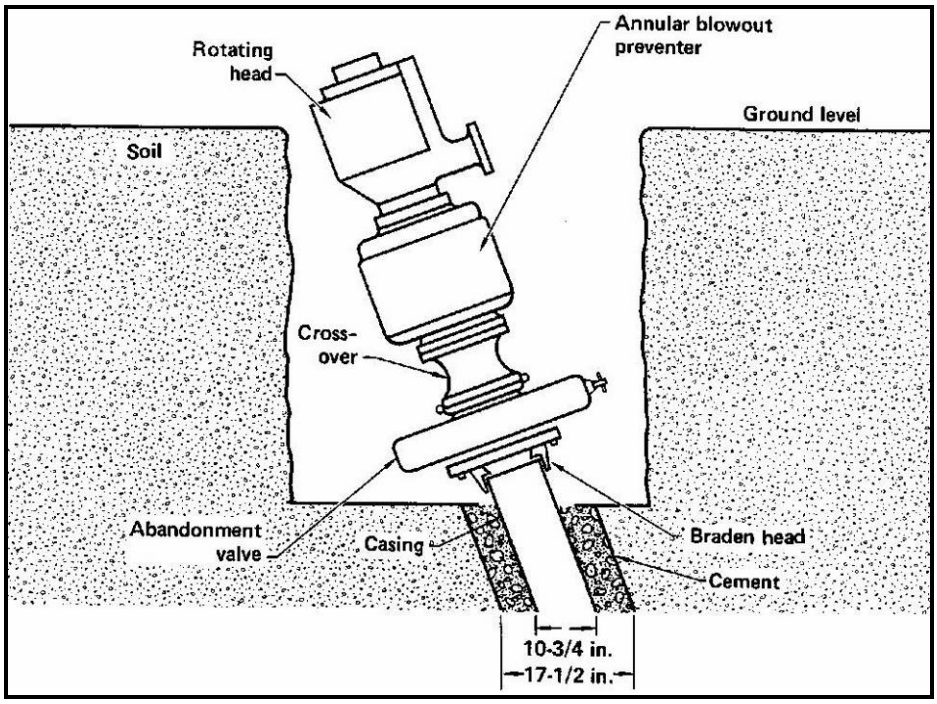

Figure D-7. Blowout preventer.

After the use of BOPs began, the first post-test drilling activity following detonation was the installation of the BOP on top of the preset casing. For low-yield tests, this installation could have occurred before the test. After the BOP was installed, the ventilation system was connected to the BOP and the drill rig cellar area. The ventilation system contained two sets of charcoal filter beds,

gas-sampling and analysis equipment, and 2,000-cfm blowers on each train that drew air from the BOP. The preset casing was several inches wider in diameter than the drill string. When circulation was lost, the radioactive gases that came up around the drill string (annulus) were pulled off through the BOP by the ventilation system. This reduced the noble gas doses on the drill rig platform.

Both LLNL and LANL used BOPs. The flow from the BOP, the cellar, and the flow through the sampling trailer to the ventilation systems were checked for normal operation before the start of LLNL drilling. LLNL had a core-hygrading trailer and a gas-sampling and analysis system hooked to the ventilation system. LANL used a post-test containment system that had a 20-ft stack using a BOP (Eberhart 1993).

Other precautions were taken to reduce release of radioactivity to the surface after circulation was lost. Significant activity was trapped by the BOP and sent out through the ventilation system. However, a procedure of sending soap down the drill hole caused large quantities of bubbles to flow into the fracture zone, which also reduced gaseous releases. Some minor amounts could be released through the core-sampling process and through the drill stem, but the exposure was insignificant in comparison to the gas fields caused by loss of circulatory pressure before use of the BOPs. The use of BOPs, soap, and the ventilation systems resulted in a significant reduction in the exposure from the noble gases during drill-back operations.

D.5 Post-Test Radiation Monitoring

The LLNL NTS Health and Safety Engineers that supported a post-test drilling operation had three main responsibilities (Johnson et al. 1966, Appendix 8):

- To protect personnel from radiological and toxicological hazards
- To determine the type and amount of radioactive effluents
- To process radioactive core samples for shipment or storage

The Health and Safety engineers depended on REECo Rad-Safe as their main support unit. The routine sampling and monitoring program on the drill rigs and on the area perimeter was carried out by Rad-Safe under the overall coordination of LLNL NTS Health and Safety group. The sampling program was standardized as far as possible, and changes were made only when necessary because of changing conditions.

Protection of personnel from radiological and toxicological hazards was dependent on an effective monitoring program on the drill rigs. The drill rig monitoring program had been divided into two phases: Monitoring with portable instruments and monitoring with stationary instruments that either recorded automatically or gave remote readout and alarm at a central observation point.

Monitoring with portable instruments was carried out by Rad-Safe Monitors in areas where radiation release was most likely. Portable monitoring was usually reserved for critical periods of the post-test drilling operation and for investigating possible hazard situations indicated by the continuously monitoring stationary instruments. Any radiation above background levels was due either to a release of radioactive gas from the retention system or to the shine from a radioactive gas buildup within the system. Airborne gas was distinguished from shine by running a high-volume air sampler for a short period of time (usually 5 to 10 min) and then analyzing the sample.

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Continuous monitoring of the environmental air on the drill rig platform was accomplished by an array of four air-sampling heads on each corner of the platform. This array was activated when drilling began and operated continuously until the abandonment valve was closed. The results of this sampling gave an indication of the exposure, if any, to workers on the platform during the drilling operation.

REECo Rad-Safe monitors made routine hourly surveys of the drill platform and substructures, especially in the vicinity of the BOP and the cellar. During these surveys, the monitor determined the level of radioactivity, the presence and amount of any toxic gases, and the percentage of any explosive mixtures that could have been present. When work had to be performed during the release of radioactive gases (which could have caused increased dose rates), the Rad-Safe monitor periodically checked the workers' personal dosimeters to control excessive exposures. At times when airborne radioactivity was detected and it was necessary to require personnel to wear respiratory gear, the Rad-Safe monitors checked to see that the respiratory protection was fitted properly and being worn correctly. The half-face and full-face respirators were not effective for removing noble gases, but were effective for the removal of radioiodines, radioactive particulates, and toxic materials. If self-contained breathing apparatus was worn, it was effective in eliminating the noble gas exposure, but required periodic air bottle change outs.

Monitoring with remote readout and automatic stationary instruments was standardized and consisted of the following:

- 1 remote air monitoring (RAM) unit on the drill platform for monitoring gamma intensities.
- 1 RAM unit on the mud return line for monitoring gamma intensities (Both of these RAM units had their readouts in the Rad-Safe base station trailer and were recorded on charts).
- 1 gate alarm on the mud return line near the BOP. This unit was generally set to alarm at some point just above normal background; the alarm was positioned where it could be easily seen or heard by the driller.
- 1 gamma alarm on the mast. This instrument was generally set to alarm at about 5 mR/hr.
- 1 CO_2 alarm with its sensing unit near the BOP and its alarm near the driller.

Standard perimeter sampling consisted of an array of 8 to 16 air-sampling trailers (in multiples of 4) and the same number of RAMs evenly spaced around a circle of 1,000 ft or greater radius that covered the drill rig area. Air samples were changed every 8 hr to provide a record of release on any given shift. Rad-Safe had standing instructions to report any radioactivity levels above background to the LLNL Health and Safety engineer and the LANL safety representative (Eberhart 1993) and to keep them informed as conditions changed. All necessary Anti-C clothing and respiratory gear was provided by Rad-Safe. Both LLNL and LANL workers were trained in the use of the various types of respiratory protection equipment (Johnson et al. 1966) and (Eberhart 1993)

An LLNL stack monitor trailer near the vent line blower to monitor for radioactive effluent was standard equipment on all post-test drilling operations. If present, radioactive effluent picked up by the ventilation system was first drawn through a charcoal filter bed, just beyond which Rad-Safe operated

a sequential charcoal filter to sample a small amount of the vent line air. Any iodine not filtered out in the charcoal filter bed was picked up by this sequential sampler, which consisted of 12 charcoal air-filter heads set to operate 2 hr each for a total of 24 hr. The changeover from one filter to the next occurred sequentially and automatically.

LANL had similar monitoring systems in its Rad Lab Trailer, which was under the direction of LANL and was supported by REECo Rad Safe. LANL also had the safety representative on the site for the entire post-test drilling campaign to provide technical direction to the Rad Safe Monitors through coring and gas sampling if required until site closure. This representative provided technical support to the INC Representative for core sampling, analysis, and preparation for core shipments to Las Alamos (Eberhart 1993)

To monitor high-level releases, Health and Safety operated three RAM units on the vent line—one in front of the charcoal filter, one on the charcoal filter, and one after the charcoal filter—that were read in the stack monitor trailer. Releases of a low or intermediate nature were determined by drawing a small volume of the vent-line air through tubing into the stack monitor trailer. The air was scanned by a scintillation system, and the counts were registered on a scaler unit and recorded periodically on tape. If counts in excess of normal background were encountered, they were manipulated with suitable equations to compute the quantity of the release. The velocity of the vent-line air, generally 1,000 to 1,500 ft/min, was automatically recorded in the stack trailer. The stack trailer was equipped with a remote audible alarm in the form of an electronic siren and a visible alarm in the form of colored lights on the end of the trailer. The alarm systems could be preset to trip at any predetermined level. The LANL monitoring system was very similar, and the Rad Safe support was under the technical direction of their HSE-1 representative.

The last function of LLNL NTS Health and Safety, to provide technical direction for processing radioactive core samples for shipment, was accomplished in the following manner. When the core samples had been selected for shipment, the Health and Safety engineer had Rad-Safe place them in pigs and identify each pig with the number of the sample it contained. The Health and Safety engineer then monitored the pigs and attached shipment tags. At this point, the cores for shipment were sent to Warehouse No. 7, and the backup samples were taken for storage in the core library.

As soon as the abandonment valve was closed and determined to be free of leaks, Rad-Safe placed an air-sampling unit next to the cellar. This air-sampling unit operated continuously for 48 hr to monitor for delayed leaks.

As stated above, the LANL INC representative was also responsible for packaging, onsite storage, and shipping of the core samples to Las Alamos for analysis through the J-3 NTS warehouse (Eberhart 1993).

D.6 Exposed Workers

Workers normally present at the time of gaseous releases were REECo drillers, roughnecks, equipment oilers, and Rad Safe monitors. Health physics professionals from LLNL, LANL, and REECo were also present on the drill rigs. Sampling personnel who prepared the core samples for analysis were exposed to direct radiation from the core samples and were a part of this work group.

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After the BOPs were used for post-test drilling, this group of workers was the workers exposed if gaseous releases occurred.