

<p>ORAU Team NIOSH Dose Reconstruction Project</p> <p>Technical Basis Document for the Los Alamos National Laboratory – Site Description</p>	<p>Document Number: ORAUT-TKBS-0010-2 Effective Date: 05/07/2004 Revision No.: 00 Controlled Copy No.: _____ Page 1 of 65</p>
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RECORD OF ISSUE/REVISIONS

ISSUE AUTHORIZATION DATE	EFFECTIVE DATE	REV. NO.	DESCRIPTION
Draft	11/17/2003	00-A	New technical basis document for the Los Alamos National Laboratory – Site Description. Initiated by Jack Buddenbaum.
Draft	04/13/2004	00-B	Incorporates internal review comments. Initiated by Jack Buddenbaum.
05/07/2004	05/07/2004	00	First approved issue. Initiated by Jack Buddenbaum.

ACRONYMS AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
a.k.a.	also known as
Be	beryllium
Ba	barium
C	Celsius
CEDE	committed effective dose equivalent
cfm	cubic feet per minute
Ci	curie
cm ³	cubic centimeter
CMR	Chemistry and Metallurgy Research
cpm	counts per minute
DARHT	Dual Axis Radiographic Hydrodynamics Test
dpm	disintegrations per minute
DU	depleted uranium
EU	enriched uranium
F	Fahrenheit
fCi	femtocurie
fpm	feet per minute
ft	foot
ft ³	cubic foot
g	gram
gal	gallon
gpm	gallons per minute
HE	high explosives
HTGR	High Temperature Gas Reactor
HYPO	high-power [Water Boiler]
in.	inch
keV	kilovolt-electron, 1,000 electron volts
kg	kilogram
kJ	kilojoule
km	kilometer
km ²	square kilometer
kW	kilowatt
kWh	kilowatt-hour

L	liter
La	lanthanum
LAMPF	Los Alamos Meson Physics Facility
LAMPRE	Los Alamos Molten Plutonium Reactor Experiment
LANL	Los Alamos National Laboratory (as of January 1981)
LANSCE	Los Alamos Neutron Science Center
LAPRE	Los Alamos Power Reactor Experiment
LASL	Los Alamos Scientific Laboratory (1943 to 1981)
LOFC	
LOPO	low-power [Water Boiler]
m ³	cubic meter
mA	milliampere
MAP	mixed activation products
mCi	millicurie
MDA	Materials Disposal Area
MeV	megavolt-electron, 1 million electron volts
MFP	Mixed Fission Products
mi	mile
min	minute
MPC	maximum permissible concentration
mph	miles per hour
mR	milliroentgen
mrem	millirem
MV	megavolt, 1 million volts
MW	megawatt
MWh	megawatt-hour
NASA	National Aeronautics and Space Administration
NTS	Nevada Test Site
OWR	Omega West Reactor
OWREX	Omega West Reactor Experiment
pCi	picocurie
PHERMEX	Pulsed High-Energy Radiation Machine Emitting X-Rays
psi	pounds per square inch
Po	polonium
PSR	Proton Storage Ring
Pu	plutonium
PVAP	Particulate and Vapor Activation Products
R	roentgen
Ra	radium
RaLa	Radioactive Lanthanum

SIS	Special Isotope Separation
SUPO	super-power [Water Boiler] (assumed)
t	ton
TA	technical area
TSTA	Tritium Systems Test Assembly
VFP	Volatile Fission Product
WNR	Weapons Neutron Research Facility
U	uranium
μCi	microcurie
μg	microgram
UHTREX	Ultra High Temperature Reactor Experiment
μm	micrometer

2.1 INTRODUCTION

Technical Basis Documents and Site Profile Documents are general working documents that provide guidance concerning 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 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 facility” as defined in the Energy Employee Occupational Illness Compensation Program Act of 2000 (42 U.S.C. § 7384I (5) and (12)).

The U.S. Department of Energy owns the Los Alamos National Laboratory (LANL) in northern New Mexico. LANL is also referred to as the “Lab” in this document. The University of California has managed the laboratory since its establishment in 1943 as part of the Manhattan Project to create the first atomic weapons. The facility name was Los Alamos Scientific Laboratory until 1981. LANL’s responsibilities have expanded since then to include thermonuclear weapons design, high explosives and ordnance development and testing, weapons safety, nuclear reactor research, waste disposal, waste incineration, chemistry, criticality experimentation, tritium handling, biophysics, and radiobiology.

After World War II, LANL’s primary mission has been to serve as an experimental facility for defense related programs and for basic scientific research and development (R&D). While at times LANL has provided production capacity as a backup to other U.S. nuclear weapon sites, its primary R&D mission has largely continued uninterrupted throughout the lab’s history and to the present day. The development of these LANL Technical Basis Documents (TBDs) is particularly challenging due to the wide range of research and development activities and intermittent involvement in the production and testing of nuclear weapons. The challenge in developing the LANL TBDs is, in part, to account for the many changes that have occurred over the lab’s history with regards to radioactive sources of occupational exposures and the facilities and processes within which these sources were present.

The diversity of lab operations may be second-to-none when compared to other sites within the DOE complex. With a few exceptions, most man-made or natural radionuclides known to exist have, at one time or another, been present and/or processed at LANL. Many of these have been handled in small quantities for research and development while others were experimented with and processed on much larger scales (e.g., plutonium isotopes). This document attempts to highlight those radioactive materials or radiation sources that can be tied to particular operations and have been well documented over time. **As new information becomes available or as claimant information requirements change or expand over time, descriptions of other sources of radiation at LANL will be added to this document in future revisions.**

Section 2.2 describes general site activities and lists site facilities. Section 2.3 discusses individual processes.

2.2 SITE ACTIVITIES OVERVIEW

When the Los Alamos facility opened, it had a single mission—perfection of the design and manufacture of the first atomic weapons. The initial plan for the first atomic weapon was for a gun-assembled device that would use slow-burning propellants, as shown in concept in Figure 2-1. Gun-assembled weapons can be designed on the principle of using a propellant to drive a mass of

fissile material at a target of the same material to attain a supercritical assembly. To develop and build gun-assembled weapons, Los Alamos personnel initially experimented with enriched uranium and plutonium as the fissionable material. Other necessary materials included the explosive propellant, a detonator to set off that propellant, and precision-machined housings to support assembly of the critical mass in the necessary configuration within the required time frame. Part of the housings were cases of heavy metal, such as uranium, called tampers, that confined the explosion, reflected some neutrons that would otherwise escape, and thereby decreased the critical mass of fissile material required to give rise to an atomic explosion.

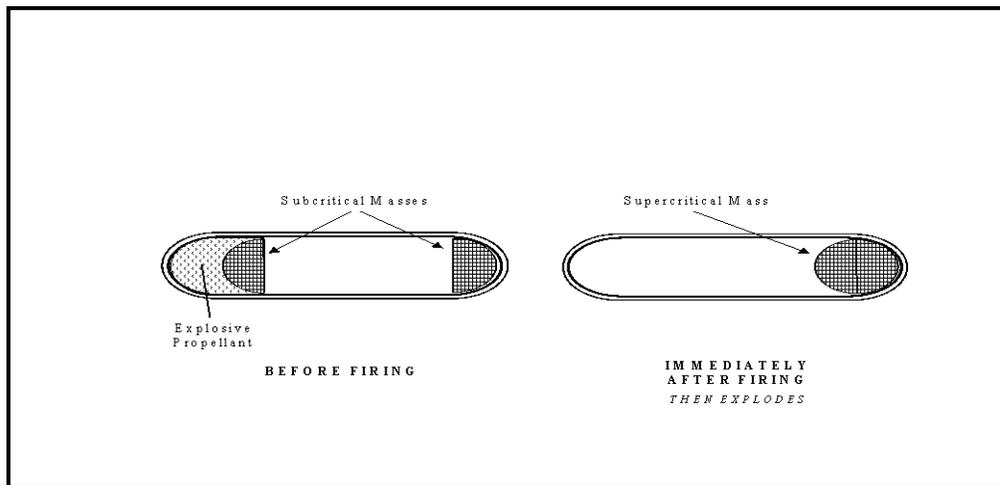


Figure 2-1. Concept of a gun-assembled atomic weapon (LANL 1983).

Early development work centered on use of ^{235}U or ^{239}Pu in gun-assembled devices. Top priority was given to development of a plutonium-projectile gun device, which posed more problems than the uranium design due to tighter purity specifications and the need for a faster assembly velocity. In July 1944, it was found that the plutonium received at Los Alamos would not work in gun-assembled weapons because of the presence of more of the ^{240}Pu isotope than expected amidst the desired ^{239}Pu . The spontaneous neutron emission rate from that ^{240}Pu was several hundred times greater than allowable. As a result, while research on the certain-to-work enriched uranium gun-assembled weapon continued, development of a plutonium device shifted to an implosion-assembled design.

A second design was needed because the delivery rate for enriched uranium would only support production of a single uranium weapon within the imposed schedule, and it was thought that more than one weapon would be necessary. Implosion-assembled weapons can be designed on the principle of compressing the fissile material to super-criticality by detonation of a high-explosive implosion-assembled system. Figure 2-2 shows a concept of the implosion bomb.

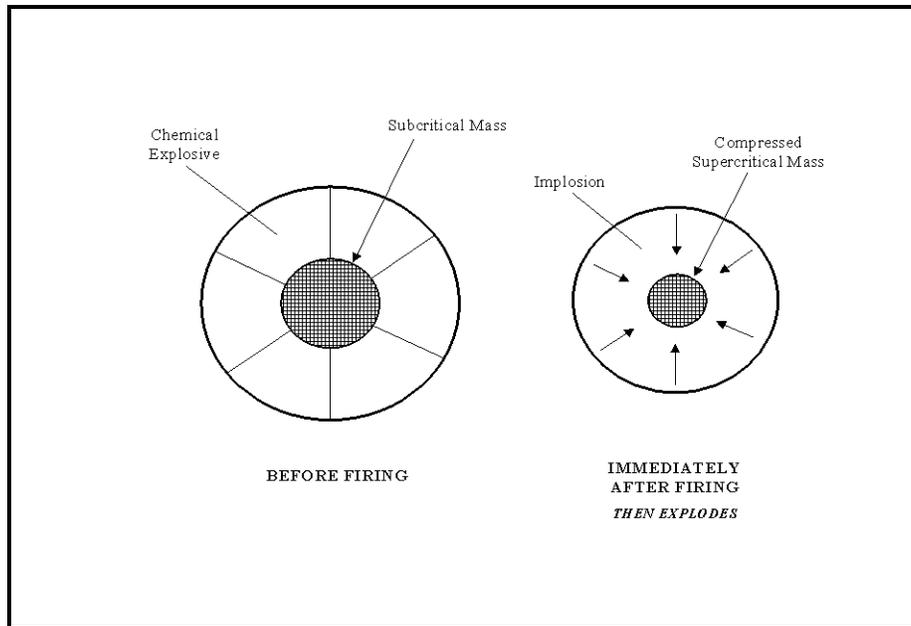


Figure 2-2. Concept of the implosion-assembled atomic weapon (LANL 1983).

To develop and build implosion-assembled devices, much experimentation had to be done with chemical high explosives to achieve precise assembly of something with great symmetry, in contrast to the typical destructive use of explosives. In addition to fissionable material, high explosives, detonators, and tamper material, work on implosion-assembled devices included development of initiators that acted as strong sources of neutrons at the precise time that the supercritical masses came into position. These initiators used materials including ^{226}Ra , ^{210}Po , and beryllium.

With the successful demonstration of fission devices, scientists were able to achieve the high temperatures necessary to bring about fusion of hydrogen nuclei for use in the superbomb that had been studied for years as a theoretical possibility. Viewed by some as Los Alamos' second historic mission, development of thermonuclear or hydrogen devices led to the first full-scale testing in the Mike shot in the Pacific in late 1952. Thermonuclear devices rely on a two-stage process, in which energy from a fission primary is contained and used to trigger a fusion or fusion-fission reaction in a physically separate, secondary portion of the device. Figure 2-3 shows these concepts of a staged thermonuclear weapon.

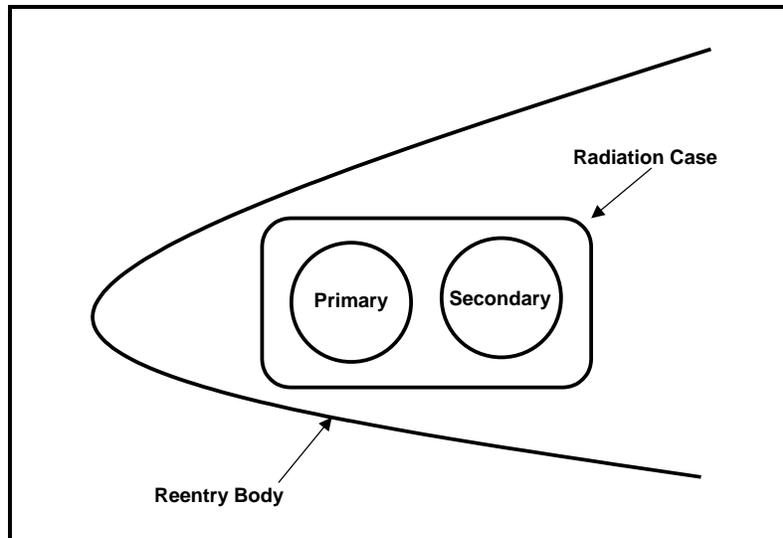


Figure 2-3. Concept of a staged nuclear weapon (LANL 1983).

Materials needed for thermonuclear devices included many of those for a gun-assembled or implosion-assembled device, plus fuel for the fusion reaction. The first thermonuclear devices used liquid fuel, such as deuterium, which required significant developments in cryogenics to keep the fuel below its boiling point of -250°C . Later devices used lithium deuteride fuel, in solid form, which breeds tritium when exposed to neutrons.

After World War II, Los Alamos scientists and engineers were involved in development and testing of numerous designs of nuclear devices. These new devices were designed to be more powerful, compact, reliable, dependably deployable in the field, and packaged in a variety of delivery vehicles suited to various combat objectives. They were involved in many tests of nuclear devices in the continental United States, the Pacific, and Alaska, including some that were part of the Plowshare program for development of peaceful applications for nuclear explosives.

Los Alamos was the lead site for U.S. nuclear component fabrication until 1949, when the Hanford Plutonium Finishing Plant in Washington began making pits, the central cores of the primary stages of nuclear devices. In 1952, the Rocky Flats Plant near Denver began making pit components. After 1949, Los Alamos was a backup production facility and designed, developed, and fabricated nuclear components for test devices. Pit production stopped at the Hanford facility in 1965, and the Rocky Flats Plant ceased operations in 1989. LANL is the only remaining U.S. pit production facility. From time to time, Los Alamos performed special functions in its backup role. For example, because of an accident at the Hanford Plutonium Finishing Plant in 1984, plutonium was sent in oxide form to Los Alamos for conversion to metal. In addition, Los Alamos served in a backup for limited periods after major fires in plutonium facilities at Rocky Flats in 1957 and 1969.

Operations, facilities, and capabilities to support development and production of the various types of nuclear devices expanded in many cases to support other missions after World War II. Programs in chemistry, metallurgy, and low-temperature physics expanded into nonmilitary development and fundamental research. For example, Los Alamos developed one of the largest experimental machine shops in the country. The Health Division grew significantly, expanding into many areas of health physics, industrial hygiene, medicine, safety, and biomedical research in relation to people and radiation. Early reactors, built to confirm critical masses for fissionable materials and to study properties of fission and the behavior of the resultant neutrons, were the forerunners of a variety of

reactors designed, and in some cases built and operated, at Los Alamos. While some of these reactors served as sources of neutrons for various nuclear research or for materials testing, other designs related to potential applications in power generation and propulsion of nuclear rockets into deep space. Some of the first significant steps towards controlled nuclear fusion as a power source were taken at Los Alamos, and the plasma thermocouple program explored methods for direct conversion of fission energy to electricity for potential application in spacecraft.

Operations at Los Alamos have taken place in land divisions called technical areas (TAs). The current convention for describing locations at LANL is TA-3-66, where 3 is the area number and 66 is the building number. For TA-3, buildings are identified by letters (for example, TA-3-29 Building 29). Some buildings in TA-3 are identified as SM-66 for South Mesa Site.

Table 2-1 lists all TAs, including date abandoned, date combined with other TAs, and cancelled if never operational. (Section 2.3 lists the details of operations, if known.) The table shows the radionuclides known to have been used in operations at each TA. Figure 2-4 shows the present TAs, and Figure 2-5 shows a timeline of some selected operations and activities at or related to Los Alamos.

Table 2-1. LANL technical areas.

TA	Name and description	Radiation sources ^{a,b}
TA-0	Los Alamos Townsite: leased space in Los Alamos and White Rock for training, support, unclassified research and development, community outreach, museum	None
TA-1	Original Main Technical Area (inactive): 1943-65 active; turned over to Los Alamos County or private interest in 1966; all contamination removed by 1975.	enriched U, DU, ^{238,239} Pu, ²⁴¹ Am, ²¹⁰ Po, ¹⁴⁰ Ba, ¹⁴⁰ La
TA-2	a.k.a Omega Site: Early critical assembly experiments. Water Boilers (1944-1974); Pu Fast Reactor, a.k.a. Clementine (1946-1952) was disassembled in 1953; and Omega West Reactor (1956-1992); reactors used for critical experiments up until 1946 when experiments were moved to TA-18. Omega Site reactors operations were then centered around neutron experiments and isotope production. Major decommissioning activity took place in 1991.	²³⁵ U; ²³⁹ Pu; ¹³¹ I; ⁸⁸ Rb; ¹³⁷ Cs; ¹³¹ Xe; ¹²⁵ I; ⁴¹ Ar, ³ H
TA-3	Core Area (a.k.a. ^c South Mesa Site; active 1949 to present): detonator manufacturing, metallurgy burn pit, firing sites from 1943-49. Listed below is brief descriptions of key TA-3 operations.	^{238,239} Pu, ^{235,238} U, DU, U-natural, ²¹⁰ Po,
TA-3-SM-16	Van De Graaff – Accelerator and Tritium operations.	³ H
TA-3-29	Chemistry and Metallurgy Research: actinide chemistry and metallurgy research since 1952 to present	²³⁹ Pu; ²³⁸ Pu; ²³⁵ U; ²³⁸ U, DU
TA-3-34	Cryogenics laboratory.	³ H
TA-3-66	Sigma: materials fabrication since 1958; also -141 Rolling Mill, -35 Press Bldg, -159 thorium storage	²³⁵ U; DU
TA-3-1698	Materials Science Laboratory: processing, mechanical research	DU
TA-3-39,102	Machine shops: since 1953; Be in Bldg 39, DU in Bldg 102	DU
TA-4	Alpha Site: Constructed in 1944 as a test firing site for small to medium explosives. Firing site until 1956; Material Disposal Area C. During the summer of 1985, a clean-up operation was initiated as part of the Los Alamos Site Characterization Program. All remaining structures and their utilities were removed.	DU
TA-5	Beta Site: former firing site used extensively in 1945. Site was constructed in 1944 as a test-firing site. Environmental contaminants at this site may	DU

	include natural or depleted uranium, beryllium, and/or cadmium. Burial of debris of firing sites during the years prior to 1985.	
TA-6	Two-Mile Mesa Site: mostly undeveloped; detonator manufacturing and testing 1944-50. In the spring of 1945, a detonator manufacturing and testing laboratory consisting of one main building and several test structures were constructed.	DU
TA-7	Gomez Ranch Site: former firing site used from 1944-47 for small explosive experiments with short-lived radionuclides	DU; unknown
TA-8	GT Site (a.k.a. Anchor Site West): gun firing sites 1943-45; explosives processing 1945-50; nondestructive X-ray testing 1950-present	²³⁹ Pu; ²³⁸ Pu; ²³⁵ U; DU; ⁶⁰ Co; ¹⁹² Ir; ¹³⁷ Cs; X-rays
TA-9	Anchor Site East (a.k.a. Anchor Ranch): firing areas; explosives research (active). In 1957, the new TA-9 site included a laboratory and office buildings, six magazines, a shop, two laboratory buildings, process laboratories, machining building, and an environmental test chamber.	DU; ³ H
TA-10	Bayo Canyon: Radioactive lanthanum test shots 1944-61; Radioactive lanthanum radiochemistry 1944-50; site removed in 1963. In 1944, Bayo Canyon began to be used for firing experiments. In 1945, additional permanent structures were completed for chemistry work and firing (LASL 1947). Best estimates are that from 1944 until 1961, when firing ceased, approximately 2,000 kg of natural uranium and 3,380 kg of depleted uranium were released (LANL 1986). In 1963, all remaining buildings were removed.	⁹⁰ Sr; DU; NU; ¹⁴⁰ La
TA-11	K Site (active): implosion studies; later drop and vibration tests, TA-11 was constructed in the winter of 1944-45. The eastern part of the site, K-Site (east), was constructed of a heavily bunkered control/laboratory building, a shop, a laboratory, storage building, and a smelter (LANL 1980)..	DU; ²²⁶ Ra, betatron
TA-12	L Site: explosives testing Constructed in early spring of 1948. In the mid 1950s the firing site was abandoned	DU
TA-13	P Site: X-ray studies of explosives; later incorporated with TA-16, status unknown. This site was constructed in the early fall of 1944 for x-ray work in connection with explosives experiments (LASL 1947:10). By 1950s all the buildings except TA_13-2, -3, and -4 had been removed. These buildings were absorbed into the S-site Complex, TA-16, and were renumbered TA-16-476, -477, and -478 respectively	X-rays, DU, ²¹⁰ Po
TA-14	Q Site (active): explosives testing 1944-present. Q-Site was constructed in 1944 for close observation work on small explosive charges. In 1952, the site was completely renovated and several structures were removed In the early 1950s, a new extensive firing complex was built and remains at the site today. During the long history, TA-14 has remained an active firing site.	DU

Table 2-1. (Continued)

TA	Name and description	Radiation sources ^{a,b}
TA-15	R Site: In 1944, a small control building and two firing sites were established. In the upcoming years, the following activities took place; explosives testing; eight inactive firing sites (A-H, R44, R45); Pulsed High-Energy Radiation Machine Emitting X-Rays (PHERMEX) 1962-present; Dual-Axis Radiographic Hydrodynamics Test (DARHT) Facility. PHERMEX is a multiple-cavity electron accelerator capable of producing a very large flux of x-rays for weapons development testing. DARHT is intended to replace PHERMEX (Dateline: Los Alamos 1995 Special Issue). In 1949, firing sites J and I, were in operation but were later transferred to Kappa Site (TA-36). Several structures were removed in 1967 (LANL 1986).	²³⁹ Pu; DU; ³ H; X-rays
TA-16	S Site (active): former explosives casting/machining operations; burning ground; Weapons Engineering Tritium Facility. Began in the 1950s. TA-16 is the weapons Engineering Tritium Facility for tritium handled in glove	²³⁹ Pu; DU; ³ H; X-rays, ²³⁸ U

	boxes. Built in 1945 to make full-scale castings. The WETF facility at TA-16 replaced the tritium facility at TA-33. TA-16 as a whole was constructed in 1944 and consisted of six buildings including a steam plant. Multiple buildings at this site were demolished in the 1950s and 1960s	
TA-17	X Site (canceled)	None
TA-18	Pajarito Laboratory: criticality testing 1946-present; Rover 1955-73; Hydro assembly 1957. This site was first used in mid-1943, by the Radioactivity Group. About 1 year later that group moved to the East Gate Laboratory. The Pajarito Canyon site, the nation's first critical assembly facility, was rushed to completion in April 1947. A heavily bunkered laboratory was built at the junction of the two canyons, and a trimming building and magazine were constructed back along the road toward Anchor Ranch (LASL 1979). In 1979, 20 grams of UF ⁶ were released from Building 23 at TA-18.	²³⁵ U; ²³⁹ Pu; ²⁴⁰ Pu; ²³³ U; MFP; ¹³¹ I; polonium; neutron
TA-19	East Gate Laboratory: released to U.S. Atomic Energy Commission in 1962	None
TA-20	Sandia Canyon Site: former firing site abandoned in 1957	DU
TA-21	DP Site: a.k.a. DP Mesa: former plutonium operations (DP West); uranium/polonium operations (DP East); Material Disposal Areas A,B,T,U,V; Tritium Systems Test Assembly, Tritium Science and Fabrication Facility (1945 to 1978) TA-21 was conceived of and built during the spring and summer of 1945 for chemical and metallurgical work. The site as it was developed and used over the years can be divided into two main sections- DP East and DP West. DP East activities primarily consisted of tritium research. DP West activities primarily included inorganic and biochemistry research. In 1977, a transfer of work to the new plutonium facility began and much of the complex was vacated (LANL, 1986).	²³⁹ Pu; ²³⁸ Pu; ²⁴⁰ Pu; ²⁴¹ Pu; ²⁴¹ Am; ²³⁵ U; ²³⁸ U; ²¹⁰ Po; ²²⁷ Ac; ³ H
TA-22	TD (Trap Door) Site: detonator development; shops; disposal pits	DU
TA-23	NU Site: reduced firing load at TA-9 1945-50. Nu Site, TA-23, was constructed in the spring of 1945 for X-Division (LASL 1947). TA-23 is described as primarily a firing site with two laboratories,	Unknown
TA-24	T Site: X-ray studies of explosives; later incorporated with TA-16. T Site was constructed in the fall of 1944 as a service area for x-ray examination of high explosive charges. A year later a large storage magazine was constructed, In 1946, a fire damaged the main laboratory building, and it was rebuilt in the spring of 1947 (LASL 1947). Facilities at TA-16 are believed to have once been TA-24 facilities (LANL, 1986).	X-rays, DU
TA-25	V Site: explosives assembly; later incorporated with TA-16. V Site, with its two main buildings, was constructed in 1944 for experimental work in connection with special assemblies. In 1945, the work was transferred to TD-Site (TA-22) and the site underwent extensive alterations to fit it for S-Site process work on explosive charges. In July 1945, V-Site was taken over by S-Site (LANL 1986)	DU
TA-26	D Site: storage vault and guard building 1946-48; removed in 1966. D-Site was constructed in the summer of 1946, consisted of a concrete storage vault and a small sentry building and guard tower. (LASL 1947).	³ H, ²³⁵ U; ²³³ U
TA-27	Gamma Site: plutonium gun assembly 1945-47. Gamma Site was active from 1944 to late 1946/early 1947. This firing site was an extension of Pajarito Site (TA-18) and during that time (1944-1945) it was called Far Point.	²³⁹ Pu, DU thorium
TA-28	Magazine Area A (active): firing site 1979; explosives storage area	DU
TA-29	Magazine Area B: explosives storage area; abandoned in 1957.	DU
TA-30	Electronics Test Area: electronics testing 1945-48	Unknown
TA-31	East Receiving Yard: 1948-54 warehouses W of airport; removed 1954	Unknown
TA-32	Medical Research Laboratory: bio-research facility; 1943-54; removed in 1954; incinerator use included. TA-32, known as the Rat Lab, was a small area located behind the Zia Company's Supply Division Building. Most	Unknown

	studies performed here were on internal metabolism of radionuclides, which would have necessitated using low concentrations of radioactive materials (LANL 1986).	
TA-33	HP (Hot Point) Site: 1948-56 shaft experiments; High Pressure Tritium Laboratory 1970s; Material Disposal Areas D, E, K. Research at TA-33 released the largest amount of airborne tritium from routine LASL operations. Releases in 1978 were considerably higher than previous years. From 1973 to 1977, the average routine release of tritium gas from TA-33 was 3050 Ci (range 615 to 5916 Ci) ().	³ H
TA-34	New Laboratory Warehouse Area (canceled)	None
TA-35	Ten Site: Radioactive lanthanum 1951-63; Los Alamos Power Reactor Experiment (LAPRE) I/II 1950s; Los Alamos Molten Plutonium Reactor Experiment (LAMPRE) I 1960s; laser fusion research 1974. This site is divided into five facility management units. Work here includes nuclear safeguards research and development that are concerned with techniques for nondestructive detection, identification, and analysis of fissionable isotopes. Research is also done on reactor safety, laser fusion, optical sciences, pulsed-power systems, high-energy physics, tritium fabrication, metallurgy, ceramic technology, and chemical plating (LANL 1986). Major decommissioning activities were completed in 1981: Decommissioning of the Los Alamos Molten Plutonium Reactor Experiment (LAMPRE I) and Decommissioning of a titanium-contaminated laboratory and Removal of contaminated air scrubbers latter being TA-35-7 (DOE 1999).	³ H; ⁹⁰ Sr; ¹⁴⁰ Ba; ¹⁴⁰ La; ²³⁵ U; DU; ²³⁷ Np; Pu; Po; Co; VFP
TA-36	Kappa Site: replaced TAs-9, 23, 12 in 1950; four active firing sites; non-nuclear ordnance and armor	DU
TA-37	Magazine Area C (active): explosives storage area	DU
TA-38	Monterey Site (canceled)	None
TA-39	Ancho Canyon Site: five firing points; incinerator 1955-60; photographic study of the behavior of non-nuclear weapons	NU; DU; thorium
TA-40	DF (Detonator Firing) Site: six firing points; detonator development	³ H
TA-41	W (Weapons Group WX) Site: engineering of nuclear components; fabrication of test materials	³ H; plutonium; uranium; americium
TA-42	Incinerator Site: reduce low-level Pu contaminated waste; abandoned in 1970	All
TA-43	Health Research Laboratory: biological research 1953-70; replaced TA-32	All
TA-44	Los Angeles Shop: experimental machine shop in Los Angeles, CA 1949-58; abandoned in 1958	Unknown
TA-45	Radioactive Liquid Waste Treatment Plant (inactive): removed majority of plutonium before discharge to Acid Canyon	^{238/239} Pu, ^{235/238} U
TA-46	WA Site: Rover batteries 1950-74; U isotope separation 1976-early 1980s; photochemistry research; lasers	²³⁵ U, ²³⁸ U thorium
TA-47	BR Site (Bruns Railhead): shipped materials via Bruns Hospital in Santa Fe near rail line 1943-58; abandoned in 1958	DU; unknown
TA-48	Radiochemistry Site: actinide chemistry and hot cell isotope production, area used for analyzing samples from weapon test shots, 1950s to present	U; TRU; MAP; MFP

Table 2-1. (Continued)

TA	Name and description	Radiation sources ^{a,b}
TA-49	Frijoles Mesa Site: underground hydronuclear experiments 1960-61; now Hazardous Devices Team Training	³ H; plutonium; uranium
TA-50	Waste Management Site: treated liquid wastes before discharge to Mortandad Canyon; replaced TA-45,-35; controlled air incinerator 1976	All
TA-51	Environmental Research Site: animal exposure facility 1962; now studies of impact of waste and waste storage on the environment	⁶⁰ Co, strontium
TA-52	Reactor Development Site: Ultra-High Temperature Reactor Experiment (UHTREX)	²³⁵ U; ²³⁸ Pu; ³ H; VFP; Kr; Xe

TA-53	Los Alamos Neutron Science Center (LANSCE)	³ H; ⁴¹ Ar; ⁷ Be; ¹¹ C; ¹³ N; ¹⁵ O; U
TA-54	Waste Disposal Site: solid wastes; Materials Disposal Areas G, H, J, L	All
TA-55	Plutonium Facility Site (active): replaced TA-21; SNM storage, 1978 to present	²³⁹ Pu; ³ H
TA-56	Subterrene Basalt Site: melting basalt with electrically heated penetrator; abandoned in 1976	Unknown
TA-57	Fenton Hill Site: Hot Dry Rock geothermal project (inactive)	Unknown
TA-58	Two-Mile North Site: experimental sciences for TA-3 programs	Unknown
TA-59	Occupational Health Site: Office of Environment, Safety, and Health offices, emergency management	None
TA-60	Sigma Mesa: Test Fabrication Facility and Rack Assembly; Alignment Complex	Unknown
TA-61	East Jemez Road: physical support and sanitary landfill	Unknown
TA-62	Northwest Site: reserved for experiments, research, buffer zones	Unknown
TA-63	Pajarito Service Area: environmental and waste management functions	Unknown
TA-64	Central Guard Facility, Hazardous Materials Response Team	None
TA-65	Not currently active or never assigned	None
TA-66	Central Technical Support Site: industrial partnership activities	Unknown
TA-67	Pajarito Mesa: former TA-12; dynamic testing area; archeological sites	DU
TA-68	Water Canyon Site: dynamic testing area with study areas	DU
TA-69	Anchor North Site: undeveloped; buffer for the dynamic testing area	Unknown
TA-70	Rio Grande Site: undeveloped; buffer for the high-explosives test area	Unknown
TA-71	Southeast Site: undeveloped; buffer for the high-explosives test area	Unknown
TA-72	East Entry Site: Protective Forces Training Facility	Unknown
TA-73	Los Alamos Airport: on-site disposal area; incinerator 1950s	All
TA-74	Otowi Tract: water wells, archeological sites, endangered breeding area	None
Pacific	Nuclear tests: Marshall Islands (1945-51)	All
AK	Nuclear tests: Amchitka (Long Shot, Milrow, Cannikin) 1965,1969,1971	All
NV	Nuclear tests, non-NTS: Fallon (Shoal); Tonopah (Faultless) 1968	All
CO	Nuclear tests: Grand Valley (Rulison) 1970; Rifle (Rio Blanco) 1973	All esp. ³ H; ⁸⁵ Kr
NM	Nuclear tests: White Sands (Trinity) 1945; Carlsbad (Gnome) 1961; Farmington (Gasbuggy) 1967	All esp. ¹³¹ I; ¹³³ I; ¹³⁵ I; ¹³⁷ Cs; ¹⁴⁰ Ba/ ¹⁴⁰ La
MS	Nuclear tests: Hattiesburg (Salmon and Sterling)	Unknown

- a. All = ²³⁹Pu; ²⁴⁰Pu; ²³⁸Pu; ²⁴¹Am; ²³⁵U; DU; ³H; ²¹⁰Po; ²²⁷Ac; ²²⁶Ra; DU = depleted-²³⁸U; MAP = mixed activation products (e.g., ⁴¹Ar; ⁷Be; ¹¹C; ¹³N; ¹⁵O); MFP = mixed fission products; NU = natural uranium; VFP = volatile fission products.
- b. Element names without number (e.g., plutonium, uranium) indicate isotope not specified.
- c. a.k.a. = also known as.

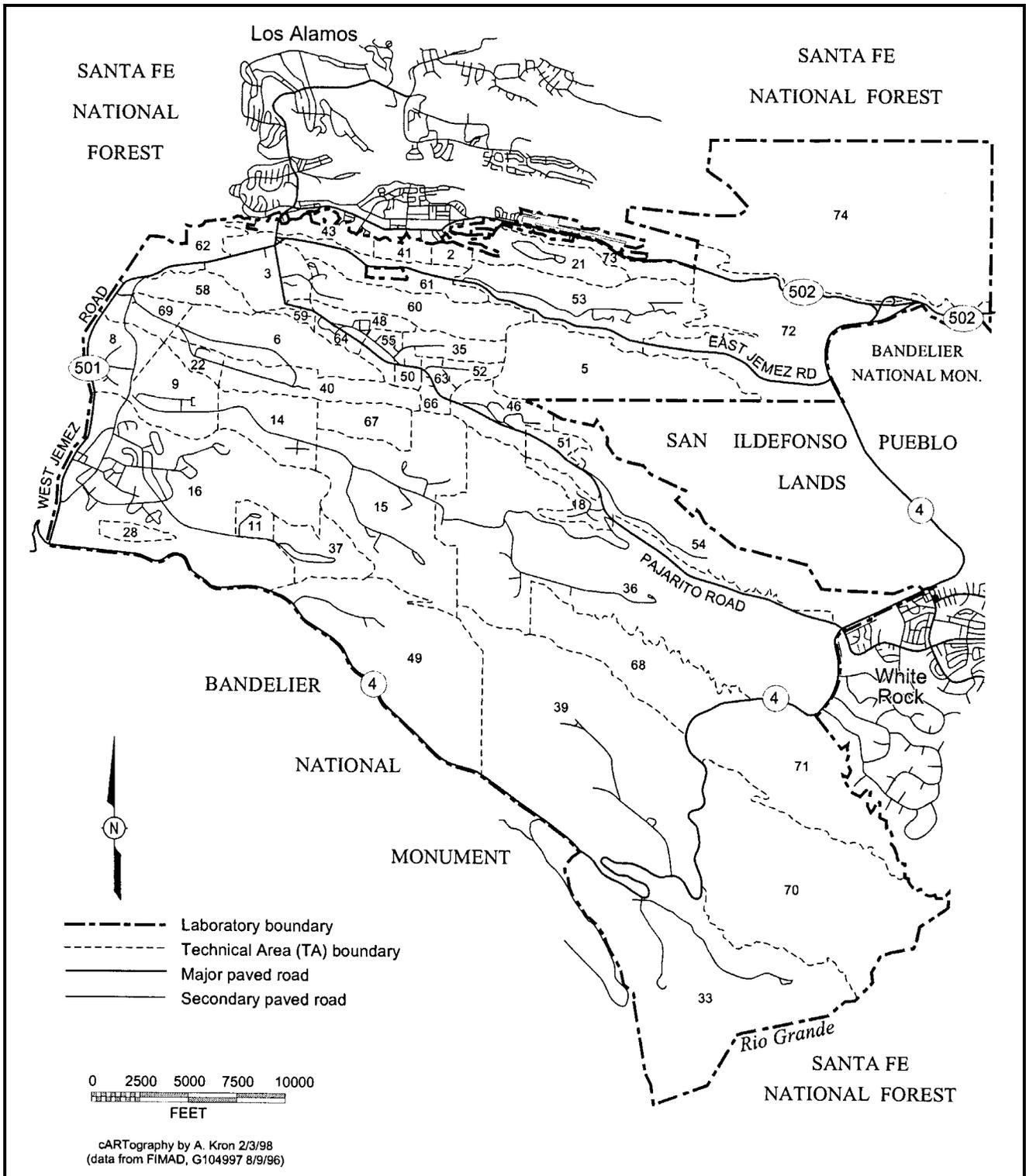
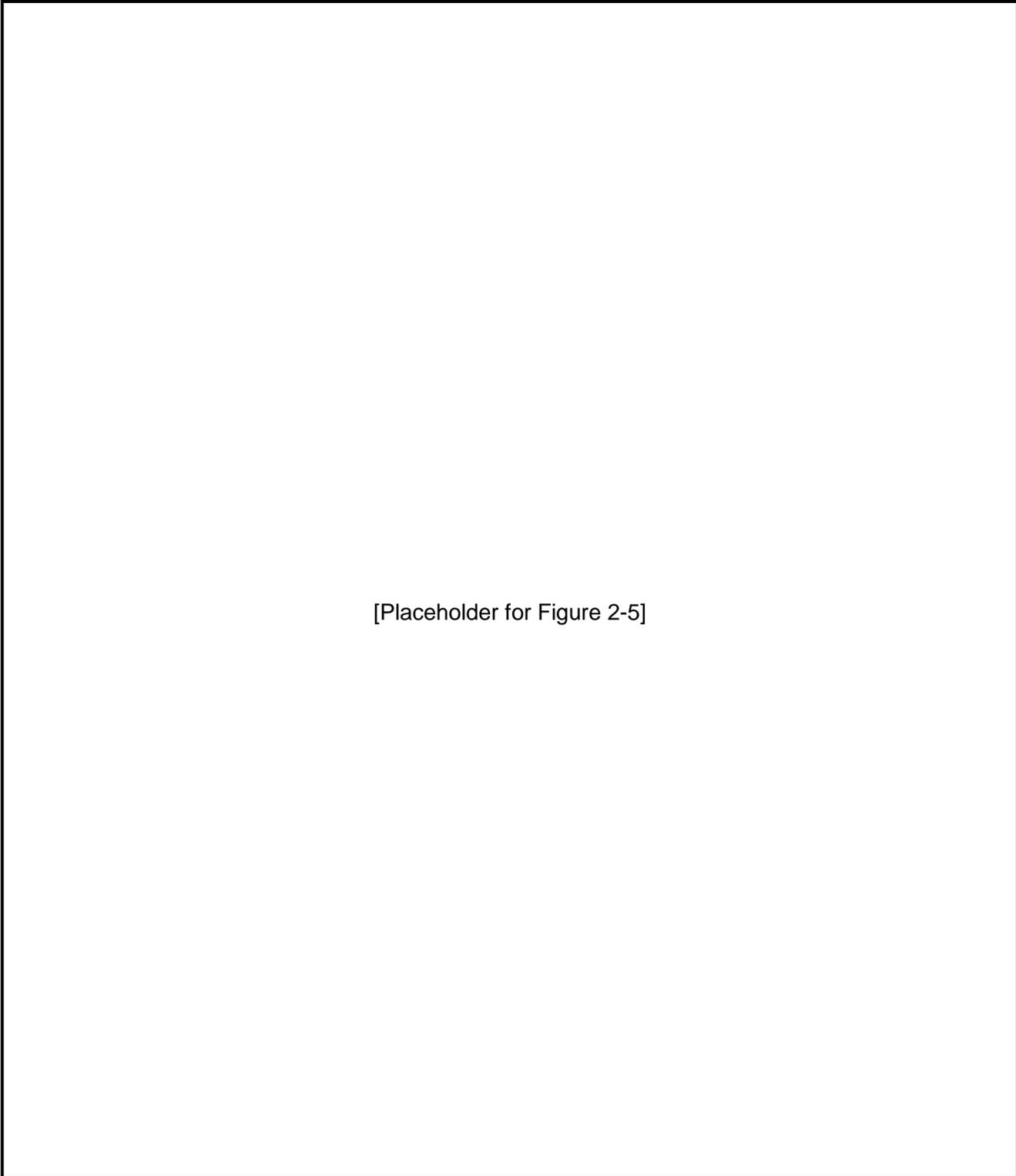


Figure 2-4. Map of technical areas and roads.



[Placeholder for Figure 2-5]

Figure 2-5. Timeline of selected operations and activities.

2.3 DESCRIPTIONS OF SITE ACTIVITIES AND PROCESSES

2.3.1 Plutonium and Americium

One of the important early roles of the Laboratory was the processing of the newly created element known as plutonium. The assignments given to Los Alamos in the early 1940s were to:

- Perform the final purification of the plutonium received at Los Alamos
- Reduce the plutonium to its metallic state
- Determine the relevant physical and metallurgical properties
- Develop the necessary weapons component fabrication technologies

2.3.1.1 Early Plutonium Processing at TA-1

Los Alamos was the first site in the world to receive quantities of plutonium large enough to manufacture weapons components. Plutonium processing was originally performed in TA-1 near Ashley Pond, as shown in Figure 2-6.

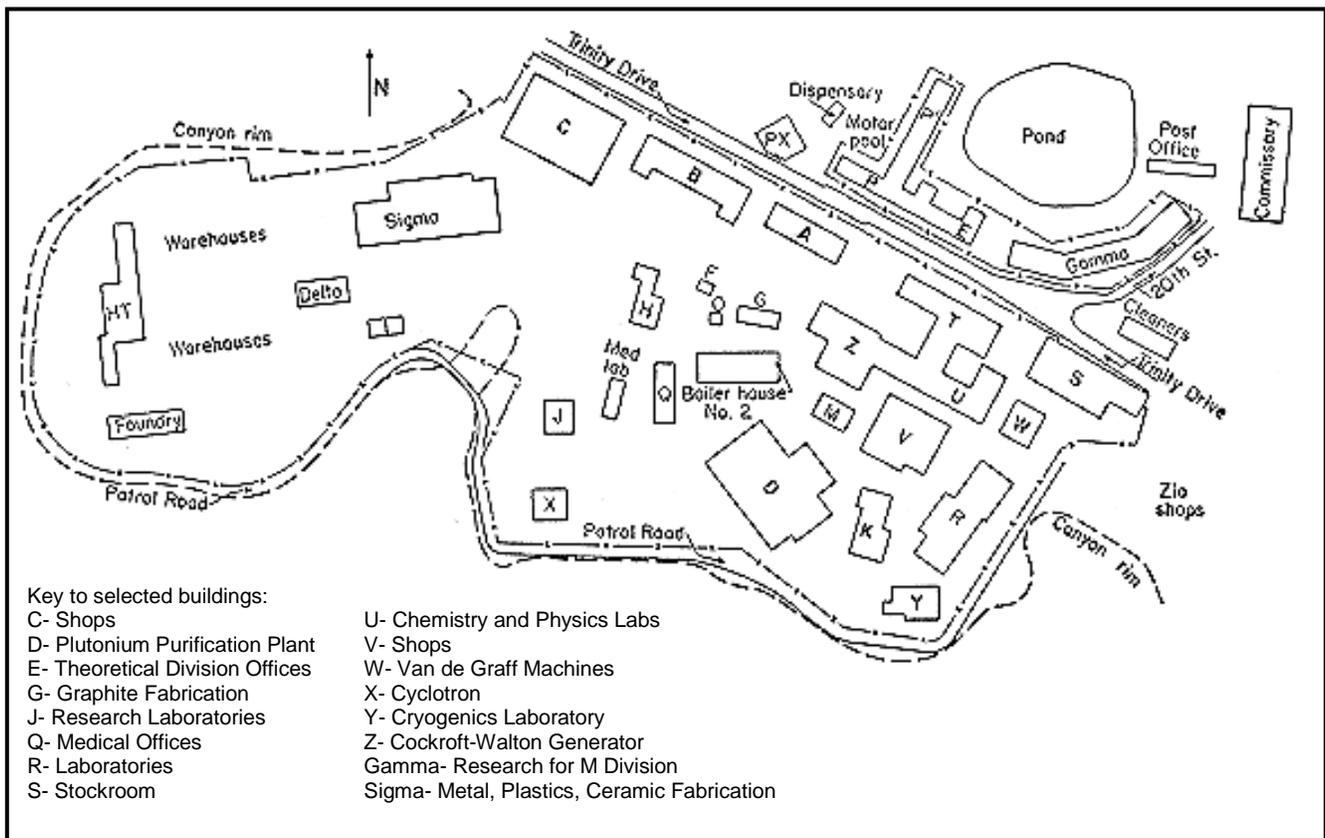


Figure 2-6. Map of the original TA-1.

Facilities housing plutonium operations at TA-1 included (LASL 1977):

D Building

Plutonium chemistry, metallurgy, and processing. Workers involved in these operations were members of Group CM-8. ^{239}Pu , ^{235}U (enriched), and ^{238}U ("non-enriched") were the prevalent radionuclides processed in D Building. Americium is normally associated with most key Pu

operations as an in-growth product and handled in small quantities for research and development. Key plutonium operations included (LASL 1977):

- 1) Reduction involving fluorides and chlorides of Pu. Plutonium work was carried in rooms 109 and 110. Room 101 was later used to experiment with plutonium halide with lithium and calcium during centrifugation reduction. Plutonium was also used on a limited basis in Room 103;
- 2) Re-melting, recasting and alloying of Pu metal and oxides in rooms 101, 102, and 103;3) Loading, pickling, firing, unloading bombs in rooms 111 and 112;
- 4) Polography and study of Pu solutions in room 142;
- 5) Separation of Pu and bismuth in rooms 144 through 146;
- 6) Cleaning and combustion of ^{235}U and Pu in room 301, preparation of Pu compounds in room 303;
- 7) Pu assay in room 309;
- 8) Preparation of Pu-Be alloys in room 320;
- 9) Electrolytic reduction of plutonium with trichlorides of Pu and extraction of Pu metal; and
- 10) Plutonium fabrication into metal shapes and parts through hot pressing, rolling and machining. Only chunks of metal turnings were present in these operations. Dust or powders were reported not to be present.

Group CM-5 (prior to 1945 known as Group C-5) handled large-scale operations involving Pu. Operations included radioassay of products, dry chemistry and purification, and recovery. These involved a variety of compounds including Pu green salt (e.g., PuF_4), and oxides.

D Building was demolished between March and November 1954.

- | | |
|-----------------|---|
| D-2 Building | Contaminated laundry and glassware decontamination. Drain lines emptied to an open area near the rim of Los Alamos Canyon. After the laundry moved to DP Site, D-2 building was used as electronics repair shop and for decontamination of equipment such as pumps from D Building. Uranium was also present. Building was removed in October 1953. |
| D-5 Sigma Vault | Used for storage of ^{239}Pu and ^{235}U . Facility was demolished in December 1965. |

C Building	The Machine Shop. Operations started October 1943. Roof caught fire on January 18, 1945, and was rebuilt. Building removed in December 1964.
Gamma 1 Building	The Ice House. ^{239}Pu and ^{235}U assembly and storage. Building removed in February 1959.
ML Building	Medical Laboratory. Site of human uptake and excretion studies by Health Group and analysis of urine bioassay samples. After Groups H-4 and H-5 moved out, Group J-11 used the building for radiochemical processing of americium and curium.
J-2 Building	Used by Group J-2 for radiochemistry work on weapons test debris, processing of plutonium; uranium also present. ^{239}Pu , ^{235}U , ^{238}U . Building removed by 1964.

In January 1945, another fire occurred at TA-1, raising concerns about the possibility of a fire in D Building. This concern, a dramatic increase in the amounts of plutonium handled in D Building, and concerns about the need to house plutonium and polonium safely led to planning of a new facility, to be called DP West Site and TA-21.

2.3.1.2 Plutonium Processing at TA-21

TA-21, also known as the DP West site, replaced the original plutonium facilities in Building D of TA-1. Most of these facilities were constructed from 1944 to 1945 from used warehouses. The necessary process equipment was installed during that time, and operations started by the end of November 1945.

The primary functions of the facility were:

1. To produce metal and alloys of plutonium (^{238}Pu , ^{239}Pu , ^{240}Pu , and ^{241}Pu) and other transuranic elements from nitrate solution feedstock
2. To fabricate these metals into precise shapes
3. To provide and install protective claddings
4. To measure the chemical and physical properties of these metals and alloys
5. To permit recycling of scrap or materials used in experiments

Figure 2-7 shows the early layout of the main buildings at DP West. Buildings 2 and 3 housed wet chemistry processes, and Buildings 4 and 5 housed dry chemistry processes. Building 12 was the main filter building.

Some of the major changes during the lifetime of TA-21 were:

- In 1949, plutonium gloveboxes were connected with short, pass-through tunnels.

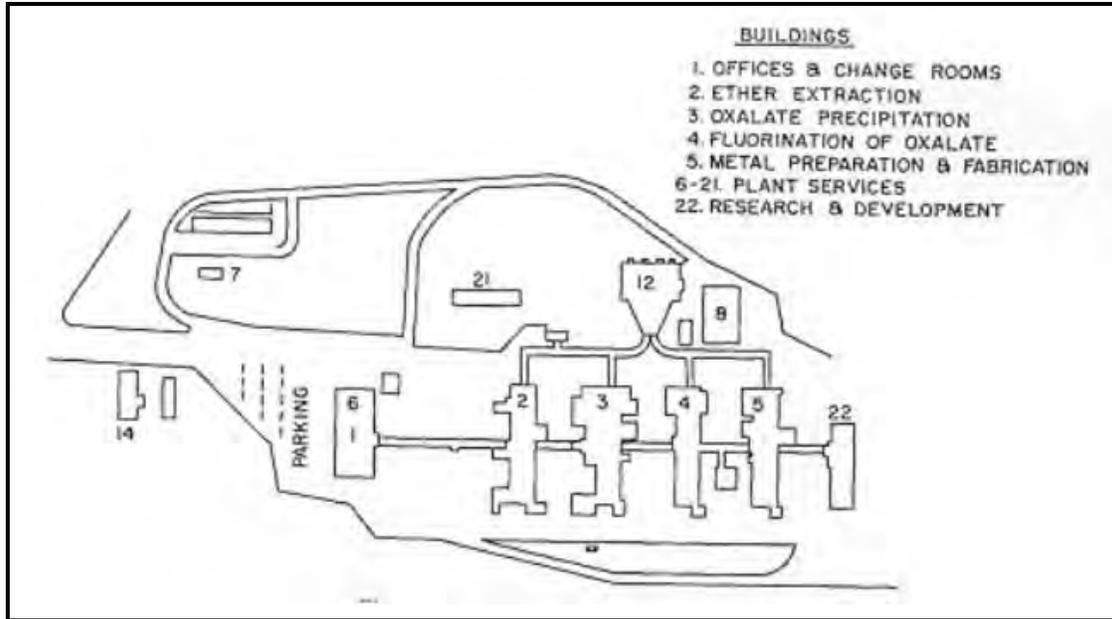


Figure 2-7. Early DP west layout (LASL 1969).

- In 1951, a semi-automated metal production line began operation. A facility was completed for recovering plutonium in dilute residues. Secondary containment rooms were constructed around potentially hazardous operations.
- In 1952, a liquid waste treatment plant was constructed, TA-21-35, which was decommissioned in 1968.
- In 1956, the plutonium metallurgical and metal fabrication systems were rebuilt. Conveyor tunnel systems were placed above the gloveboxes, allowing improved plutonium transfer capabilities and personnel passage under the tunnels.
- In 1959, a nuclear criticality alarm system based on detection of gamma radiation was installed. The process exhaust system was separated from the plant exhaust system so the exhaust filter building, TA-21-12, handled only plant exhaust. The system included a high-efficiency filtration system in TA-21-146.
- In 1963, plutonium fuels development building TA-21-150 was constructed.
- In 1967, liquid waste treatment plant TA-21-257 was constructed.
- In 1968, personnel corridors between major buildings were converted to ventilated air locks.
- In 1971, room exhaust air systems were installed in plutonium areas and utility services were upgraded.
- In 1973, the exhaust filter building, TA-21-12, was decommissioned after having been used only for room air since 1959. Demolition was completed in 1975.

- In 1974, a wet pipe sprinkler system was installed throughout the plutonium processing buildings.
- In 1977, the transfer of equipment to the Plutonium Facility at TA-55 began.
- Decontamination began in 1978 and was completed in 1981, and the areas were transferred to other tenants.

The following paragraphs summarize the activities in each major building at TA-21:

Building 2 (TA-21-2)

Building 2 housed numerous gloveboxes for dissolution and recovery of plutonium and storage of ²⁴¹Am wastes. In addition, the building housed a scrap incinerator, solvent extraction columns, and a liquid waste loading area.

Building 3 (TA-21-3)

This facility housed oxalate precipitation operations. No additional information concerning Building 3 wet chemistry operations was available for this document.

Building 4 (TA-21-4)

Rooms 401 and 401E housed development laboratories for plutonium research from 1945 to 1948, when the laboratories were converted to production areas for enriched uranium hydride. In 1960, the hydride equipment was replaced by a hot cell for the examination of irradiated plutonium and enriched uranium fuel elements. In 1965, two glovebox lines were added to support the ²³⁸Pu metal production. Rooms 403, 404, 405, 406, and 407 had gloveboxes for ²³⁹Pu and ²³⁸Pu metal preparation in the early years. Metal preparation involved a number of steps with a particular emphasis placed on reducing the amounts of impurity. Plutonium oxide, plutonium hexafluoride, and plutonium trichloride were the primary materials handled in these operations.

Building 5 (TA-21-5)

Building 5 was the plutonium metal fabrication facility. Work centered around the production of plutonium metal and metal alloys and the fabrication of plutonium parts for nuclear devices. In 1963, Room 506 was constructed to house electro-refining equipment for production of high-purity plutonium metal. Electro-refining was one technique used to further remove impurities from the plutonium metal. Also added in 1963, Room 500A housed an air-drying system for air supplied to the conveyor tunnels and gloveboxes. In 1964, Rooms 530 to 534 were added as additional fabrication and testing facilities.

Until 1974, all work in Building 5 was with ²³⁹Pu for the weapons program. In 1975, ²³⁸Pu was introduced into one glovebox line in Room 500 for limited research work on testing high-efficiency particulate air (HEPA) filters.

Building 7 & 8 (TA-21-7 & 8)

Building 7 and 8 were warehouses and were removed in 1967, according to ENG-R-113.

Building 9 (TA-21-9)

For a number of years, reports expressed concerns about stack emissions from DP (LASL 1944 and 1960). In 1970, the concentrations of plutonium and strontium were measured in the vicinity of TA-21. The concentrations measured north of East Road was .11 pCi/g in surface soil and .9 pCi/g south of it. The study concluded that the plutonium must be from deposition of the releases from DP-Site's

airborne effluents (Stoker, 1976). Another report indicates the estimated area of soil contaminated by TA-21 is approximately 300,000 meters squared, with 239-plutonium concentrations ranging from .005-.006 pCi/g (Voelz 1980).

Building 12 (TA-21-12)

Building 12 was the filter building, placed in service in May 1945. The plutonium process buildings, 2, 3, 4, and 5, were ventilated with a 60,000-cubic-meters-a-minute central air exhaust system. Building 12 had four exhaust stacks. This system handled air from rooms and fume hoods, sparging of dissolvers, and venting of solution tanks. (*Sparging* typically indicates injection of high-pressure air into a system, but the LANL documentation does not precisely define sparging of dissolvers). At that time it was not believed necessary to exhaust the air from the gloveboxes, but several years later gloveboxes were vented, without filtering, through the room air exhaust system (LAHDRA 2349.pdf). Electrostatic precipitators backed up by a single bank of American Air Filter Company type PL-24 filters (10-ply air mat) removed the particulates from the exhaust air. These filters had about a 10 % efficiency for the removal of 0.3 micron particles. This system was considered the best available for air cleaning at that time and was later replaced by a more efficient filter called the Aerosolve 95 (LASL 1968). In 1957, LANL began studies to find new and improved methods/equipment to filter process air. Work was started to upgrade this system but was stopped due to the 1957 plenum fire at the Rocky Flats Plant. LANL evaluated the use of flammable filters (e.g., Aerosolve 95) for plutonium filtration. LANL concluded not to upgrade the system because of the fire hazard potential and because measured effluent plutonium (^{238}Pu and ^{239}Pu) concentrations (1.3×10^{-12} $\mu\text{Ci/cc}$) were about one-half the maximum permissible air concentration for occupational exposures (LASL 1972).

Building 12 continued in service for room and process air until July 1, 1959. In that year, another system was installed for the process air, and Building 12 then handled only room air. In 1960, the interior of the plenum and the largest portions of the air ducts were vacuumed and cleaned. Approximately 3000 kg of dust was removed from the system along with several hundred pounds of sand that had been used for sandblasting plutonium parts. Samples of dirt removed were analyzed and showed a plutonium content ranging between 0.001 and 0.05 % by weight. The measurement results indicated that the dirt contained about 600 g of plutonium (93.5% ^{239}Pu , 6% ^{240}Pu , and 0.5% ^{241}Pu) (LASL 1975).

Building 12 continued in service until February 1973, when new room air HEPA filtration systems were completed, one for each process building.

Major decommissioning activity at building 12 was completed in 1975 (DOE/EIS-0238, Jan 99).

Building 21 (TA-21-21)

Building 21 was the old vault that stored the produced uranium and plutonium metal.

Building 22 (TA-21-22)

Building 22 was a warehouse used to store slightly contaminated equipment (LASL 1957a). It was removed in 1967

Building 32 (TA-21-32)

Building 32 was surveyed in 1959 and was found to be free of contamination (LASL 1959b). This building had been used as a warehouse and was removed in 1960.

Building 33 (TA-21-33)

Building 33 housed research efforts designed to improve the collection of plutonium from waste streams. Engineering drawings ENG-R-5113 shows that building TA-21-33 was removed in 1965.

Building 54 (TA-21-54)

Building 54, noted as a laboratory was removed in 1968.

Building 146 (TA-21-146)

Building 146 handled process air for TA-21 and was equipped with HEPA filtration, although these were a single series and not in series as late as 1968 (LASL 1972). It is no known if these ever were upgraded to multiple banks of filter series because, by the mid-1970s, design of the new plutonium facility (TA-55) had begun.

Building 150 (TA-21-150)

Building 150 was built in 1963 as a plutonium fuels development building. The building was next to Building 5.

Some of the programs the building supported included:

- The development of ^{238}Pu heat sources for space electric power applications
- Investigations of various ceramic materials containing plutonium for use in the Liquid Metal Fast Breeder Reactor (LMFBR) program
- The development of ^{238}Pu fuels for isotopic powered heat sources for powering artificial organs
- Served as a filtration system (Aerosolve 95 filters and later HEPA filtration systems) for process air and airborne effluents. It is not certain at this time which buildings' process air were exhausted through Building 150.

DP East at TA-21

DP East is somewhat smaller than DP West and has not had the long history of handling plutonium that DP West had. In 1947, the group responsible for the chemistry work necessary to develop and manufacture initiators occupied DP East. The work included processing polonium (LASL 1947b). Since that time, various projects have taken place at this site. By 1957, little work involving radioactive material was being carried on here. Descriptions of the buildings say that building 151 had offices and a few chemistry laboratories, 152 had high temperature laboratories, building 155 was used for storage, and 153—the filter building—had some residual activity (LASL 1957a).

Building 210 (TA-21-210)

Building 210 housed additional research activities on the properties and uses of plutonium.

2.3.1.3 Plutonium at TA-3

The Laboratory's main technical facilities moved from TA-1 to TA-3 in 1953. Plutonium was processed at TA-3, the new Core Area (also called the South Mesa Site).

Areas at TA-3 that involved plutonium processing include:

TA-3-29	Chemical and Metallurgical Research (CMR) Building was constructed in 1951 and 1952. Wing 9 was constructed in 1961.
TA-3-32	Cryogenics
TA-3-34	Cryogenics
TA-3-35	Press Building (also handled uranium and graphite)
TA-3-39	Tech Shops
TA-3-40	Physics
TA-3-65	Source Storage
TA-3-66	Sigma Complex
TA-3-102	Tech Shops (also handled uranium, beryllium, and lithium)
TA-3-141	Rolling Mill
TA-3-184	Occupational Health
TA-3-216	Weapons Test Support
TA-3-700	Acid Neutralization and Pump Building

As of 1969 the CMR Building, except for Wing 9, was used for laboratory work on small quantities of uranium and plutonium. Wing 9 contained hot cells for irradiated uranium and sometimes plutonium. Effluents could have contained mixed fission products, including iodine. Filters were counted for both alpha and beta radiation. In the years leading up to 1973, there was increased use of ²³⁸Pu at Building 29 in TA-3.

2.3.1.4 Plutonium Processing at TA-55

In 1969, TA-55, the Plutonium Facility (PF) Site, was built to process plutonium and conduct research on plutonium metallurgy and take over operations conducted at TA-21. Past and current operations have included the processing and recovery of ²³⁹Pu from scrap materials, recycling, metal production, metal fabrication, and research and development. The site has hosted special isotope separation (SIS) research. The SIS-III was designed to provide special plutonium isotopes for LANL weapons research. The site has also manufactured plutonium heat sources for weapons-related programs. Los Alamos is now the only U.S. source for plutonium pit production on an as-needed basis.

2.3.2 Uranium

2.3.2.1 Uranium at TA-1

Facilities at TA-1 housing uranium operations included:

C Building	The Machine Shop (uranium machining in southeast area). Operations started October 1943. Roof caught fire on January 18, 1945, and was rebuilt. Building removed in December 1964.
D Building	²³⁵ U (enriched), and ²³⁸ U ("nonenriched") were the prevalent radionuclides processed in D Building. Key operations included (LASL 1946):

- 1) Reduction involving fluorides and chlorides of U. Uranium work was performed in rooms 111 and 112;
- 2) Preparation of uranium hydride (enriched, natural, and depleted uranium) by passing hydrogen over hot metal was performed in rooms 103 and 113; and
- 3) Electrolytic reduction of uranium with trichlorides of U and extraction of U metal. Uranium metal was then machined into desired shapes.

G Building	Housed the uranium and graphite Sigma Pile operated by Group R-3. Leak testing of radium-226 sources. Was also performed in this building. Building removed in June 1959.
HT Building	Heat treatment and machining of normal and enriched uranium. Very large castings were handled. Building removed in December 1965.
HT Barrel House	Storage of ²³⁹ Pu and enriched uranium. Building demolished in July 1964.
M Building	Processing, metallurgy, and recovery of enriched uranium. Building removed by 1975.
Sigma Building	Building used for processing enriched, natural and depleted uranium. Workers were assigned to Group CM-11. Operations included melting, casting, hot pressing, rolling, machining, cleaning, and pickling. Powder metallurgy was part of these operations and included UF ₄ and oxides. Thorium oxide was experimented with as well, the extent of which was not reported. Building was demolished in December 1965.
TU Building	Machining of depleted and normal uranium. Building removed in 1964.
TU-1 Building	Recovery and storage of enriched uranium. Furnace for burning rags, etc. Building removed in July 1964.
V Building	Original machine shop. Some uranium and beryllium machined there. Handled unusual assignments such as welding thin stainless steel into envelopes and machining and grinding tungsten carbide. 1943-44 workload was 10,000 worker-hours per month, double the work-capacity design of the building. A second shop, C Shop, was completed in October 1943. V Building was removed in February 1959.

2.3.2.2 Uranium at TA-3

The Laboratory's main technical facilities moved from TA-1 to TA-3 in 1953. The Sigma Complex in TA-3 (TA-3-66) housed large-scale metallurgy and fabrication of normal and enriched uranium. Air from areas for casting and machining enriched uranium was filtered through Aerosolve 95 filters. Air from areas handling enriched uranium in powder form was filtered in earlier years through bag filters and Aerosolve 95 filters and through HEPA filters in later years.

2.3.3 Fission Products

TA-1 facilities housing fission-product operations included:

Gamma Building	^{137}Cs . A ^{137}Cs contamination incident occurred. Practice assembly of the high explosives for the first atomic weapon. Building removed in February 1959.
H Building	Radiochemical and radioactive tracer processing. Initially used for work with ^{210}Po source preparation, later used by CMR-10 for office and work space. $^{140}\text{Ba}/^{140}\text{La}/^{90}\text{Sr}$ contamination from radioactive lanthanum (RaLa) operations. Building demolished in 1957.

2.3.4 Radium

TA-1 facilities housing radium operations included:

O Building	Storage of sealed radium and radium-beryllium sources that leaked. In the front of the building, radon was cooked off radium sources on a hot plate before re-soldering. Group G-4 used a 50 and 200 mCi radium calibration sources and small Ra-Be neutron source for testing newly built radiation measurement equipment. Building demolished November 1956.
Q Building	Used by medical and health-monitoring group. Some film calibration operations with ^{226}Ra sources. Building removed in February 1959.

2.3.5 Other Materials

TA-1 facilities built in 1943 and 1944 that contained operations with other materials included:

D-1 Building	Calcium metal storage. Operations moved to TA-21 in 1946. Calcium metal was the reducing agent for converting UF_4 "green salt" UO_2 and uranium metal. Building removed by 1964.
D-7 Building	CMR HF gas analysis. HF was used in converting UO_2 to UF_4 . Building removed by 1964.
FP Building	Foundry for non-radioactive, nonferrous metals. Building removed in April 1965.
I Building	Used for machining beryllium. Sold to Dog Obedience Club in 1958 and moved to Airport Road. Found to be contaminated with beryllium and was demolished in 1959.
K-1 Building	Machining of graphite. Building removed by 1964.
M-1 Building	Originally used for machining lithium, later for ^{238}U samples. Building removed by 1964.
R Building	Glass shop, cryogenics, model shop, carpenter shop. Building removed by 1964.

Saw Building	Sawing of graphite. Building removed in February 1953.
T-1 Building	Original Administration Building. Building removed by 1964.
W Building	<p>Van de Graaf accelerator operated by Group R-2. Uranium, ²¹⁰Po, tritium. Exposures of neutrons and gamma rays also occurred from accelerator operation (LASL 1946). Photo-neutron sources were also produced using the following methods:</p> <p>1) Gamma Producer: "Mesothorium" (²²⁸Ra) with Be target produced 880 KV neutrons; 2) ²²⁸Ra with deuterium target produced 220 KV neutrons; and 3) Yttrium with Be Target produced 170 KV neutrons. It required 10⁵ gammas to produce one neutron and therefore gamma exposures were most significant for these procedures. W Building removed by 1964.</p>
X Building	<p>Cyclotron. Deuterons were accelerated into beryllium targets producing fast and moderated neutrons and gamma rays (LAHDRA 136.pdf). This unit was operated Group R-1. The cyclotron was surrounded by a water-borax shield. Boron was added to the water shield to increase neutron capture and help reduce gamma radiation. Unspecified targets were also placed in the path of the neutrons and resulted in the production of activation products. Beta exposures were also likely for those workers that handled irradiated targets. Gamma dose limits for the time was 0.1 R/day and neutron was 0.01 R/day. Based on reported exposures of 20% neutron and 80% gamma, health staff set a dose limit of 0.4 R/day by applying a safety factor. X Building was removed by 1964.</p>
Y Building	Physics laboratory. Tritium and uranium. Building removed by 1964.
Z Building	Cockroft-Walton accelerator operated by Group R-3. Workers were exposed to both neutron and gamma radiation. Pocket minometers and film badges were issued to workers that required dosimeters. Building removed by 1964.

Building W had two high-voltage electrostatic generators that produced variable energy neutrons for cross-section measurements. Protons were accelerated and hit a target (usually lithium), producing hazards from neutrons and X-rays.

2.3.6 Tritium

Building U located at TA-1 was used to study cross-sections for deuterium and tritium and perform measurements of neutrons produced. Group F-4 led these efforts. Neutron and beta and gamma exposures from natural sources were reported for these operations (LASL 1946). The type of natural sources and dates of operations were not reported.

Building 155 at DP East (TA-21-155) most recently housed the Tritium Systems Test Assembly (TSTA), which conducted research for developing and demonstrating effective technology for handling and processing deuterium and tritium fuels for use in fusion reactors. As of April 1990, TSTA had operated for 70 months. Throughput totaled more than 10 billion Ci, the maximum inventory was

1.3 million Ci, and stack releases were reportedly 110 Ci. An equipment failure in the CMB-3 tritium facility resulted in the release of about 13.8 Ci of tritium from Building 209 at DP East from April 11 to 14, 1981. Tritium was also handled in some areas of DP West.

Research at TA-33 released the largest amount of airborne tritium from routine LANL operations. Reports indicate that tens of thousands of curies of tritium were released from pressurized filling of tritium containers at TA-33 from the early 1950s to the late 1980s. Hot cells here opened to the environment (no double containment). From 1973 to 1977, the average annual routine release of tritium gas from TA-33 was 3,050 Ci (the range was 615 to 5,916 Ci). Releases in 1978 totaled 17,780 Ci (1.85 g), 95% of all routine tritium released from LANL in 1978. The total for 1977 was 615 Ci. TA-33 also had some firing points, and soils are contaminated with depleted uranium. A new replacement facility at TA-41 with a system to capture and recycle tritium was proposed for funding in 1979. The Weapons Engineering Tritium Facility at TA-16 eventually replaced the tritium facility at TA-33 after TA-41 was considered but rejected as a replacement site.

Whenever firing experiments proposed by GMX Division would result in the release of more than 100 Ci of tritium in a single shot or would raise the annual total above 5,000 Ci, a review by GMX and H Division leaders was required. Before this policy, about 180 Ci per shot were used.

Releases of tritium from the Van de Graff accelerator at TA-3-16 occurred from 1977 to 1982. . Releases of tritium from the cryogenics area at TA-3-34 occurred in 1976 and 1979. Technical areas where releases of tritium have also occurred include:

TA-41-4	W Site (1978–1991)
TA-55	Plutonium Facility (1980–1999)
TA-9	Anchor Site East
TA-15	R Site
TA-49	Frijoles Mesa
TA-2	Omega West
TA-53	Los Alamos Neutron Science Center (LANSCE)

2.3.7 Polonium and Actinium

Polonium was used in initiators, utilizing the (α,n) reaction of ^{210}Po and ^9Be . In February 1945, the schedule for polonium delivery from Monsanto to TA-1 was increased from a few curies to 100 curies per month by June and 500 curies per month by December. At TA-1, polonium and radium was handled in H Building and Gamma Building. H Building was used for preparation of neutron and alpha sources for initiators and isotopic experiments. Workers involved in these operations were part of Group CM-15. Operations in H Building were carried out between 1943 to July 1945 when operations were moved to the DP Site. Polonium (^{210}Po) and, on a smaller scale, ^{226}Ra were processed through various operations that included: 1) solution chemistry, 2) electrodeposition, 3) high-vacuum distillation, 4) metal plating, and 5) counting and assay of polonium and radium. Monthly health reports (Group A-6) describe work performed in H Building along with room numbers, names of workers assigned to particular task(s), and complete exposure records (LASL 1946).

DP East began operation in September 1945 and included Buildings 151, 152, and 153. Building 155 was completed in December 1949. These buildings were used to process polonium and actinium to produce initiators. Building 209 was built in 1964 to house research efforts in high-temperature and actinide chemistry. Building 155 later housed the TSTA, which conducted research for developing

and demonstrating effective technology for handling and processing deuterium and tritium fuels for fusion reactors.

Building 153 exhausted the air from several buildings at DP East and was constructed in a fashion similar to Building 12 at DP West. TA-21-153 was in service until March 1970. The primary radioactive contaminant of this filter house was ²²⁷Ac. Building 153 had transitional plenums and filter housings for electromatic filters, two blowers and two stacks.

2.3.8 Radioactive Lanthanum

TA-10, Bayo Canyon Site, was used between 1944 and 1961 for a set of experiments with conventional high explosives, (RaLa), and depleted or natural uranium for implosion diagnostics. A total of 254 of hydrodynamic tests were conducted, 71 by the end of 1946 (see Table 2-2). The shots used RaLa sources ranging in size from about 25 Ci to 7,090 Ci of ¹⁴⁰La. The explosions resulted in the dispersion of depleted and natural uranium, ¹⁴⁰La, and ⁹⁰Sr in the form of aerosols and debris to the atmosphere and onto the ground. Strontium-90 was present based on similar chemical properties of barium and was not completely removed during the barium/lanthanum extraction process. These extractions were performed at sites in Oak Ridge and Idaho. Radiochemical operations conducted at the site resulted in the generation of liquid and solid radioactive wastes, which were disposed in subsurface pits and leach fields. The site was decommissioned by 1963 and transferred to Los Alamos County on July 1, 1967.

During the 18 years of the RaLa series of experiments in Bayo Canyon, about 226 mCi of ⁹⁰Sr was reportedly released; over 80% of the 226 mCi was released in seven shots in 1945. In a dose assessment conducted by LANL personnel, the highest annual dose from the RaLa shots (17 mrem) was calculated to have occurred in 1955. If an individual had been in Los Alamos throughout all of the experiments, the calculated dose to that hypothetical individual would have been approximately 110 mrem. Results of a resurvey of the area show that residual surface contamination of ⁹⁰Sr in Bayo Canyon averaged 1.4 pCi g⁻¹, or approximately three times the levels attributable to worldwide fallout.

The RaLa sources were prepared by Group G-7 or Group G-6 workers at the TA-10 Chemical Process Building from 1944 to 1950 (LASL 1946). CMR monthly reports also describe air sample results for RaLa in Sigma, H, and U Buildings in 1948 (LASL 1956). This function moved to TA-35 (Ten Site) for 1951 to 1963. The name of the site is likely tied to the operating group, CMR-10. The CMR-10 group relocated to Ten Site (TA-35) some time

Table 2-2. Quantities (curies) of radioactive lanthanum used.

Year	Curies of RaLa used in Bayo Canyon shots	Number of shots
1944	1,112	10
1945	18,363	36
1946	20,556	24
1947	22,734	27
1948	12,236	19
1949	28,255	26
1950	19,788	12
1951	0	0
1952	6,370	4
1953	1,065	4
1954	15,580	13

1955	40,763	21
1956	35,976	21
1957	17,358	9
1958	9,845	7
1959	8,322	8
1960	5,560	5
1961	24,312	5
1962	13,607	3
Totals	301,802	254

between April and December 1950. In the early 1950s, the applied worker dose limit at TA-10 was 0.3 rem per week, up to a maximum of 15.6 rem yr⁻¹. In general, attempts were made to limit exposures to 3.0 rem in a thirteen-week period. After that the NBS Handbook external dose limits to critical organs of 3 rem per 13 consecutive weeks and no more than 5(N-18) rem were used. The Idaho Chemical Processing Plant became the source of purified ¹⁴⁰Ba in 1956, and a typical shipment was about 40,000 Ci of ¹⁴⁰Ba. The ¹⁴⁰La sources prepared at Ten Site were usually in the range of 2,000 to 4,000 Ci. Almost 2 million Ci of ¹⁴⁰Ba had been handled at Ten Site by 1963 when the RaLa program was terminated. The TA-35 RaLa cell and control room have been completely dismantled.

2.3.9 Explosives Operations Involving Radionuclides

Research, development, and testing of high explosives were conducted at more than 25 different TAs at LANL. The initial plan for the first atomic weapon was for a gun-type weapon that would use slow-burning propellants. When it became clear in July 1944 that the weapon would have to be an implosion design due to the presence of the ²⁴⁰Pu in the active material, high explosives became a key component of the plan. In the August 1944 reorganization, Division X was formed to experiment with explosives and their fabrication and to set up a production system. Three groups from the old Ordnance Division (E-Division) in U Building Implosion Experimentation, HE Development, and S-Site Group) were transferred to the new Explosives (X) Division. Investigation of implosion dynamics and design of the active core were given to the Weapon Physics (G) Division.

2.3.9.1 Uranium

Each year, kilogram quantities of uranium are utilized in dynamic testing at LANL with an estimated 10% (based on limited measurements) being aerosolized. An estimated 35,000 to 45,000 kg of natural uranium and 40,000 to 50,000 kg of depleted uranium have been expended during conventional explosive tests at several LANL testing sites from 1949 to 1970. In 1978, 1,371 kg of depleted uranium were expended in dynamic testing at LANL. These amounts reportedly do not go far beyond the test pad. Approximate dispersion calculations indicate that the resultant airborne uranium concentrations at site boundaries from testing would be in the same range as that attributable to natural crustal abundance uranium in resuspended dust. Individual stations with higher annual averages and maximum values are all in dusty area where higher filter dust loading accounts for the collection of more natural uranium. Ecological studies have shown that of the uranium on the ground only minor amounts (less than 0.1%) have moved an appreciable distance from the test areas.

Between 1944 and 1948 eight firing sites (A-H) were established at TA-15 (R-Site). Firing points E and F were the most active. Up to 65,000 kg of uranium and 350 kg of beryllium have been expended at these two firing sites. Hazardous materials, including uranium, beryllium, and lead, have largely been left in place at these sites where the materials were deposited by the explosion.

2.3.9.2 X-Rays

TA-15 (R-Site) is currently the home of the Pulsed High-Energy Radiographic Machine Emitting X-Rays (PHERMEX), a multiple-cavity electron accelerator capable of producing a very large flux of X-rays for weapons development testing that was completed in 1962. PHERMEX sends X-rays through an imploding mockup of a weapons assembly and provides researchers with detailed snapshots of the locations and configurations of implosion systems. TA-15 is also the site where the Dual-Axis Radiographic Hydrotest (DARHT) facility is being constructed. This site is also used for the investigation of weapons functioning and systems behavior in non-nuclear tests, principally through electronic recordings. The DARHT is intended to replace PHERMEX.

TA-8 (GT Site, or Anchor Site West) is a dynamic testing site that maintains capability in all modern nondestructive testing techniques for ensuring quality of material, ranging from test weapons components to high-pressure dies and molds. Principal tools include radiographic techniques (X-ray machines with potentials up to 1 MV and a 24-MeV betatron), radioisotope techniques, ultrasonic and penetrant testing, and electromagnetic test methods. Radionuclides involved include ^{238}Pu , ^{239}Pu , ^{235}U , ^{238}U , ^{60}Co sources up to 500 Ci, ^{192}Ir sources up to 100 Ci, and ^{137}Cs sources up to 30 Ci.

The Trinity weapon was assembled in Building 516 at TA-16 (S-Site). In Building 45 at TA-16, portable 150- and 220-keV X-ray machines were used to examine explosive castings because the Lab was concerned about dangers of a one-point detonation of a nuclear device containing weapons-grade plutonium in Building 410 at TA-16.

A betatron used to study implosions was housed in the Gamma Building at TA-1. The intensity of betatron's photon beam was reported to be 25 R/minute at one meter and 0.16 R/minute at 12.5 meters (LASL 1946). The beam was directed outside and into a second building with no access controls in place. In 1947, TA-11 (K Site) had a 20-MeV betatron and a 500-mCi radium-beryllium source. Present day facilities at TA-11 (K Site) are arranged so that testing is controlled and observed remotely and so that devices containing explosives or radioactive materials, as well as those containing non-hazardous materials, can be tested

2.3.10 Reactors and Reactor Development

When first established in 1943, TA-2 (also known as Omega Site), was used for both nuclear criticality experiments (e.g., critical assemblies with fissile and tamper materials) and as the location for the Water Boiler reactor. Assembly of the first Water Boiler (the low-power model) began in late 1943. In April of 1946, nuclear criticality experimentation was relocated from TA-2 to TA-18 (Pajarito Site). Construction of the Plutonium Fast Reactor (Clementine) began in August 1946, and from then on Omega Site was used primarily for reactors for neutron experiments and isotope production. Over its history, three reactors have operated at TA-2: the Water Boilers (three different versions), the Plutonium Fast Reactor (Clementine), and the Omega West Reactor (OWR). No reactors have operated at TA-2 since the shutdown of the OWR in December of 1992. The Water Boiler was deactivated in June of 1974. The Clementine reactor was deactivated in December of 1950 following 4 years of problematic operations.

Details regarding potential radiation exposure conditions encountered during LANL's early critical assembly experiments can reportedly be found in Omega notebooks 101, 186, 408, 480, 595, 603,

607, 685, and 733 (LASL 1946). Attempts to locate these notebooks for inclusion in this report have been unsuccessful to date. Further efforts to locate these documents may be warranted based on the information needs required to complete LANL claims on a case-by-case basis.

2.3.10.1 The Water Boiler Reactors

During the Manhattan Project, a reactor was needed to confirm critical mass calculations, to measure fission cross-sections, and to determine the neutron scattering and absorption properties for materials being considered for moderators and reflectors in the first atomic bombs. Enrico Fermi advocated the construction of a homogeneous, liquid-fueled reactor using enriched uranium. Three versions were built, all based on this concept. For security reasons, these reactors were all referred to as Water Boilers. The name was appropriate, since dissociation of the fuel solution would occur in the higher-power versions, giving an appearance of boiling.

The first Water Boiler was assembled in late 1943 at Omega Site. At that time, the fuel for this reactor (14% enriched uranium) consumed the Nation's total supply of enriched uranium. Two machine gun posts were therefore placed at the site to ensure its security. The first Water Boiler was called LOPO (for low-power) because its power output was virtually zero. This allowed for a simple design and eliminated the need for shielding. The fuel for the LOPO was an aqueous solution of enriched uranyl sulfate. The fuel was contained in a 1-ft diameter spherical shell of stainless steel surrounded by a reflector of beryllium blocks on a graphite base. Control and safety rods passed through the reflector assembly. The fuel solution (known as the soup) was pumped into the steel shell from a conical storage basin below. Because the system was intended for low power, no provisions for cooling were included. The LOPO achieved initial criticality in May of 1944.

The purpose of the LOPO was to determine the critical mass of a simple fuel configuration and to test the Water Boiler concept. With these goals met, the LOPO was dismantled to make way for a second design that could be operated at a power level up to 5.5 kW and thus serve as a neutron source needed for cross-section measurements and other studies. This second version was called the HYPO (for high power). The fuel solution was changed from uranyl sulfate to uranyl nitrate, and cooling coils were added within the shell. A tube passing through the shell (called the Glory Hole) was also added to allow placement of samples in the region of maximum neutron flux. The reactor was surrounded with a concrete shield. The HYPO began operation in December of 1944, and was used for many of the key neutron measurements needed in the early days of atomic bomb design.

In March of 1951, significant modifications to the HYPO were completed in response to demands for higher neutron flux and more research capability. These modifications allowed the Water Boiler to operate at power levels up to 35 kW. This modified version of the HYPO was dubbed the SUPO (super power). Modifications made in the conversion of the HYPO to the SUPO included:

- Installation of additional cooling coils within the fuel vessel for greater cooling capacity.
- Significant increase in the enrichment of the uranyl nitrate fuel solution, from 14% ^{235}U to 88.7% ^{235}U .
- Beryllium-oxide portion of the reflector was replaced with graphite to allow for more rapid shutdown.
- Gas recombination system was connected to the reactor vessel to eliminate the explosion hazard posed by the radiolytic dissociation of hydrogen and oxygen from the fuel solution. The water formed in the recombination chamber of this system was returned to the fuel vessel.

To reduce the emission of short-lived radioactive gasses from the Water Boiler, a delay line was installed. Before the installation of the delay line, it reportedly could not be determined how much ^{131}I was present because of masking by ^{88}Rb . Charcoal samples reportedly showed that essentially no ^{131}I was present before or after the delay line was installed.

The SUPO Water Boiler experienced a water leak into its moderator shield, and had to be shut down in 1973. The stack was contaminated with ^{137}Cs , and contamination in the reactor had migrated to the bioshield. SUPO was operated almost daily until its deactivation in 1974. Like its predecessors, it was used extensively for cross-section studies and other neutron measurements. However, it was also used for studying reactor physics (perturbation effects) and for biological research.

Planning for decontamination and decommissioning of the SUPO facility began in July of 1988. The decommissioning process was completed in April of 1990, with the facility (TA-2-1-122) subsequently being released to the Isotope and Nuclear Chemistry division.

2.3.10.2 The Plutonium Fast Reactor

The Plutonium Fast Reactor (known as Clementine) was proposed and approved in 1945 as a high-intensity fission neutron source that could also be used to assess the suitability of plutonium as a reactor fuel. Because a fast reactor requires no moderating material, the reactor could be of small size. The site chosen for the fast reactor was adjacent to the Water Boiler building at Omega Site. Construction began in August of 1946. The fuel for the fast reactor was in the form of small rods clad in steel jackets. The rods were installed in a steel cage through which the coolant, liquid mercury, flowed at a rate of approximately 9 L min^{-1} . Flow was maintained via an electromagnetic pump. The fuel cage was surrounded with a 6-in.-thick natural uranium reflector, most of which was plated with silver to reduce corrosion. A 6-in.-thick steel reflector and 4-in.-thick lead shield surrounded the uranium reflector. Reactor reactivity control was affected via insertion of uranium fuel rods into the cage—a positive reactivity control method as opposed to the negative reactivity control method typically used in reactors.

Initial criticality of the fast reactor was achieved in late 1946, though its design power of 25 kW was not reached until March of 1949. During the interim, measurements were made at low power, including determination of the neutron energy spectrum, reactivity effects, cross sections, and so forth. Changes in the control system were made during this time as experience in the operation of a fast reactor was gained.

In March of 1950, following nearly a full year of operation, the fast reactor was shut down to correct a malfunction in the operation of the control and shim rods. During this shutdown, a ruptured uranium rod was discovered and replaced. Operation resumed in September 1950 and continued until late in December of that year when it was determined that a plutonium fuel rod had ruptured and released plutonium into the mercury coolant. The hazard created by this condition and the identification of serious abnormalities in the uranium reflector prompted the decision to permanently shut down and disassemble the reactor. One of the lessons learned from experience with the fast reactor was that mercury was unacceptable as a coolant because of poor heat transfer properties and other concerns. When Clementine was decommissioned, its parts were stored in a hutment at Area C. The parts could be buried there. The disposal location of the plutonium-contaminated mercury coolant is not known.

2.3.10.3 The Omega West Reactor

After the early demise of the Plutonium Fast Reactor, the Omega West Reactor (OWR) was needed to meet the needs for neutron measurements for various laboratory activities. Evaluation of the options available at that time led to a conclusion that a design patterned after the Materials Test Reactor at the Idaho National Laboratory was the most attractive. A reactor designed to use the Test Reactor's plate-type fuel elements, which had already undergone extensive testing, meant core design and licensing could be expedited. The conceptual design for the new reactor was completed by the end of 1953. The core was to sit at the bottom of a water tank 8 ft in diameter and 24 ft high. The reactor would be cooled by water flowing at 3500 gpm. The proposed power level was 5 MW, but the shield was designed so that a power level of 10 MW could be tolerated. To save time and money, the reactor was built in the same room that had housed the Plutonium Fast Reactor.

The OWR reportedly got an exemption from the reactor-siting criteria in Part 100 of Title 10 of the Code of Federal Regulations. The OWR was a small, low-pressure, low-temperature research reactor. Natural convective circulation of the reactor pool water was reported as sufficient to cool the reactor. The maximum credible accident that was assessed would release 822 Ci of ^{131}I to the air, along with 10,900 Ci of other radioactive iodines, 168 Ci of ^{131}Xe , and 153,000 Ci of other rare gases. Doses were calculated at a Residential Area (0.4 mi cross canyon), Skating Rink (1.9 mi up canyon), and State Road 4 (4.0 mi Down Canyon). Maximum doses calculated by LANL personnel for this accident were 57 rem to the thyroid and 22 rem whole-body dose at State Road 4. Construction of the new reactor began in mid-1954. Initial criticality was achieved on June 29, 1956, and a few months later the OWR was operating at 1 to 2 MW. In May of 1966, new operating limits were established that allowed a maximum operating power level of 6.5 MW. A modification to the cooling system allowed the OWR maximum operating power level to be increased to 8 MW in August of 1967. The technical specifications for the OWR prescribed a Limiting Safety System Setting of 11 MW. The OWR safety limit was 14 MW.

The OWR routinely operated at a minimum of 1 hr a week during its first 16 yr. The OWR reportedly had a ^{125}I production loop, and at times the reactor was operated essentially around the clock on an Iodine Production Loop schedule. Use dropped off to around 40 hr per week thereafter until the reactor was permanently shut down. Research conducted at the OWR included: cross-section studies, measurement of weapon yields (via comparison fission counting), neutron radiography, condensed matter studies (via neutron scattering), testing of power reactor components, testing of power reactor fuels, tests of plasma thermocouples, neutron activation analyses, and radioisotope production.

OWREX capsules were placed in the reactor (e.g., OWREX-5 insert, OWREX-8 insert around 1966). These capsules evidently contained fuel and sodium. Fission gas traps and sweep-gas monitoring detected leaks of capsules on several occasions. The combination of an unusual occurrence that resulted in a challenge to a safety system and the discovery of coolant leaks in underground piping prompted the shutdown of the OWR in December of 1992. The unusual occurrence took place on December 11, 1992, when human error resulted in the reactor power rising to an administrative control limit of 9.6 MW, prompting an automatic shutdown. The investigation report compiled for this event identified three root causes for the incident, but drew an overall conclusion that conduct of operations at the OWR facility was inadequate. The three root causes specifically identified in the report were task performance errors on the part of various personnel, inadequate procedures for removal of samples from the reactor, and inadequate procedures and policies for ensuring reactor control was not compromised in the event of abnormal conditions.

In 1994, all of the fuel and control blades were removed from the OWR and the facility was placed in a safe shutdown mode. Inspection of the fuel elements conducted during the defueling operation showed that no fuel damage had occurred. All coolant was drained from the reactor vessel. A preliminary characterization in support of planning decommissioning activities was conducted in 1995.

2.3.10.4 The Omega Stack

A 1945 memorandum described the off-gas line from the HYPO Water Boiler and reports exposure rate readings made beneath and to the sides of the line. These readings were given in terms of the time in hours one would need to be at a location to receive an exposure equal to the daily limit at that time. The first part of the line was described as being hung on tree supports and ascending the canyon wall. The last half of the line had four points where it sagged to the ground. Breaks in the line were noted at 75 yards and 25 yards from its exhaust end. There is no mention of a stack.

A 1947 memorandum reported the discovery that the off-gas line from the HYPO Water Boiler was shattered about 100 ft before the outlet, which was in the top of a pine tree. It is surmised that the line became brittle from the off gas and broke due to swinging caused by recent high winds.

In later years, a 150-ft-tall stack on the south mesa was used to ventilate the OWR thermal column region and experiment. The flow rate in this stack was 880 cfm. About 600 Ci of ^{41}Ar was discharged per year. In 1968, a charcoal filter was added in the vent line from the OWR surge tank to the 150-ft stack.

A 1957 memorandum requests removal of the barbed-wire exclusion fence that kept people 50 or so ft away from the Omega stack. It also stated that the old Omega stack was still in the top of a dead tree just outside the fence surrounding the current stack. The memorandum requested that the old stack be taken down and sent to the contaminated waste pit. A reply to that request states that Group P-2 planned to connect the off-gas system for the OWR to the existing system for the SUPO Water Boiler. This action was completed between September 20 and October 20, 1957.

A charcoal filter was installed in the vent line for the OWR surge tank air space in 1968. The filter was installed as a precaution against a large radioiodine release that might otherwise have occurred in the event of a fuel element or experiment failure.

The Omega stack was 150 ft long with an inside diameter of 8 in. The 2-in. inside diameter vent pipe from the reactor to the stack was 1,100 ft long. The vent pipe included a settling tank and two water traps to collect water that condensed out of the effluent. The delay time of gas in the vent pipe was originally 2.3 days, but the addition of the vent line from the OWR cut this time to about 8 to 10 hr. The effluent in the vent pipe flowed to the stack at a rate of about 100 to 200 $\text{cm}^3 \text{min}^{-1}$, resulting in a dilution factor of about 100,000 in the stack. The stack flow rate was measured to be 845 cfm at a velocity of 2400 fpm.

The combination of the recombiner, the long length of the vent pipe, and the low flow rates resulted in the particulate component of the effluent consisting of very small particles. It is reported that 65% were less than 0.05 μm , 93% were less than 0.1 μm , and none were larger than 1.0 μm .

Figure 2-8 shows a timeline of events of operational significance for Omega Site reactors.

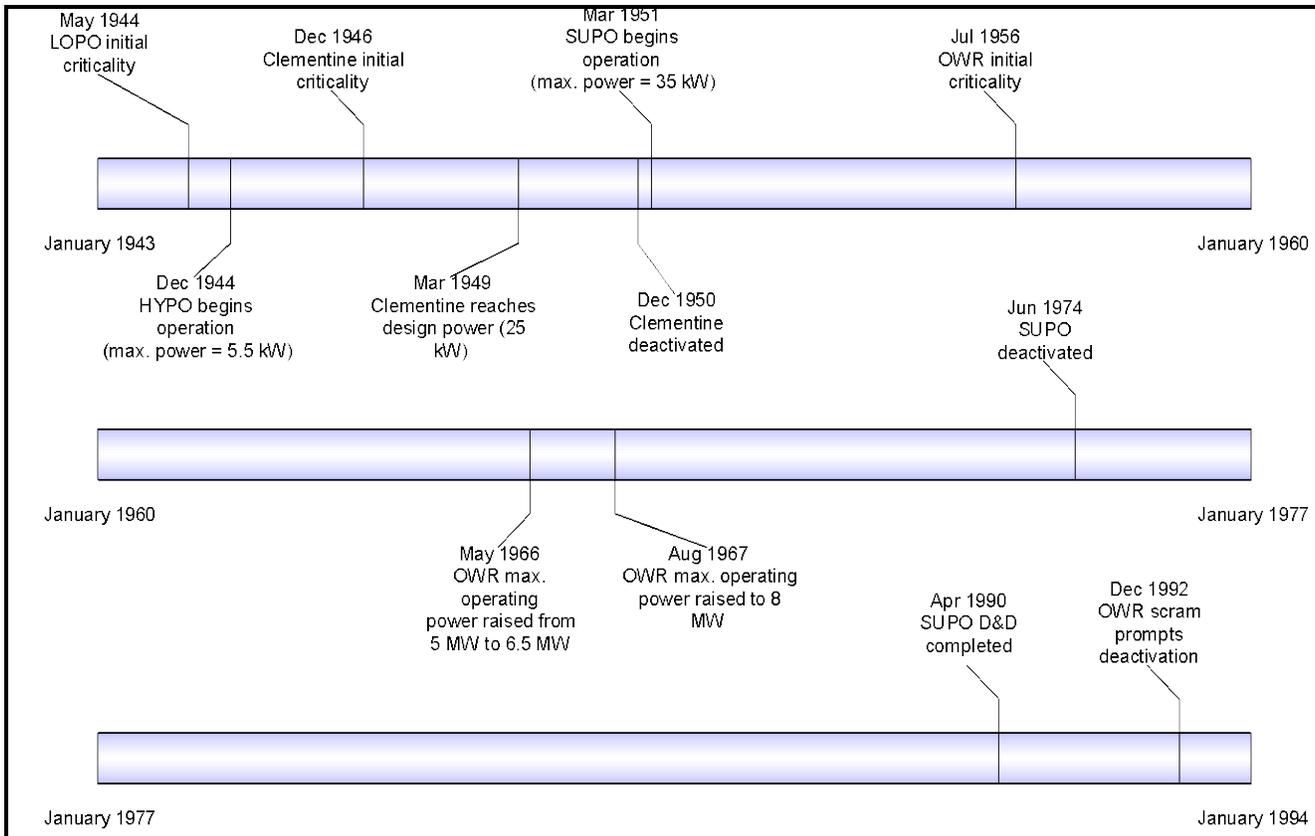


Figure 2-8. Timeline of events of operational significance for Omega Site reactors.

2.3.10.5 LAPRE I and LAPRE II

The Los Alamos Power Reactor Experiment (LAPRE) explored the use of a homogeneous reactor fuel consisting of highly enriched UO_2 (93.5% ^{235}U) dissolved in 95% phosphoric acid. Such a reactor system was thought to show promise for portable power sources for military applications if a method for containing the highly corrosive fuel solution could be found. Two test reactors (LAPRE I and II) were constructed and operated at Ten Site (TA-35) by K Division between 1955 and 1960. LAPRE I was in one of the hot cells of the main laboratory building. LAPRE II was outside the main building in an underground enclosure tank.

The purpose of the LAPRE I experiment was to study the use of phosphoric acid solutions of uranium for a high-temperature reactor fuel in a simple, compact design in which the reactor core and the heat exchanger were contained in a single vessel. Protection of the reactor internals from the highly corrosive fuel solution was supposed to have been achieved by coating the exposed surfaces with a thin layer of gold. While it was known that the problem of pinholes in the gold plating could not be completely eliminated (despite the use of multiple layers), it was thought that the corrosion rate of the stainless steel under a pinhole in the plating would be tolerable.

The first critical experiments with LAPRE I began on February 15, 1956. The reactor power was raised to a level of 20 kW and held there for 5 hr. Radioactivity was then detected in the steam line, and shortly thereafter criticality could not be maintained without dropping the temperature. The experiment was terminated, and the fuel was transferred to an external tank. After 9 days, the reactor was disassembled to determine the cause of the failure. Some of the gold plating on the heat exchanger tubes had been damaged during assembly of the reactor, which allowed the hot fuel

solution to come into direct contact with the stainless-steel tubing. The fuel solution corroded several of the tubes, causing the failure. The observed corrosion rate was unexpectedly high relative to predictions based on laboratory tests. Chemical attack was also noted at imperfections in the plating of the vessel and the boron poison can.

Because the failure of LAPRE I was not due to the reactor itself, components were repaired or replaced as thought necessary, and a second attempt at operating the reactor was made. This second experiment was conducted on October 15, 1956. The reactor reached a power level of 160 kW and had been held there for approximately 2 hr when radioactivity was detected in the feed water and steam systems, prompting a shutdown. Activity in the steam line rose rapidly, resulting in dose rates of 300 mR hr⁻¹ in the control room. This was thought to be due to gaseous activity released from the end of the steam line and drawn into the building ventilation system. Inspection of the reactor after shutdown determined that the failure was again due to the heat exchanger tubes having been eaten away by the fuel solution. Because construction of LAPRE II was already underway at this time, further work with LAPRE I was abandoned.

LAPRE II used a different fuel solution. This solution had a lower vapor pressure than the LAPRE I fuel, at the expense of less uranium solubility and thus the requirement for a larger vessel to achieve a critical mass. LAPRE II was also to make use of bonded components, in hopes of solving the failures associated with the protective gold plating. Construction of LAPRE II was begun in February of 1956. The reactor was in an underground enclosure tank on the south side of the main laboratory building at TA-35. This arrangement provided the necessary radiation shielding. The design thermal power of the reactor was 800 kW. The primary purpose of the LAPRE II experiment was to demonstrate containment of phosphate fuels through suitable corrosion protection techniques.

Operation of LAPRE II began in February of 1959 and continued into May of 1959. Full-power operation was achieved on April 22, 1959. The fuel solution was kept in the reactor vessel at a temperature above 200°F for 46 days. A maximum temperature of 826°F was achieved. Like LAPRE I, LAPRE II experienced problems with the leakage of volatile fission products into the steam system. At full power, dose rates of several thousand roentgens per hour were present adjacent to the feed water heater. Though it could never be clearly determined, it was suspected that the leakage occurred via containment problems with the heat exchanger, similar to LAPRE I. Dismantlement of LAPRE II began on May 8, 1959, with the transfer of the fuel solution back to the storage tanks. The LAPRE program was terminated in 1960.

2.3.10.6 LAMPRE I

The purpose of the Los Alamos Molten Plutonium Reactor Experiment (LAMPRE) program was to explore fast breeder reactors fueled by molten plutonium and cooled by molten sodium. While the original design power level of the LAMPRE I reactor was 20 MW, the researchers concluded that the knowledge base required to develop such a system was not yet sufficient. The design of the LAMPRE I therefore underwent substantial changes, going from 20-MW system to a 1-MW test reactor. The LAMPRE I core matrix could accommodate up to 199 separate fuel elements. Each element consisted of plutonium-iron fuel material in a tantalum thimble. The core matrix allowed several fuel element designs to be tested simultaneously.

The 1-MW design power for the LAMPRE I allowed it to be placed in an existing building at Ten Site (TA-35). LAMPRE I was in the cell next to that for ¹⁴⁰La separation. A gas-fired 2-MW sodium cooling loop was included to gain experience with high-temperature sodium-to-water heat exchangers. LAMPRE I achieved initial criticality in early 1961 and operated for several thousand hours thereafter. One of the problems encountered was corrosion of the tantalum fuel thimbles by both the fuel and the

coolant. LAMPRE I experienced three separate fuel failures during operation; official reports say that these fuel failures did not cause any operational problems. By mid-1963, LAMPRE I had achieved its intended purpose and was shut down. The LAMPRE fuel was transferred to Wing 9 of the CMR Building at TA-3.

LAMPRE II, which was to be the original 20-MW design, was never funded because the U.S. Atomic Energy Commission (AEC) chose to pursue reactors fueled by uranium oxide.

2.3.10.7 Project Rover

In 1955, the Federal government initiated Project Rover to develop a nuclear rocket engine to be used in defense systems and space exploration. The plan was to carry large payloads into deep space by passing hydrogen through a very-high temperature nuclear reactor, where it would expand and be blasted out of the reactor at high velocity. The program was a joint project between the National Aeronautics and Space Administration (NASA) and LANL. Los Alamos was given the tasks to establish the basic reactor design and to lead the fuel development effort. A series of test reactors were designed and built at Los Alamos before testing at the Nevada Test Site (NTS). These reactors were intended first to demonstrate proof of principle, then to establish and test the requisite design considerations. In 1962, Rover was the second largest program at LANL. The program was cancelled in January of 1973.

The Rover reactors were developed by the Los Alamos Critical Experiments Group using the facilities of the Pajarito Site (TA-18). In general, each successive reactor was developed following the same basic progression. First, parametric studies were performed using the Honeycomb assembly to establish the appropriate dimensions. The design then proceeded to the mockup phase, in which details for controls and internal structures were finalized. Last, the completed reactors were assembled and checked out before shipment to NTS for testing. Adjustments were made if any deviations from specifications were noted during checkout. Table 2-3 lists each Rover reactor along with the date the reactor was tested at NTS.

Table 2-3. Rover program reactors.

Reactor	Date(s) tested at Nevada Test Site
Kiwi-A	July 1, 1959
Kiwi-A'	July 8, 1960
Kiwi-A3	October 19, 1960
Kiwi-B1A	December 7, 1961
Kiwi-B1B	September 1, 1962
Kiwi-B2A	Test cancelled
Kiwi-B4A	November 30, 1962
Kiwi-B4D	May 13, 1964
Kiwi-B4E	August 28 and September 11, 1964
Kiwi-TNT	January 13, 1965
Phoebus-1A	June 25, 1965
Phoebus-1B	June 26, 1968
Phoebus-2A	June 26, 1968
Pewee-1	November 21, 1968
Pewee-2	Test cancelled
NF-1 (Nuclear Fuel Furnace)	June 29, July 12, 21, and 27, 1972

Before shipment to NTS, the Kiwi-TNT reactor was operated at Pajarito Site beside the PARKA reactor (essentially a Phoebus 1 reactor set up as a critical assembly) to measure their interactions at various separating distances. (The origin of *PARKA* is unknown.)

According to a 1969 memorandum regarding waste management information for various LANL technical areas, the DP East facility processed Rover fuel elements containing enriched uranium. Air from the exhaust systems for radioactive materials passed through HEPA filters. All four stacks from these systems were monitored but concentrations were below detectable levels.

2.3.10.8 Ultra-High Temperature Reactor Experiment

The Ultra-High Temperature Reactor Experiment (UHTREX) involved the construction and operation of a test reactor to advance the technology of high-temperature, graphite-moderated, gas-cooled reactors. The reactor was constructed in the late 1960s at TA-52, and operated for approximately 1 yr before shutdown in February of 1970. The UHTREX was cooled by helium gas in a system consisting of a primary and secondary loops with a single heat exchanger. Gas pressure in the two loops ranged from 475 psi to 545 psi, with the secondary loop kept at higher pressure than the primary in case leakage occurred in the main heat exchanger. Under maximum conditions, the gas temperature at the core inlet was 1,600°F, and the exit temperature was 2,400°F. The secondary loop coolant entered the heat exchanger at 200°F and exited at 1,000°F. A regenerative heat exchanger called the recuperator reheated the primary coolant on its way back to the core. The recuperator also lowered the primary coolant temperature from 2,400°F to 1,400°F before it reached the main heat exchanger. The secondary loop released heat to the atmosphere in a building outside the main reactor building. This heat dump building housed finned tubes cooled by large fans. The UHTREX used 93% enriched uranium fuel in the form of small spheres of UO₂ coated with three layers of pyrolytic carbon bound in a graphite matrix. Fuel for the UHTREX was made in the CMR Building. The UHTREX had a rotating core that allowed the reactor to be fueled while operating. The design thermal power for the UHTREX was 3 MW.

The UHTREX used a gas cleanup system on the primary coolant loop to remove fission products and outgases from the unclad fuel. The UHTREX reactor, primary cooling system, and the gas cleanup system were in a gas-tight secondary containment provided by the main reactor building. The gas cleanup system consisted of metallic filters (to remove particulate matter), a copper oxide bed (to oxidize reducing agents), molecular sieve beds (to adsorb carbon dioxide and water), and water-cooled beds of activated carbon (either to trap volatile fission products or to delay fission gases to allow decay). Delay times for the carbon bed were 1.2 hr for krypton and 20 hr for xenon. Under maximum conditions, 13 kW of decay heat were produced in the charcoal bed. Tritium produced in the primary coolant via the ³He (n,p) ³H reaction accumulated in the cleanup system in the copper-oxide bed and in the molecular sieve beds. This tritium was eventually discharged up the 100-ft main stack during regeneration of the sieve beds. This process also resulted in the discharge of entrained fission gases.

Air from the secondary containment, the fuel handling and gas sampling areas, and the change rooms and other such potentially contaminated areas passed through absolute (HEPA) and activated charcoal filters before entering the main stack. Stack releases were monitored via a Tracerlab model MAP-1B/MGP-1A combination gas and particulate monitor. The particulate monitor comprised a moving filter and a plastic scintillation detector. The gas monitor used a sodium-iodide detector. A removable charcoal filter between the particulate and gas monitors allowed periodic assay of radioiodine concentrations via gamma-ray spectrometry. The stack monitor did not provide real-time radioiodine monitoring. Air from the control room, offices, laboratories, equipment rooms, and other such clean areas was exhausted through rooftop vents. The UHTREX facility was designed so that air flowed from clean areas to potentially contaminated areas.

Spent fuel from UHTREX was loaded into casks and transported by truck to Wing 9 of the CMR Building where it was evaluated in hot cells. Contaminated waste lines carried liquid radioactive

wastes to the TA-50 treatment facility. Decontamination and decommissioning of the UHTREX site and facilities began in the late 1980s. All radioactively contaminated solid waste was buried at TA-54, the central waste disposal facility at LANL.

2.3.11 Accelerators

During World War II, accelerators were used to determine the critical masses for each proposed atomic bomb design. The machines supplied neutrons for study of the neutron interactions involved in an explosive fission chain reaction. Efforts with early graphite reactors had not studied these interactions at all of the neutron energies relevant to a nuclear explosion, in which fast neutrons are emitted without slowing or moderation. . In addition, the accelerators supported the effort to find a way to prevent a *fizzle*, or predetonation, in the gun-assembled plutonium bomb. To pursue these objectives, LANL acquired two Van de Graff accelerators from the University of Wisconsin, borrowed a Cockroft-Walton accelerator from the University of Illinois, and purchased a cyclotron from Harvard.

During the postwar years, the emphasis was on building a foundation of basic scientific research with weapons applications. Three wartime accelerators were purchased and retained: the Short Tank, the Cockroft-Walton, and the cyclotron. The Long Tank was returned to the University of Wisconsin, but was replaced by a high-energy Van de Graff accelerator with a vertical configuration. The neutrons from that device and those provided by the Cockroft-Walton were used to study neutron interactions relevant to nuclear fusion. The old Harvard cyclotron was upgraded to a variable-energy cyclotron for study of the angular distributions of accelerated particles after they scattered off the nucleus of various target elements. LANL later obtained a circular electron accelerator called a betatron to obtain sequences of images of spheres of mock fission fuel as they were imploded by high explosives.

Two electron linear accelerators were later built to provide radiographs of the implosion process, in work that led to the 1963 construction of the Pulsed High-Energy Radiographic Machine Emitting X-Rays(PHERMEX--). PHERMEX generates X-rays by accelerating an electron beam into a tungsten target; the X-ray bursts are sent through model weapons at a remote blasting site to provide three-dimensional images of imploding spheres.

Relatively small accelerators used at Los Alamos include a Van de Graff accelerator housed at TA-1, W Building. The accelerator had two high-voltage electrostatic generators for production of variable energy neutrons for cross-section measurements. Protons were accelerated, hit a target (usually lithium), and produced neutrons. Some X-rays were also produced. There were also hazards from neutrons and X-rays. In addition, TA-3-16 housed a Van de Graff accelerator.

The largest accelerator at Los Alamos is at TA-53. The primary facility at TA-53 is a large accelerator complex originally called the Los Alamos Meson Physics Facility (LAMPF). The original sections of LAMPF were later renamed the Clinton P. Anderson Meson Physics Facility. LAMPF is a nominal 800-MeV, 1-mA intensity proton linear accelerator. Construction on LAMPF began in 1968. On June 12, 1972, LAMPF first achieved a full-energy beam. The facility was originally for study of sub-atomic particles. At the present, LAMPF serves as an accelerator generating intense pulses of neutrons (by sending the protons into such high-atomic-number targets as uranium) for scattering research at the Weapons Neutron Research (WNR) Facility and LANSCE facilities. The Proton Storage Ring is used to accumulate protons and provide a short-duration pulse of protons for targeting into uranium and other high-atomic-number targets for neutron production at WNR. The LANSCE complex includes the linear proton accelerator LAMPF, the Manuel Lujan Jr. Neutron Scattering Center, and a medical isotope production facility. In addition, TA-53 is the site for the Accelerator Production of Tritium

Project Office including the Low-Energy Demonstration Accelerator and research and development activities in accelerator technology and high-power microwaves.

LAMPF releases to air consist primarily of short-lived radioactive materials that have been activated from air. Site documents refer to the mix of short-lived materials as mixed activation products (MAP). These materials are produced when the proton beam from LAMPF is sent through air, or when a fraction of the proton beam is lost through interactions with accelerator components or targets. These interactions generate neutrons, which subsequently activate the air. Activated air products are exhausted to the air through a tall stack. The amount released increases proportionally as the power levels and beam time increase.

For some periods of time, these emissions reportedly accounted for the largest boundary dose and individual dose from all of LANL operations. The doses reported were among the highest nationwide among DOE operations in 1979. LAMPF was at 40% to 50% of design beam time in 1978. In 1978, 117,000 Ci of air activation products were released to the environment from LAMPF. Principal radionuclides were ^{11}C (20 min), N-13N (10 min), ^{15}O (2 min). A trace amount of ^{41}Ar (1.8 h) was also released. Measured doses at the site boundary were 14 mrem. Calculated boundary and individual doses were much higher (126, 67, and 22 mrem at the boundary for 1978, 1977, and 1976, respectively). The calculations are based on conservative plume diffusion models that are of limited value in the complex terrain of Los Alamos.

LAMPF has been the dominant source of radionuclides to air at LANL since the late 1970s. Short-lived activation gases were not reported at LAMPF for the 1974 to 1978 period. It is possible that LAMPF dominates site releases before the late 1970s. LAMPF airborne emissions were reported to the AEC in 1970, so limited operations could have occurred before 1972.

The TA-53 data suggest that there are at least four stacks for which data are available. These stack designations include FE-3 (North Stack, also called main stack in 1981), FE-4 (South Stack), FE-16, and FE-2. The FE-3 fan serviced the main accelerator tunnel, and was terminated in 1980. The FE-4 fan was added in 1977. FE-3 and FE-4 have reported emissions primarily of short-lived air activation products such as: ^{11}C , ^{13}N , ^{15}O , ^{41}Ar , and ^7Be . FE-2 services the WNR, and was added in 1981. FE-16 services TA-53-1 D-wing, with releases reported for other longer-lived radionuclides such as ^7Be .

Fugitive releases from LAMPF for 1990 were 0.21 Ci, a small fraction of the 120,000 Ci of short-lived gases that were reported. The fugitive emissions comprised longer-lived radionuclides, and a comparison of curies alone could be misleading. However, the magnitude of fugitive emissions is clearly less significant than that of the primary release points.

Cooling water used for accelerator components provides a source for liquid radioactive releases. Cooling water for accelerator components, including targets, also becomes radioactive, in addition to accumulating corrosion products from the target and magnet systems. This water has been released by the site to concrete-walled cooling-water ponds with bentonite clay on the bottom. The cooling water is held up, and no short-lived nuclides are observed in water. The cooling water and ponds are a source for subsequent releases off the site to surface water. Cooling water was released to floor drains that fed two 2,500-gal carbon-steel tanks. These tanks were discharged to the cooling-water ponds. Laboratory measurements have been identified for lagoon and cooling-pond waters, and for long-lived activity that can be collected on filtering media. The short-lived MAP is assessed with on-line monitoring, and through TLDs located at various locations.

2.3.12 Criticality Testing

TA-18 (Pajarito Canyon Laboratory) was first developed in mid-1943 and used by the Radioactivity Group. The site was chosen because it provided a remote location where experiments could be performed away from the radiation background associated with the main technical area (TA-1). In 1944, G- Division began using the area as a firing site for explosives (implosion) diagnostics. Three firing sites were established, called small, medium, and large. The small site in the west wing of the canyon was intended for small explosive charges of a few pounds each. The medium site in the south wing was for charges up to several hundred pounds; and the large site in the east wing was for charges of up to 2 t. However, the large firing site was never used for this purpose. The medium site was instead modified to make it suitable for up to 2-t charges in 1945. It appears the large site was used for drop testing of both inert and high-explosive units. The small and medium firing sites included two large, concrete structures called battleships for equipment protection during tests of the magnetic method for implosion diagnostics.

Nuclear criticality experiments first moved from Omega Site (TA-2) to Pajarito Site in April of 1946 following a fatal radiation injury. Initial work was done in a 26- by 40-ft addition to the central laboratory building previously used by M-Division. A second fatal radiation injury about a year later prompted a ban on hand-operated critical experiments and, as a consequence, a need for a facility for remotely operated critical assemblies. The Integral Assembly Building (more commonly known as Kiva 1) was therefore commissioned, with operations there beginning in April of 1947.

The initial work at Kiva 1 was to establish handling and storage guidelines for weapons and weapons components. Experiments involved a combination of assembly machines and critical assemblies. The first assembly machine was known as the bomb mockup, as it was close in size to the Fat Man weapon used at Nagasaki. This machine was used for sub-critical experiments only. In October of 1948, the W-2 group reported criticality of the Topsy machine. Topsy, which consisted of enriched uranium in a natural uranium reflector, was the first in a series of devices that provided fast neutron data for benchmarking computer programs. Topsy was initially used for sub-critical experiments, but was dedicated to critical work in the fall of 1948. Topsy was replaced with a machine called Elsie. Little Eva followed Elsie and was similar to Topsy in that it consisted of enriched uranium in a natural uranium reflector. Little Eva was moved to the Nevada Test Site in 1958 to calibrate activation foils for diagnostic measurements on the various Rover program reactors. The Comet machine also followed the Elsie machine for both critical and sub-critical work. Comet proved to be such a popular device that a twin called Planet was constructed. A betatron (electron accelerator) was used at Pajarito Site from May of 1951 until the fall of 1954.

In August of 1951, an unclad sphere of enriched uranium metal called Lady Godiva began operation. This assembly was for delayed-critical work through 1952. A plutonium core was added to the Topsy assembly about a year after startup. Use of the Lady Godiva assembly prompted the construction of a second experiments facility, called Kiva 2, which was completed in February of 1953. At this time, the entire critical experiments group re-located to TA-18. The group's offices had previously been at TA-1 in the Gamma Building.

The Lady Godiva assembly was moved to Kiva 2 upon completion and began operations there. However, it was portable and sometimes used at other areas of the LANL site. In mid-1953, Lady Godiva began being used for super-prompt critical bursts to supply pulses for a variety of experiments including evaluation of weapon test instrumentation, materials research, and biological research. The assembly was used for approximately 1,000 prompt-critical bursts until 1957. The last burst caused severe warping and oxidation, rendering Lady Godiva unusable. The assembly had actually been

similarly damaged in February of 1954, but the warping at that time was repairable. Lady Godiva was replaced with the Godiva II assembly, which was specifically designed for prompt-critical bursts.

In late 1954, an assembly called Jezebel came into operation. Jezebel was an unreflected sphere of delta-phase plutonium containing 4.5% ^{240}Pu . In later years, it also operated using a bare sphere of ^{233}U (98.1%) and an additional plutonium sphere of 20.1% ^{240}Pu . Use of the ^{233}U core was discontinued following its evaluation because the intense gamma-ray emission due to the ^{232}U impurity made for handling and measurement problems.

In 1958, the Topsy machine was replaced with a machine called Flattop. It first operated with an enriched uranium core, with cores of ^{233}U and plutonium being added subsequently. Unlike the ^{233}U core for the Jezebel assembly, the one for Flattop was retained because it was small enough that the gamma emission was tolerable.

Other critical assemblies at TA-18, Pajarito Laboratory, included:

- Jemima: Intermediate-enriched uranium used in the Comet machine in 1952.
- Molly G: A prompt-critical burst assembly modeled after Godiva 2. Following calibration at Kiva 2, Molly G was shipped to the White Sands Missile Range in July of 1964 where it became the Fast Burst Reactor.
- Hydro: A 10-kW neutron source consisting of a cylindrical core of 93% enriched uranium. Hydro was operated outside of Kiva 2 to eliminate room return of scattered neutrons.
- PARKA: A Phoebus 1 reactor left over from the Rover program and set up as a critical assembly.
- Big Ten: A cylindrical system consisting of enriched uranium used to establish cross-sections for fast power reactors.
- Kinglet: Experiments to establish design parameters for the kinetic intense neutron generator reactor project that was never funded.
- Mars: A large, general-purpose vertical assembly machine.
- Godiva IV: A portable fast burst assembly (successor to Godiva II).
- SHEBA: The solution high-energy burst assembly, used to evaluate criticality accident detection systems.
- SKUA: The supercritical uranium assembly (another fast burst assembly).
- Thor: A spherical plutonium benchmark assembly.

In the spring of 1955, the critical experiments group became involved in the Rover nuclear propulsion program. They were involved in the design, assembly, and zero-power testing of a series of graphite-moderated propulsion reactors. The Rover program dominated activities at Pajarito Site until 1972. The Rover effort required a third experimental facility (Kiva 3) at TA-18. Kiva 3 was completed in 1960.

The bulk of the Rover effort went to development of a series of graphite-moderated test reactors called Kiwis. However, an alternative to graphite-moderated reactors was pursued for a short time earlier in the program. This project, called Dumbo, was abandoned in the fall of 1959. The Kiwi reactors evolved from the Kiwi-A series, the first of which was tested at the Nevada Test Site in July of 1959, to a water-moderated system called the Nuclear Fuel Furnace tested at Nevada in July of 1972. In addition, Rover research at Pajarito Site included a horizontal assembly of square aluminum tubes called Honeycomb used for parametric studies to support development of the Rover reactors. Section 2.3.10.7 discusses the Rover program in more detail.

Following the cancellation of the Rover program, the critical experiments group conducted research for NASA into the development of plasma-core power reactors. Mock-ups for this research initially used components left over from the Rover program before progressing to systems using gaseous UF_6 . A complete UF_6 system was never achieved, however. The NASA work involved the study of lasers for power transmission, resulting in the first demonstration of a laser pumped by uranium fission products.

Operations of the various assemblies at the Pajarito Site resulted in elevated radiation levels along Pajarito Road while the devices were in use. Extensive gamma and neutron measurements were made during operations of the various machines at Pajarito Site in 1975. Extrapolations from these measurements indicated that the annual dose rate from gamma plus neutron radiation at the most exposed location on Pajarito Road was $1,120 \text{ mrem yr}^{-1}$ in 1975 using an assumption of continuous occupancy along the TA-18 boundary. However, actual occupancy time is very small for members of public. A member of the public would receive an annual dose of 1 mrem from Pajarito Site operations in 1975, assuming that 15 round trips a week past the site at 40 mph and a dose rate was uniform throughout the work day.

Other impacts of operations at the Pajarito Site include: 1) instances of releases of airborne radioactive material from the Kivas, 2) instances of removable radioactive contamination being tracked out of the Kivas and spread to offsite locations, and 3) releases associated with the processing of irradiated fuel elements at other areas of the LANL site. Examples of TA-18 activities include:

- Neutron dose rates at Kappa Site (TA-36) resulting from operations at TA-18 were identified as a concern in 1957. The highest neutron flux was measured in December of that year when the Hydro assembly was operating. An 18.5-min tolerance was measured at the Kappa Site guard station, with a caveat that the film badges being used had a blind spot for the neutron energies that made up a good share of the flux at that location.
- Air samples in 1957 in the vicinity of the Honeycomb assembly were half of the applicable tolerance level for that era, and samples in the vicinity of the Lady Godiva assembly were asserted to be excessively high. This is cited as justification for plating the new Godiva (presumably Godiva II).
- Three air samples obtained in 1960 during loading of the Super Comet machine with ^{235}U averaged 160 dpm m^{-3} , with a maximum reading of 295 dpm m^{-3} . These measurements were significantly higher than the applicable tolerance level for that era of 66 dpm m^{-3} .
- Above normal air counts were detected during disassembly of the Molly G assembly in preparation for shipping it to White Sands on July 20, 1964.

- In November 1964, ^{131}I concentrations in room air, in the exhaust system, and at a position 500 ft northeast of the TA-46 facility where fuel elements from one of the Rover reactors (Kiwi B4-D) were being processed were measured. The highest concentration found in the exhaust system was $4.9 \times 10^{-2} \mu\text{Ci m}^{-3}$. The highest concentration in an intermittently occupied room was $3 \times 10^{-3} \mu\text{Ci m}^{-3}$, and the highest concentration measured northeast of the building was $1.3 \times 10^{-6} \mu\text{Ci m}^{-3}$.

The Pajarito Lab facility was in standdown (a temporary stop work) after workers discovered bones in a Native-American burial area near Kiva 3 and because Local American Indians consider this a sacred area.

2.3.13 Fusion Research

Some of the first steps towards producing controlled nuclear fusion were taken at LANL. The AEC called the project Sherwood. The project started at LANL in 1951, and expanded beyond Los Alamos to become a nationwide effort. In 1952, six men and \$50,000 were assigned to a laboratory trial of the theories concerning the isotopes of hydrogen. Experiments began in a corner of the old U Building at TA-1 with the heavy core of an abandoned betatron machine as the heart of what was dubbed the Perhapsatron, because perhaps it would work and perhaps it would not. The Perhapsatron was first operated in the fall of 1952, shortly after the Mike Test in the Pacific proved that thermonuclear fusion was indeed possible. The Perhapsatron did not work, but it encouraged further study in a new field of science, plasma physics. Huge electrical condensers were assembled in the Project Sherwood Building. The unfulfilled promise of fusion led to the closing of the project by the mid-1970s.

The Perhapsatron used a toroidal Z-pinch, in which an induced toroidal current in the plasma produced a self-magnetic field that pinched the plasma column. After the Perhapsatron came a series of devices that used the pinch effect to seek the high temperatures needed for fusion. After the doughnut-shaped torus of the Perhapsatron came linear pinch machines such as the Columbus devices. Next, Scylla devices applied sudden compression on all sides through a strong magnetic field. Scyllac was at TA-3 in Building SM-287. Scyllac was an 8-m-diameter controlled thermonuclear reaction device. Los Alamos achieved the first controlled thermonuclear plasma in 1957 in the Scyllac theta pinch device, which used a rapidly rising axial magnetic field to heat plasma through a combination of shock and compression heating.

In 1958, physicist John Marshall developed a hydro-magnetic gun capable of shooting a plasma at terrific velocities. This was a new method for use in testing theories of plasma heating and confinement. The Pu Gun reported (in 1981) to be at TA-35 could have been this device.

Construction on laser laboratories for fusion research began at TA-35 in 1974. The HELIOS and ANTARES are laser facilities for inertial confinement fusion research. HELIOS is a 10-kJ CO_2 laser fusion system with a 10- μm wavelength, and ANTARES is a 40-kJ 24-beam CO_2 laser fusion driver. ANTARES was completed in December 1983.

2.3.14 Plasma Thermocouple

The plasma thermocouple program involved research into methods for converting nuclear fission energy directly into electrical power. This idea was born around 1942, and direct conversion was first achieved by LANL physicists in 1958. N Division was created at LANL in 1955 to study potential methods of nuclear propulsion in space. The group centered their efforts on Project Rover, in which

the LANL Kiwi reactors were developed, and ion or plasma propulsion for the far reaches of space. Direct conversion was the first choice as power source for plasma propulsion.

As of 1963, there were more than 50 people working on the plasma thermocouple problem. The method involved the principle of conventional two-metal thermocouples that produce small amounts of electricity when one junction is hotter than the other. Scientists substituted an easily ionized gas for one of the metals. When they electrically heated the metal emitter of the plasma thermocouple, cooled the container around it, and introduced plasma or ionized gas such as cesium, a stream of electrons flowed to the outside wall where they were collected. Later models used the energy of nuclear fission to provide the heat. The goal of the program was to provide a power supply package for space application with no moving parts or heavy turbines or generators.

2.3.15 Health Division

The Health Division at LANL was responsible for monitoring worker health and instances of overexposure to chemicals, explosives, and radionuclides in the workplace. The primary function of the Health Group (A-6) was to establish safe tolerance levels, develop monitoring methods, and to ensure that tolerance levels were not exceeded. Routine monitoring procedures were turned over to the specific group concerned whenever possible. In 1943 the Health Group consisted of 10 people. On June 1, 1947 the Health Group became the Health Division. In 1949, there were 97 members of H- Division, and in 1951, there were 158. The Health Research Laboratory at TA-43 was built next to the Los Alamos Medical Center from 1952 to 1954. Research performed at this site included structural, molecular, and cellular radiobiology, biophysics, mammalian radiobiology, mammalian metabolism, biochemistry, and genetics.

The Health Group (later Division) produced over 150 Progress Reports. The reports were produced on a monthly basis; the oldest is dated November 1943, and the most recent report was published in October 1960. The original policy of the Health Group was to depend entirely on information from health research groups elsewhere. Because that policy did not always provide the proper data in time to establish safe operating procedures, research projects were set up within the Health Group. The monthly reports describe various areas of research and papers published on the health effects of radiation and instrument development work conducted by the electronic and biophysics sections of Radiologic Safety (H-1). Accidents are reported in the Occupational Safety group (H-3) section of the division reports.

2.3.15.1 Accidents and Incidents

In 1943, the hazards of the project were reported to be limited to external radiation from the cyclotron, the Van de Graff, the D-D source, and the radium sources. There were also hazards due to uranium and the usual chemical laboratory hazards, but these were not considered serious. Only one accident occurred during the first year that involved overexposure to radiation from the cyclotron.

In February 1944, plutonium arrived at LANL in significant quantities. The members of Chemistry and Metallurgy Division and the Health Group became concerned about the dangers of working with this material. Control of alpha-emitting materials worked out well for the first year, while a research program developed tests for detecting overexposure of personnel to plutonium.

The initial external radiation hazard at LANL did not change until September 1944 when the Water Boiler at Omega Site went into operation. When the power boiler went into operation in January 1945, there were several instances of overexposure when the exhaust line developed leaks. In addition, there was an accident that resulted in serious exposures to several chemists during

decontamination of the active material. There were two serious accidents that resulted from critical assembly work, also at Omega: one that overexposed four individuals to gamma and neutron radiation, and one fatality. During the radioactive barium and RaLa implosion tests that started in September 1944, members of the chemistry group CM-4 received periodic overexposures to beta radiation.

A proportional counter using a methane-filled thin-windowed tube was developed at LANL and installed in the D-Building washroom as a hand counter in June 1944. In January 1945, it was necessary to redesign the existing facilities in D Building to safely handle large amounts of plutonium. The facilities were adequate with one exception. In July 1945, CM-5 handled amounts of plutonium that exceeded the capacity of its safety equipment and four workers were exposed to more than 1 μ g of plutonium, according to urine tests.

A urine test was developed in January 1945 which required a new laboratory free of alpha contamination (ML Building). Following the first human tracer experiment in April 1945, results of the urine tests were evaluated with some certainty. Until the urine test was perfected, nose counts were the only index of personnel exposure. Due to the difficult and time-consuming nature of the urine test, the most heavily exposed persons (as indicated by nose counts) had the most urine examinations. Available alpha-monitoring equipment lacked either sensitivity or portability, so swipe samples were used to detect contamination of hands and nostrils.

Polonium was never considered to be the hazard that plutonium was because of its short half-life, an easy urine test method, and relatively simple technical operations. Only two persons ever exceeded the tolerance limit for polonium (1,500 cpm in a 24-hr urine sample).

Monthly H- Division reports from 1947 forward repeatedly mention the hazards of beryllium, but there is no mention of beryllium in 1945.

According to the environmental impact statement for LANL (DOE 1979), some workers received radiation doses at levels higher than the general public. All operations were conducted with the intent of minimizing exposures to radiation and keeping all exposures as low as practicable as required by DOE policy. Actual exposures were measured by badge or other dosimeters for all workers in locations where there were potentials for above background exposure. The dosimetry met all requirements of DOE regulations established to meet Federal radiation protection standards. Further checks for possible inhalation or ingestion of radioactive materials were carried out on employees working in circumstances where exposures could occur. These checks included bioassays by means of urine sampling and *in vivo* whole-body counting.

During routine operations at Los Alamos there have been inadvertent releases of hazardous material. Safety procedures and methods of operation ensure rapid response to these incidents. Constant monitoring by automatic equipment (e.g., continuous room air stack monitors, radiation level alarms, portal monitors) and a large staff of health physics technicians ensure rapid detection of radiation or radioactivity in abnormal amounts or unexpected locations.

Table 2-4 lists a summary of accidents and incidents at LANL that were either reported to DOE or the subject of a Los Alamos report, or that involved criticality events with or without exposure.

Table 2-4. Accidents and incidents.

Date	Location	Description ^a	Source ^b
1943	TA-1, X Bldg	Overexposure to radiation from the cyclotron	1
Aug 1944	TA-1, D Bldg	10 mg of plutonium exploded in a worker's face	1
Jan 1945	TA-1, C Bldg	Fire in oil quench tank spread through frame shop building	3
Feb 11, 1945	TA-2 Omega Site	Criticality during experiment with EUH ₃ Dragon assembly for prompt bursts (no personnel exposure)	4
June 6, 1945	TA-2 Omega Site	Criticality during an experiment to establish the critical mass of EU (3 exposures of 66 rep, 66 rep, 7 rep)	2
July 1945	CM-5	Four workers exposed to more than 1 µg of Pu by urine tests	1
Aug 21, 1945	TA-2 Omega Site	Criticality while creating a Pu core critical assembly (fatality 510 rem; one exposure of 50 rem)	3
May 21, 1946	TA-18 Pajarito Lab	Criticality during demonstration of a Pu core critical assembly (fatality 2,100 rem; seven exposures of 360, 250, 160, 110, 65, 47, and 37 rem)	3
Sept 7, 1948	Not specified	Beta burns to legs while unpacking radioactive material	3
Dec 1949	TA-2 Omega Site	Criticality while testing control rods in the Water Boiler (one exposure of 2.5 rad)	4
Feb 1, 1951	TA-18 Pajarito Lab	Criticality during measurement of critical separation distance for EU cylinders (no personnel exposures)	4
Apr 18, 1952	TA-18 Pajarito Lab	Criticality during experiment with an EU plate critical assembly (no personnel exposures)	4
July 9, 1952	Not specified	Beta burns to hands while unpacking radioactive material	3
Jan 8, 1953	TA-18 Pajarito Lab	Polonium-beryllium source ruptured (2 Ci Po lost; three homes and the facility were decontaminated)	1
Feb 3, 1954	TA-18 Pajarito Lab	Criticality during preparations for a scheduled prompt burst in the EU Lady Godiva assembly (no personnel exposures)	4
Apr 30, 1956	Not specified	Beta burns to hands while unpacking radioactive material	3
June 26, 1956	Not specified	Explosive detonation caused fatal blast injuries to a technician	3
July 3, 1956	TA-18 Pajarito Lab	Criticality occurred during an experiment with the Honeycomb EU assembly (no personnel exposures)	4
Feb 12, 1957	TA-18 Pajarito Lab	Criticality during preparations of an experiment for Godiva to provide a pulse of fast neutrons (no personnel exposures)	4
Dec 30, 1958	TA-21-2S, Rms 213-218	Criticality during Pu recovery operations (fatality 12,000 rem; two exposures of 134 rem and 53 rem)	3
Feb 24, 1959	Not specified	Explosives detonated during machining (2 fatalities)	3
July 15, 1959	TA-21-5, Rm 501	Fire in exhaust filters during welding; fans turned off; stack release	1
July 17, 1959	Not specified	RA-Gas release	3
Oct 14, 1959	Not specified	Explosive scrap detonated at a burning ground (4 fatalities)	3
June 17, 1960	TA-18 Pajarito Lab	Criticality while investigating the critical parameters of EU (no personnel exposures)	4
Dec 11, 1962	Not specified	Criticality during experiment to measure axial fission distribution of Zepo assembly (no personnel exposures)	4
Sept-Dec 1962	Not specified	Recovery operation quarterly exposure (6.4 rem)	3
Oct-Sept 1963	Not specified	Two exposures while casting normal U (15.2 rem, 17 rem)	3
Oct 12-21, 1965	Not specified	Three exposures while removing pins from a partially dismantled reactor (4, 3.8, and 3.6 rem)	3
Oct-Dec 1965	Not specified	Two exposures while machining reactor pins (3.8 rem, 3.2 rem)	3
Jan-Feb 1966	Not specified	One exposure during Pu processing (5.1 rem)	3
Apr-Jun 1966	Not specified	One exposure while dissolving test shot samples (3.4 rem)	3
April 15, 1966	Not specified	One ³ H exposure while removing bolts (3.1 rem)	3
May 18, 1967	Not specified	Criticality in mockup of high power density reactor (insignificant personnel exposure)	3
July-Aug 1967	Not specified	One external quarterly ⁶⁰ Co exposure (5.9 rem)	3
Oct 7, 1970	Not specified	Capsule of tritiated salt was missing from inventory	
Oct 7, 1970	TA-21-150	Sealed capsule of ²³⁸ Pu broke (10 ug ²³⁸ Pu released up a vent)	3

Table 2-4. (Continued)

Date	Location	Description ^a	Source ^b
July 13, 1971	TA-3-29, CMR Hot Cell	²³⁸ Pu released to the working area during the disassembly of a transit SNAP capsule	3
Oct-Dec 1972	TA-15	One exposure to X-rays while working on PHERMEX (5.43 rem)	3
March 1975	LOFC	HTGR ¹³¹ I release	2
May 24, 1977	TA-3-16	³ H release (800 Ci) from Van de Graaf accelerator	1
Oct 6, 1977	TA-33	³ H release (30,800 Ci)	1
May 4, 1979	TA-3-34	3,000 Ci of ³ H released- one 13-rem exposure, 10 exposures less than 0.6 rem	2
Aug 22, 1979	TA-18	220 g ²³⁵ UF6 released into Kiva 1 (small personnel exposures)	1
Oct 14, 1981	TA-3-29, CMR	Ten analysis samples containing PuO ₂ incorrectly labeled as uncontaminated (11 persons received unquantifiable contamination)	2
Aug 26, 1983	TA-33	³ H release (52,100 Ci)	1
Nov 9, 1987	Not specified	Capacitor failure shock and burn	2
Sept 10, 1988	Not specified	Glass vial overpressure explosion	2
Jan 10, 1991	LA County Landfill	Dumpster (Class C)	2
June 10, 1992	CMR/LLRW OS	Contamination	2
May 28, 1993	LA County Landfill	Disposal of radioactive waste from TA-3-66 in a non-radioactive landfill (Type C- 5,000 dpm per 10-cm ² waste bag)	2
June 11, 1993	LA County Landfill	Disposal of DU and thorium waste from TA-3-66 in a non-radioactive landfill (Type C- 50,000 dpm per 10-cm ² waste bag)	2
Sept 8, 1993	TA-33	Three technicians placed themselves in a high radiation field of 280 R/hr (Type C 799 mrem, 229 mrem, 51 mrem)	2
Nov 14, 1996	CMR, Wing 9	Explosion/fire	2

a. Po = polonium; Pu = plutonium; rep = roentgen equivalent physical, a previous unit of absorbed dose.

b. Sources: 1-LANL H Division Reports; 2-LANL Library LA Reports Collection; 3-AEC (1975); 4-McLaughlin et al. (2000).

2.3.16 Waste Treatment and Disposal

2.3.16.1 Liquid Waste Disposal

Untreated liquid wastes from TA-1 were discharged to Acid Canyon in late 1943 or early 1944 through April 1951. By June 1951, the TA-45 Radioactive Liquid Waste Treatment Plant (also called the WD Site) began treating the wastes by a flocculation-sedimentation-filtration process. The final effluent, reported to contain about 1% of the influent plutonium, was sampled before release to Acid Canyon. Until mid-1953, TA-45 treated liquid wastes only from TA-1. Starting in June 1953, additional liquid wastes were piped in from the new TA-3, which included the CMR building plutonium research wastes. TA-3 wastes that met a criterion of 330 dpm L⁻¹ as a 2-week average were discharged untreated to Acid Canyon. By December 1953, about 30% of TA-3 waste was released untreated. In September 1953, wastes from the Health Research Laboratory (TA-43) were added to the line coming from TA-3. In 1958, wastes from a new radiochemistry facility (TA-48) were added to the same line. Fission products from this source reportedly caused increased gross beta and gamma content of TA-45 effluent from 1960 to 1963. In July 1963, wastes from TA-3 and TA-48 were redirected to the new TA-50 Central Waste Treatment Plant south of Los Alamos Canyon. Liquid wastes from TA-43 were redirected to the sanitary sewer. Only wastes from TA-1 were treated at TA-45 from July 1963 until TA-45 ceased operation near the end of May 1964. Some untreated low-level liquid wastes from decommissioning of Sigma Building at TA-1 were released until June 1964. These were reportedly

the last effluents released to Acid Canyon. Decontamination and decommissioning operations began in October 1966. By July 1967, unrestricted access to Acid Canyon was allowed.

During WWII, plutonium was an extremely valuable commodity. Storage tanks at TA-21 initially stored liquid wastes pending future improvements in the extraction processes. During the late 1940s, two tanks known as the General's Tanks were buried at TA-21 (DP Site) to collect waste plutonium solution. These tanks were immediately adjacent to Area A in a fenced area. The last time wastes were added to these tanks was in 1947.

In the late 1940s and early 1950s, it was found that the natural soils and clays at TA-21 were effective in removing radioactive contaminants from the waste liquids. Absorption beds were then used in which the process effluent was emptied into a trench filled with absorption material consisting of cobble, gravel, and fine sand. These beds were at Material Disposal Areas (MatDAs) T, U, and V (see Table 2-5). By 1952, research had made sufficient progress toward reprocessing liquid waste. A specially built waste treatment laboratory (TA-21-35) began reprocessing liquid wastes in 1952. In 1967, waste treatment operations were transferred to TA-21-257. Treated liquid wastes from both Buildings 35 and 257 were occasionally discharged to the absorption beds at MatDA T until 1967. From 1968 to 1976, wastes were mixed with cement and pumped down asphalt-coated shafts augured between the two absorption beds at MatDA T. From 1975 to 1983, transuranic wastes were mixed with cement and pumped into corrugated metal pipes, which were stored in the retrievable storage pit dug between the two absorption beds at MatDA T. These wastes were retrieved from 1984 to 1986 and relocated to MatDA G at TA-54. One of the two 50,000-gal tanks was emptied, and the second partially emptied, of their liquid plutonium-nitrate solution. The second tank contained liquid awaiting upgrade of the 1979 waste treatment system because the nitrate content of the waste was too high for the current system.

In 1957, average ^{90}Sr in TA-35 pilot plant liquid effluent was 31 times the tolerance levels, but attenuation between TA-35 and the Rio Grande River provided the required dilution. Liquid wastes were held in 50,000-gal tanks to allow ^{140}Ba and ^{140}La decay. A new waste treatment plant was placed into operation at TA-35 in 1960. It discharged treated wastes to Ten Site Canyon, a small branch of Mortandad Canyon.

TA-50, Waste Management Site, began operation around July 1963. It comprises two facility management units: the industrial liquid and radioactive liquid waste received from Laboratory technical areas and activities that are part of the waste treatment technology effort. The Radioactive Liquid Waste Treatment Facility discharges effluent to Mortandad Canyon. Discharges infiltrate into the stream channel and maintain a saturated zone in the alluvium extending about 3.5 km downstream from the outfall. The stream flow in the upper reach of the canyon is perennial with the release of cooling water from TA-46 and industrial effluents from TA-50. Storm runoff adds to the volume, extending stream flow into the middle and lower reaches of the canyon, both of which are within DOE property.

Continuous surface flow has not reached the Pueblo of San Ildefonso boundary since observations began in the early 1960s due to the small drainage area of the canyon and the large volume of unsaturated alluvium. In June 1974, the analytical facilities used for environmental monitoring were located in the basement of TA-50, the waste treatment facility

The streambed and soil of TA-2 (Omega Site) are affected from both historical operations there and from releases that occurred upstream. Examples of the latter include discharges from laundry operations at TA-1 and an overflow from the industrial waste line that ran through the canyon near the Omega Bridge. The line carried waste from TA-3 to the TA-45 treatment plant. The overflow

occurred in January 1955 during attempts to thaw a frozen line. Discharges of liquid effluents from TA-1 included significant amounts of plutonium and polonium.

Environmental sampling started in Los Alamos Canyon in the 1940s to monitor the effluents from TA-1 and TA-2. In 1945, fluids in pools in the bottom of the canyon were 20 times the maximum permissible concentration (MPC) for plutonium and 15 times the MPC for polonium in drinking water. In 1946, these values had dropped to 3 times the MPC for plutonium. Soil and water samples taken in 1945, 1953, 1954, and 1957 were well below MPC on surface samples and on samples as far as 6 in. below the surface. The principal source of the contamination was the laundry effluents from TA-1.

Before 1963, all radioactive liquid effluents from the OWR deionizers and system wastewater were discharged directly to the stream bed. In 1963, a liquid waste storage system was installed that provided three underground tanks. Liquid wastes were held in these tanks for a period to allow for radioactive decay. Between 1963 and 1968, the solutions would be diluted as necessary following decay and then discharged to the stream bed. Early in 1968, a transfer system was installed to allow the solutions to be transferred to portable tanks and then transported by truck to the TA-50 waste management facility. However, 1973 reports state that numerous sinks and floor drains still drained nonradioactive liquid wastes to the creek. In 1975, liquid waste from the regeneration of the OWR ion exchange columns averaged 11,000 L per month, and that this waste stream represented the most highly radioactive liquid waste from TA-2. Before connection of the TA-2 sanitary waste system to the TA-41 treatment plant in 1974, sanitary wastes went to a local septic tank, the leach field of which discharged to the local soil. In 1974, sanitary wastes from both TA-2 and TA-41 facilities were treated at a small treatment plant at TA-41 and released to Los Alamos Canyon.

Environmental monitoring since 1979 has shown that concentrations of ^{239}Pu in sediments are elevated downstream from TA-2 in comparison with samples taken upstream at the Los Alamos Bridge. The maximum was in 1982 when 4.1 pCi g^{-1} of ^{239}Pu was reported downstream, compared with 0.009 pCi g^{-1} ^{239}Pu and 0.39 pCi g^{-1} of ^{238}Pu upstream at the bridge. Historical operations from TA-1, TA-2, and TA-41 have all affected the Los Alamos Canyon streambed, surface water, and groundwater.

2.3.16.2 Solid Waste Disposal by Burial

Process wastes at TA-21 from the early 1940s until the late 1970s were largely disposed of at five MatDAs known as MatDAs A, B, T, U and V (see Table 2-5).

Table 2-5. MDA descriptions.^a

MDA	Area (acres)	Solid/Liquid Waste Disposal	Brief Description	Date Became Inactive
A	1.25	Solid	Four pits used 1944 - 1947 Large pit used 1969 - 1978 for building D&D Below ground General's tanks used 1945 - 1949	1978
B	6.03	Solid	Unknown number of pits/trenches used 1945 - 1948 Western 2/3 of site paved 1966 Eastern 1/3 of site used for trench cover studies 1982 to present	1952
T	2.21	Liquid	Four absorption beds used 1945 - 1967 62 shafts for 241Am cement paste disposal used 1968 - 1976 TRU cement paste storage 1975 - 1983	1983
U	0.2	Liquid	Two absorption beds used 1948 - 1968	1968
V	0.88	Liquid	Three absorption beds used in 1945 - 1961	1961

a. (LANL ER 1991).

Solid wastes from TA-21 were, in general, either buried or incinerated. MatDAs A and B accepted buried waste. MatDA T accepted transuranic wastes in corrugated metal pipes; the pipes could be retrieved at a later time. Debris from the destruction or remodeling of buildings at TA-21 was either buried at MatDA A or occasionally pushed over the edge of the mesa south of MatDA V, piled up northeast of DP East, or abandoned in other places at TA-21.

MatDA B south of DP Road was the first common burial ground for radioactive waste at LANL. There are 5 or 6 absorption beds used for the old TA-21 laundry in Area B. There are photos of foam on top of these beds; this foam ran off into the canyon, and included tritium. Millicurie quantities of transuranics, including americium, are reportedly present.

MatDA A is at TA-21 and was the second common burial ground for radioactive waste at LANL.

MatDA T, west of Area A at TA-21, has been in use since 1945. Four absorption beds received untreated and treated wastes from 1945 until 1967. Since 1968, treated wastes have been mixed with cement and pumped down shafts drilled between the south absorption beds and the north absorption beds. Though small in size, Area T has received more intensive study from an environmental monitoring viewpoint than any other waste disposal area at the Laboratory.

MatDA C is north of Pajarito Road near TA-50 at TA-4. MatDA D comprised two underground chambers used in 1948 at the TA-33 Hot Point. The chambers were contaminated with polonium. Area D has not been used since 1955. MatDA E was an underground chamber (destroyed in 1950) and six pits at the TA-33 New Hot Point. Area E was in use through 1962.

In addition, LANL disposed of contaminated trash from Bendix, Eberline, Lovelace Clinic, and the Decontamination Laundry in Santa Fe. The AEC told LANL to discontinue this practice in the early 1960s once commercial radioactive material disposal grounds became available in New York, Connecticut, and Nevada.

2.3.16.3 Incinerators

An incinerator was constructed in late 1950 or early 1951 at TA-42. It was designed for volume reduction of contaminated trash and included storage facilities for liquid radioactive waste. A 1954 document described the TA-42 incinerator for reducing low-level plutonium contaminated waste as having an off-gas clean up system. Pressure excursions contaminated the building and the system never worked correctly. Water from the TA-42 incinerator was dumped into Mortandad Canyon farther upstream than the TA-35 waste treatment plant discharge. Air counts for incinerator stack emissions are available for 1967 to 1970. The TA-42 incinerator was abandoned in 1970 and decommissioned in 1981.

An incinerator for alpha materials became operational on December 14, 1953. The 1953 Annual Health Division report also mentions a waste disposal incinerator beginning operations in 1953. Other 1953 and 1954 documents mention an incinerator for combustibles. A 1954 monthly H Division report discusses a meeting where it was decided that an incinerator would be shut down indefinitely. However, the location of that incinerators was not provided and the documents could refer to the TA-42 incinerator.

There was a glovebox incinerator in DP West Room 313 between 1958 and 1971 used to recover ^{235}U . There was a fire in the 313 incinerator ductwork on December 8, 1959, and at least seven explosions occurred in the incinerator between 1960 and 1971. Contaminated oils and fats from machine shops were reportedly incinerated in salamanders at TA-21. Air samples were taken in 1967 and no contamination was found.

There was a controlled air incinerator at TA-50 in 1976. It reportedly had a HEPA filtration system. It is unclear if and when it became operational because there was a trial burn in 1986.

In 1947 there was an experimental rag incinerator for recovering ^{235}U at TA-3, CMR Building. An incinerator at TA-39 burned waste including magnesium shavings between 1955 and 1960. In 1957, two incinerators at TA-1, 146 and 147, were found free of radioactive contamination and later removed in 1958 and 1959. In addition, there was reportedly an incinerator at the Los Alamos airport site in the 1950s. An incinerator was also reported to exist near the rim of Acid Canyon. Chemical analysis of the ash pile at the site reportedly indicated presence of dioxin and furans.

2.3.17 Special Studies

On April 23, 1961, two workers from Group H-1 participated with the U.S. Geological Survey in a project to seed Lake MacMillan near Carlsbad, New Mexico, with ^3H . This tracer study was designed to determine the extent/size of the Lake McMillan underground reservoir. Water from the lake seeps through the lakebed into underground waterways and comes to the surface again at various points several miles downstream in the Pecos River. It has been estimated that this underground waterway could be a vast lake more than 5 mi in diameter. Five containers of ^3H from ORNL, each holding 50 Ci of tritiated water, were transferred to the lake. Release of water from the lake was stopped on April 24 and gates were kept closed for 1 week. The amount of ^3H added was calculated so that resultant concentrations would be less than $1/500^{\text{th}}$ of the level generally and officially regarded as safe and acceptable for drinking water. A concentration of less than $0.02 \mu\text{Ci gal}^{-1}$ was expected in the lake, with even more dilution once it reached the underground reservoir.

In 1983, LANL personnel participated in uranium mapping of the impact area from the DIRECT COURSE event at White Sands Missile Range. A general-purpose heat source radioisotope thermoelectric generator containing ^{238}U to simulate normal fuel was exposed to the detonation of

609 t of ammonium nitrate/fuel oil (ANFO). This test was designed to simulate the effects of a space shuttle propellant explosion on such a generator. It was shown that the depleted uranium-simulated fuel was finely divided and widely dispersed.

In a joint experiment with Naval Oceans System Command, a vented ^{238}Pu general purpose heat source was exposed to the Pacific Ocean at San Clemente Island. LANL was apparently asked to examine the unit after exposure and analyze nearby sediment and sea cucumbers.

2.3.18 Airborne Release Points

Plutonium released from TA-3 and TA-21 was largely ^{239}Pu into the 1960s. ^{238}Pu use increased in the 1960s, until in the late 1960s and early 1970s it constituted more than 50% of the plutonium. Isotopic separations of effluent samples were made beginning in 1972. LANL reportedly did not discharge any substantial quantities of ^{238}Pu until 1967. No routine analyses were made to differentiate between ^{238}Pu and ^{239}Pu until 1971. At that time, about 80% of the plutonium activity was attributed to ^{238}Pu . This percentage has continued to increase, and ^{238}Pu now accounts for about 95% of total plutonium activity.

Operation of the three versions of the Water Boiler reactor (LOPO, HYPO, and SUPO) and the OWR produced routine airborne radionuclide releases from Omega Site from 1944 through 1992. Airborne emissions from the Water Boiler (deactivated in 1974) consisted primarily of fission gases and their particulate decay products. However, the Water Boiler gaseous effluent stream also contained smaller amounts of volatile fission products such as ^{131}I and ^{137}Cs .

Releases from the OWR consisted primarily of ^{41}Ar , which was created via neutron activation of air in the reactor's thermal column region. However, some H Division records make mention of occasional (unquantified) releases of activated material through the roof vents. It was also necessary to periodically purge fission gases from the OWR. Several H Division progress reports make mention of high local airborne radioactivity levels at Omega Site from the loss of normal ventilation equipment due to power failures.

There were two problems associated with the sampling of work area air at the SUPO facility in the early 1950s. The first was a realization that the filter paper for sampling failed to pick up gas in the air and only accounted for particulate matter. The second was that the H-1 group did not have an instrument for determining dose rates from sources containing high-energy beta emitters such as the Water Boiler fuel solution. Fission products were carried to the air space above the fuel solution by the migration of radiolysis gases through the fuel. A recombiner removed the hydrogen from the gases that collected above the fuel solution. The water from the recombiner was returned to the reactor vessel, and the remaining radioactive, gaseous effluent was discharged via the stack.

The stack effluent was sampled using a combination of filter papers, charcoal cartridges, and gas samples. Samples were analyzed via a 3- by 3-in. NaI detector and a 400-channel multichannel analyzer. The energy range covered was about 60 to 2,000 keV. The fact that several of the photon energies of interest occurred in the region of 80 keV to 250 keV degraded the accuracy of the results. It is stated that the results given are probably accurate to within a factor of two. Decay corrections for the elapsed time between sampling and counting were made for ^{88}Rb and ^{138}Cs .

In early 1964, the Omega stack monitor was modified to report the output of the stack in curies. In order to reduce the background, it was necessary to move the stack monitor building away from the stack. The isotopes identified in effluent from the Omega Stack were ^{41}Ar (from the OWR), $^{85\text{m}}\text{Kr}$, ^{87}Kr , ^{88}Kr , ^{88}Rb , ^{131}I , ^{133}Xe , ^{135}Xe , and ^{138}Cs . The noble gas and ^{88}Rb concentrations were found to

follow the reactor power history with a lag of about 10 hr due to the delay in the vent line. The ¹³¹I concentration was found to be nearly constant, which was considered to be indicative that most of the iodine created by the reactor was retained in the system and not released. Iodine-131 and ¹³⁷Cs were identified in the condensate collected from the vent line. The ¹³⁸Cs concentration in the stack effluent was found to peak before the arrival of the remainder of the constituent species.

Table 2-6 summarizes the composition of the effluent from the Omega Stack.

Table 2-6. Omega Stack effluent.

Nuclide	Concentration in stack (μCi cm ⁻³) ^a	Curies per 24 hr ^b	Activity fraction
⁴¹ Ar	1 × 10 ⁻⁴	3.8	0.022
^{85m} Kr	1 × 10 ⁻³ to 1 × 10 ⁻²	27	0.156
⁸⁸ Kr	1 × 10 ⁻³ to 1 × 10 ⁻²	21	0.121
⁸⁸ Rb	1 × 10 ⁻³ to 1 × 10 ⁻²	38	0.220
¹³¹ I	1 × 10 ⁻⁹ to 1 × 10 ⁻⁸	--	--
¹³³ Xe	1 × 10 ⁻⁴ to 1 × 10 ⁻³	4.1	0.024
¹³⁵ Xe	1 × 10 ⁻³ to 1 × 10 ⁻²	79	0.457
¹³⁸ Cs	1 × 10 ⁻⁶	--	--

- Concentration values represent averages, with the exception of that for the ¹³⁸Cs, which is a peak concentration.
- Values correspond to 24 hours of operation at an integral power of 150 kWh after a couple days of shutdown. It is asserted that the curie output would increase by 60% to 70% following consecutive days of reactor operation at 150 kWh. Note that at the time this report was compiled, the OWR operated at a power level of about 5 MW.

An incident provides some indication of the activity associated with the gaseous effluent from SUPO. When the vent line from the Water Boiler to the Omega stack was cut to tie in the effluent line from the OWR, the gas released from the cut produced an exposure rate of 80 R hr⁻¹. This rate persisted for about 30 min then gradually dissipated. The stack blower was turned on in an effort to accelerate the removal of the gas. All personnel were evacuated until the gas was removed.

A characterization of radionuclides and their concentrations in the stack effluents from the SUPO recombiner blower and valve house was performed on January 12 and February 11, 1970. The reactor power was 25 kW, and it is stated that ample time was allowed between startup and sampling to allow maximum activity to build. The nuclides found in the recombiner blower effluent were ¹³⁵Xe and ¹³⁸Cs. ¹³⁵Xe was reported at a concentration of 6.7 × 10⁻⁶ μCi cm⁻³. The ¹³⁸Cs concentration was reported to be 2.7 × 10⁻⁷ μCi cm⁻³. The ¹³⁵Xe concentration in the recombiner blower stack exceeded the occupational MPC in 1970. Radionuclides reported in the effluent from the Water Boiler valve house were ⁴¹Ar, ⁸⁸Rb, ¹³⁵Xe, ¹³⁸Xe, and ¹³⁸Cs. The individual concentrations of ¹³⁵Xe and ¹³⁸Xe were too small to be quantified. The ⁴¹Ar concentration was reported as 4.5 × 10⁻⁵ μCi cm⁻³, over 20 times the occupational MPC. The ¹³⁸Cs and ⁸⁸Rb concentrations were reported as 1.1 × 10⁻¹⁰ μCi cm⁻³ and 2.9 × 10⁻¹⁰ μCi cm⁻³, respectively. Both of these values are several orders of magnitude below the occupational MPC.

2.3.18.1 Iodine-131 Releases from the Omega Stack

In 1965, sampling was performed to quantify releases of ¹³¹I from the Omega stack and the collection efficiency for various sampling cartridges. The ¹³¹I collection efficiency of the cartridges during the various sampling runs is reported to have averaged from 95% to 98%. The ¹³¹I sampling data cover July 29, to October 4, 1965. Table 2-7 shows the ¹³¹I sampling data. No explanation was provided for why the concentration on September 16, 1965, was so much higher than for the other days.

The source of elevated gamma radiation levels observed in 1950 at the edge of Omega Canyon near the Trailer Village, 0.6 mR hr^{-1} gamma flux, was the condensate trap that filtered nongaseous constituents out of the Water Boiler off-gas before it entered the Omega stack. Exposure rate measurements made at head height at about 4 ft from the pit read more than 14 R hr^{-1} at the northeast corner and 2.2 R hr^{-1} at the southeast corner. The Water Boiler was operating at full power when these measurements were made. In addition, measurements showed that the dose rate at the Trailer Village dropped by 50% immediately after the Water Boiler was shut down, showing that the pit still remained a source of exposure when the reactor was not operating.

In 1963, an assessment of radioactive gas concentrations that could be present in the old trailer court area from the Omega stack effluent was conducted. It is presumed that "old trailer court" in this case refers to the area off of DP Road and not the Royal Crest trailer court off of East Jemez Road. The report used the information from the Water Boiler assessment as a source term and combined it with average meteorological observations to predict the average concentration to which a resident of the trailer court would be exposed. The reported conclusion was that because the Water Boiler only operated for roughly 8 hr a day, a full-time occupant would have received a dose essentially equal to the guideline value. However, it is also pointed out that there is significant uncertainty in that estimate.

2.3.18.2 Unmonitored Releases from Omega Site

A persistent source of air contamination at the Water Boiler facility was identified in 1951. The source was determined to be ^{235}U from an old spill that had seeped into the reflector of the reactor. The only means of addressing the problem was to institute additional ventilation.

In September of 1953, it was found that the bismuth blocks used in the north thermal column of the Water Boiler were binding, resulting in small amounts of the bismuth being eroded away each time a

Table 2-7. Iodine-131 sampling results for the Omega Stack from 1965.

Date	Duration (hours)	Flow Rate (cfm)	Vol. Sampled (ft ³)	I-131 Activity			Average Concentration* (µCi/cc)
				Sampler A (dpm)	Sampler B (dpm)	Average (µCi)	
7/29/65	22.3	1.0	1338.0	700617	729329	3.2E-01	8.9E-09
7/30/65	71.5	1.0	4290.0	964325	1062397	4.6E-01	4.0E-09
8/2/65	24.0	1.0	1440.0	470974	293223	1.7E-01	4.4E-09
8/3/65	23.5	1.0	1410.0	578063	380947	2.2E-01	5.7E-09
8/4/65	23.7	0.5	711.0	284514	187875	1.1E-01	5.6E-09
8/5/65	24.0	0.5	720.0	215021	133482	7.8E-02	4.1E-09
8/6/65	71.5	0.5	2145.0	494111	318514	1.8E-01	3.2E-09
8/9/65	23.8	0.5	714.0	218032	126051	7.7E-02	4.0E-09
8/10/65	24.0	0.5	720.0	243818	147114	8.8E-02	4.5E-09
8/11/65	23.3	1.5	2097.0	598642	445416	2.4E-01	4.2E-09
8/12/65	23.8	1.5	2142.0	392023	324066	1.6E-01	2.8E-09
8/13/65	71.4	1.5	6426.0	1187706	925312	4.8E-01	2.8E-09
8/17/65	23.8	1.5	2142.0	237138	220740	1.0E-01	1.8E-09
8/18/65	23.4	1.5	2106.0	181994	210043	8.8E-02	1.6E-09
8/19/65	23.9	1.5	2151.0	252037	223774	1.1E-01	1.9E-09
9/14/65	21.2	1.0	1272.0	812913	777548	3.6E-01	1.0E-08
9/15/65	23.5	1.0	1410.0	4528545	4126953	1.9E+00	5.1E-08
9/16/65	24.3	1.0	1458.0	10382164	10423331	4.7E+00	1.2E-07
9/17/65	69.6	1.0	4176.0	1750400	1668654	7.7E-01	6.9E-09
9/20/65	23.5	1.0	1410.0	719351	690034	3.2E-01	8.4E-09
9/21/65	22.5	1.5	2025.0	1253921	1267426	5.7E-01	1.0E-08
9/22/65	24.6	1.5	2214.0	1133133	1032930	4.9E-01	8.2E-09
9/23/65	22.8	1.5	2052.0	622613	664541	2.9E-01	5.3E-09
9/24/65	71.9	1.5	6471.0	1280271	1200319	5.6E-01	3.2E-09
9/27/65	23.7	1.5	2133.0	353028	354947	1.6E-01	2.8E-09
9/28/65	24.3	0.5	729.0	213553	176814	8.8E-02	4.5E-09
9/29/65	23.9	0.5	717.0	161961	117219	6.3E-02	3.3E-09
9/30/65	24.5	0.5	735.0	105608	48035	3.5E-02	1.8E-09
10/1/65	71.5	0.5	2145.0	224817	189888	9.3E-02	1.6E-09
10/4/65	23.5	0.5	705.0	219743	185989	9.1E-02	4.8E-09
Average =							1.0E-08
Std. Dev. =							2.2E-08
Pct. Std. Dev. =							224%

*includes correction for 95% collection efficiency

block was installed or removed. The eroded material contained polonium created through neutron activation of the bismuth and contaminated the floor. The problem prompted a decision to remove the blocks and either dispose of them or file them into shape. Despite precautions taken to isolate this operation and inhibit the spread of contamination, contaminated dust was still either tracked or blown to other parts of the building. The activity on the floor was reduced to 200 cpm after several days of scrubbing.

An accident at the Omega Water Boiler on August 3, 1953, caused a temporary rise in the background to 100 R hr⁻¹ in the Reactor Room. No details were provided in the report about what specifically occurred.

On July 24, 1957, 120 cm³ of acid was added to the Water Boiler fuel solution. During this action, fission product material was inadvertently drawn into an evacuated line and deposited on the top of the reactor. Exposure rates as high as 20 R hr⁻¹ were measured on the floor surface.

Between January 20 and February 20, 1958, electricians cut into a power line at Omega Site, causing a power failure. The loss of normal ventilation resulted in evacuation due to high airborne concentrations of what was reported to be ¹³⁷Cs. It was estimated that the ¹³⁷Cs concentration was at least 37 times tolerance, though no basis for this value was given. No air sampling was performed

given the urgent need to evacuate the area. This incident was followed by a rash of similar incidents, with power failures occurring on May 27, 1958 (at 2:52 p.m.); May 29, 1958 (at 4:00 p.m.); on June 6, 1958 (at 9:58 a.m.); and on June 9, 1958 (at 9:30 a.m.). All of these incidents required evacuations. The source of these failures was finally corrected.

Gaseous activity in the OWR coolant from diffusion of noble gases out of the fuel elements collected in the air space above the coolant in the surge tank. This activity was normally vented to the atmosphere at a rate of $0.2 \text{ ft}^3 \text{ hr}^{-1}$. Venting of gases from the surge tank could be switched to the Omega stack if high activity was suspected or observed. The approximate noble gas concentrations in the atmospheric effluent from the surge tank in 1964 were:

$$\begin{aligned}^{133}\text{Xe}: & 1.3 \times 10^{-2} \text{ } \mu\text{Ci cm}^{-3} \\^{135}\text{Xe}: & 5.4 \times 10^{-4} \text{ } \mu\text{Ci cm}^{-3} \\^{85}\text{Kr}: & 4.6 \times 10^{-4} \text{ } \mu\text{Ci cm}^{-3} \\^{41}\text{Ar}: & 8.6 \times 10^{-2} \text{ } \mu\text{Ci cm}^{-3}\end{aligned}$$

The OWR reactor room, which was a routine work area, was exhausted via three roof exhaust fans at a combined flow of 360 cfm in 1973. The exhaust from these fans contained small amounts of ^{41}Ar . In addition, the OWR facility had HEPA-filtered chemical hoods that exhausted to the environment.

2.3.18.3 Argon-41 Releases from the Omega West Reactor

Argon-41 releases from the Omega Stack are summarized in Table 2-8 for the years 1967 through 1992. The OWR was permanently shut down in December 1992. It is not known if the relatively large amounts of ^{41}Ar released in 1967 and 1968 are indicative of releases for previous years. In 1967, the OWR's maximum operating power level was increased to 8 MW.

Contemporary practice was to compute the amount of ^{41}Ar released from the Omega Stack on a 24-hr basis by multiplying the total power output for the OWR for that day (in megawatt-hours) by a conversion factor (in curies per megawatt-hour). In 1990, this factor was increased twice. In April, it was changed from $0.012 \text{ Ci MWh}^{-1}$ to $0.015 \text{ Ci MWh}^{-1}$; then in July of the same year it was changed from 0.015 to $0.018 \text{ Ci MWh}^{-1}$. The $0.018 \text{ Ci MWh}^{-1}$ value was then used until the OWR was permanently shut down in December of 1992. It is not known how long the value of $0.012 \text{ Ci MWh}^{-1}$ was used until it was increased in 1990, or if one or more other method(s) of determining ^{41}Ar releases were used.

Table 2-8. Argon-41 releases from the Omega Stack.

Year	Reported release (Ci)	Reported average concentration ($\mu\text{Ci cm}^{-3}$)
1967	15,546	Not given
1968	6,482	Not given
1969	1,814	Not given
1970	1,300	Not given
1971	1,600	Not given
1972	640	Not given
1973	273	2.1×10^{-5}
1974	312	2.6×10^{-5}
1975	237	1.823×10^{-5}
1976	339.2	2.560×10^{-5}
1977	314.7	2.421×10^{-5}
1978	239.2	1.840×10^{-5}
1979	350.8	2.698×10^{-5}
1980	512.7	3.944×10^{-5}
1981	300.7	2.313×10^{-5}
1982	342	2.59×10^{-5}
1983	418	3.21×10^{-5}
1984	335	2.57×10^{-5}
1985	390	2.97×10^{-5}
1986	276	2.10×10^{-5}
1987	232	1.88×10^{-5}
1988	264	2.46×10^{-5}
1989	223	1.97×10^{-5}
1990	163	2.16×10^{-5}
1991	203	Not given
1992	140	Not given

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GLOSSARY**implosion**

A sudden inward compression and reduction in volume.

Kiva

One of the remotely controlled critical assembly buildings associated with the Critical Experiment Facility.

outfall

The discharge point of a drain, sewer, or pipe as it empties into a body of water.

tuff

All LANL facilities are sited on this geologic formation of ash falls and ash flows from volcanic activity.