Chapter 5: Reactor Development and Operations at Los Alamos

When it was first established, Technical Area 2 (TA-2), also known as Omega Site, was used for both nuclear criticality experiments and as the location for the Water Boiler reactor. Assembly of the first Water Boiler (the LOPO 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 of that year, and from then on Omega Site was used primarily as the location for reactors for neutronics 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, and the Clementine reactor was deactivated in December of 1950 following four years of problematic operation.

The Water Boiler Reactors

[Much of the following was adapted from "Early Reactors" by Merle E. Bunker (Los Alamos Science, Winter/Spring 1983). Other references are as cited.]

During the Manhattan Project, a reactor was needed for confirming critical mass calculations, measuring fission cross-sections, and determining 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 eventually 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.

Fig. 5-1. A view of Omega Site, TA-2, from above

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 one-foot diameter spherical shell of stainless steel, surrounded by a reflector consisting 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 located beneath it. Since 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 of 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 for placing 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. 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.
- A significant increase in the enrichment of the uranyl nitrate fuel solution, from 14% ^{235}U to 88.7% ^{235}U.
- The beryllium oxide portion of the reflector was replaced with graphite to allow for more rapid shutdown.
- A 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 Rb-88. Charcoal samples reportedly showed that essentially no ^{131}I was present before or after the delay line was installed [3/98 memo J. Margo Clark to Ken Silver].

The SUPO Water Boiler experienced a water leak into its moderator shield, and had to shut down in 1973. Its stack was found to be contaminated with ^{137}Cs (Site Tour, 1998). 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 (D&D) of the SUPO facility began in July of 1988. The physical 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 (Montoya, 1991; LA-12049).

The Plutonium Fast Reactor (Clementine)

[Much of the following was adapted from "Early Reactors" by Merle E. Bunker (Los Alamos Science, Winter/Spring 1983). Other references are as cited.]

The plutonium fast reactor 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. Since 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, during which time the reactor was dubbed Clementine, after the song "My Darling Clementine." 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 liters per minute. Flow was maintained via an electromagnetic pump. The fuel cage was surrounded with a 6-inch thick natural uranium reflector, most of which was plated with silver to reduce corrosion. The uranium reflector was surrounded by an additional steel reflector 6 in thick, and finally by a 4-in thick lead shield. Reactor (reactivity) control was effected 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 this interim period, measurements were made at low power, including determination of the neutron energy spectrum, reactivity effects, cross sections, etc. Changes in the control system were also 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 of 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 due to its poor heat transfer properties and other concerns.

When Clementine was decommissioned, its parts were stored in a hutment at Area C, and are believed to have been subsequently buried there (Repos. No. 525). The disposal location of the mercury coolant is not known (per Repos. No. 525).

The Omega West Reactor (OWR)

[Much of the following was adapted from "Early Reactors" by Merle E. Bunker (Los Alamos Science, Winter/Spring 1983). Other references are as cited.]

With the early demise of the plutonium fast reactor, a replacement 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 (MTR) at the Idaho National Laboratory was the most attractive. A reactor designed to use the MTR'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 feet in diameter and 24 feet 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 10 CFR 100 reactor-siting criteria. The OWR was a small, low pressure, low temperature research reactor. Natural convective circulation of the reactor pool water was reportedly 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 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 reportedly 57 rem to thyroid and 22 rem whole body at State Road 4. ["Potential Environmental Issues at Los Alamos Scientific Laboratory" c. Oct. 1979, Repos. No. 615].

Construction of the new reactor began in mid 1954. Initial criticality was achieved in July of 1956, and a few months later the Omega West Reactor (as it became known) was operating at 1 to 2 megawatts. [Repos. No. 2387 states that the OWR achieved initial criticality on June 29, 1956.] In May of 1966, new operating limits were established that allowed the maximum operating power level to be increased to 6.5

MW (LA-UR-93-579). A modification to the OWR's cooling system allowed its maximum operating power level to be increased to 8 megawatts in August of 1967. The technical specifications for the OWR prescribed a Limiting Safety System Setting (LSSS) of 11 MW. The OWR's safety limit was 14 MW (LA-UR-93-579).

The OWR reportedly had an iodine-125 production loop, and at times the reactor was operated essentially around the clock on an "Iodine Production Loop schedule." "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 monitor detected leaks of capsules on several occasions [e.g., LA-3582-MS].

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 of the reactor. 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 (LA-UR-93-579). 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 is not compromised in the event of off-normal conditions (LA-UR-93-579).

In 1994, all of the fuel and control blades were removed from the OWR and the facility was placed in a safe shutdown mode (Burns et al., 1993; LA-UR-95-4294). 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 (Burns et al., 1993; LA-UR-95-4294).

The Omega West Reactor (OWR) operated routinely operated 120 hours a week during its first 16 years. Usage dropped off to around 40 hours 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.

The Omega Stack

A memo from Hornberger to Hoffman dated 25 May 1945 (Repos. No. 510) describes the off-gas line from the Water Boiler (HYPO) and reports exposure rate readings made beneath and to the sides of the line. These readings are 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 (see Figure 5-2) is 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. The memo includes a hand-drawn figure (Figure 5-2) showing the off-gas line relative to the Water Boiler building and the mesas north and south of Los Alamos Canyon.

Los Alamos document LAMD-155-I, "Manhattan District History, Volume II," states that "External radiation hazards [at LANL] were, for the most part, well controlled. However, arrangements for discharge of fission products from the Water Boiler were most unsatisfactory and represented a potential and serious health hazard. The gaseous materials were merely discharged near ground level at the top of the mesa just to the south of Los Alamos Canyon. Warning signs were inadequate and the area was accessible to any casual visitor. Intensities in excess of 50 r/hr were repeatedly measured near the discharge point when the boiler was in operation."

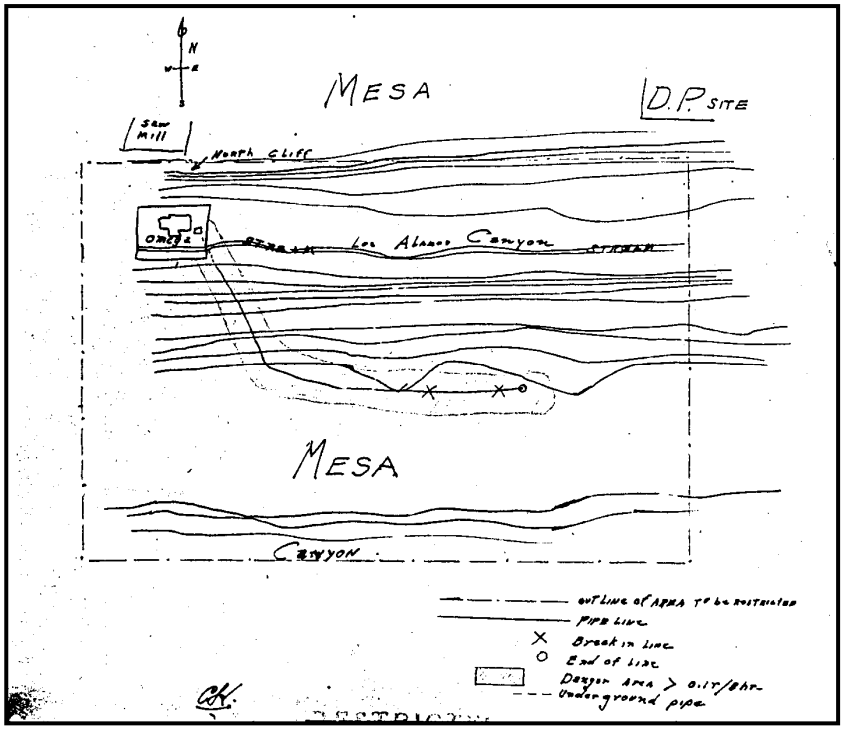


Fig. 5-2. Sketch of the Omega Site off-gas line

Repos. No. 510 includes a memo from Blackwell and Littlejohn to Hempelmann dated April 24, 1947 reporting their discovery that the offgas line from the Water Boiler (HYPO) was "shattered" at about 100 feet prior to the "outlet" (stack), which was located in the top of a pine tree. It is surmised that the line became brittle from the off- gas and was broken due to swinging caused by recent high winds.
In later years, a 150-ft tall stack on South Mesa was used to ventilate the OWR thermal column region and experiment. The flow rate in this stack was reportedly 880 $ft^3 min^{-1}$. Approximately 600 Ci of ^{41}Ar was reportedly discharged per year [Repos. No. 645]. In 1968, a charcoal filter was added in the vent line from the OWR surge talk to the 150-ft stack [Repos. No. 648].

The original stack for OWR effluents was also described as a "flexible pipeline" that ran up the mesa and was attached to a tree. Exposures to a nearby "Trailer Village" were a concern [Repos. No. 510]. This original effluent line was Tygon tubing that was laid on the ground or draped on trees. It led to a pipe that was fastened to a pine tree. Eventually a buried stainless steel line and a stack were put into place.

Repos. No. 177 includes a memo from D. D. Meyer to D. Ritter (ENG-4) dated June 11, 1957 that requests removal of the barbed wire exclusion fence that kept people 50 feet or so away from the Omega stack. It also states that the "old" Omega stack is still located in the top of a dead tree just outside the fence surrounding the current stack. It is requested that the old stack be taken down and sent to the "contaminated waste pit." A second memo included in Repos. No. 177 (from D. D Meyer to Carl Buckland), also dated June 11, 1957; states that P-2 plans to connect the off-gas system for the OWR to the existing system for the Water Boiler (SUPO). Per Repos. No. 2414, this action was completed between September 20, 1957 and October 20, 1957.

A charcoal filter was installed in the vent line for the OWR surge tank air space in 1968 (Repos. No. 648). 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.

Hankins (1963) describes the Omega stack as being 150 feet long and having an inside diameter of 8 in. The 2 inch (inside) diameter vent pipe from the reactor to the stack was 1100 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 d, but the addition of the vent line from the OWR cut this time to about 8 to 10 hours. The effluent in the vent pipe flowed to the stack at a rate of about 100 to 200 $cm^3 min^{-1}$, resulting in a dilution factor of about 100,000 in the stack. The stack flow rate was measured to be 845 $ft^3 min^{-1}$ at a velocity of 2400 ft min^{-1}.

Per Hankins (1963), 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.

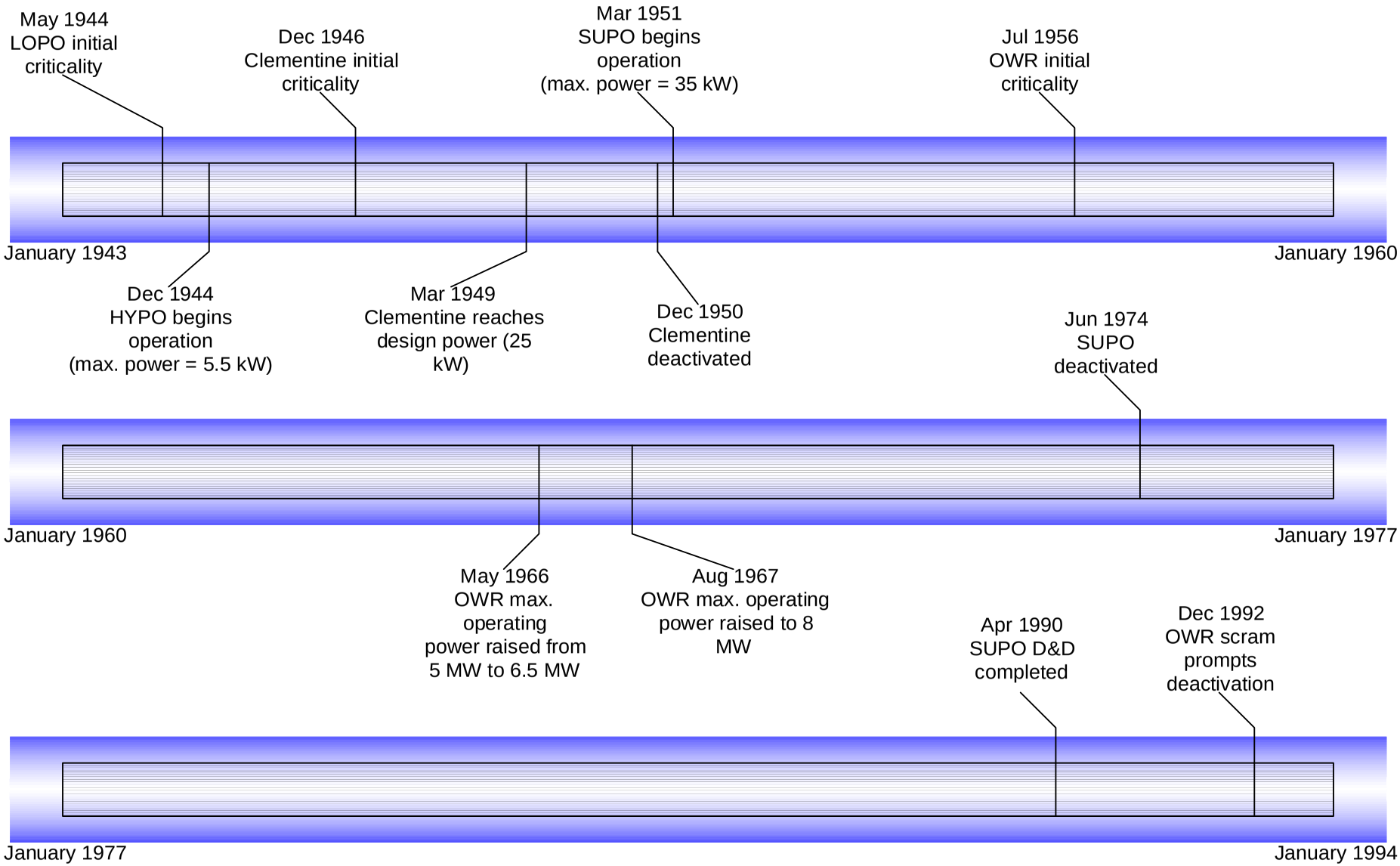
A timeline of events of operational significance for Omega Site reactors is presented as Figure 5-3.

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. Consequently, two test reactors (LAPRE I and LAPRE II) were constructed and operated at Ten Site (TA-35) by K-division personnel between 1955 and 1960. LAPRE I was located in one of the hot cells of the main laboratory building. LAPRE II was located outside the main building in an underground enclosure tank. The purpose of the LAPRE I reactor 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 (LA-2292). 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 of gold), it was thought that the corrosion rate of the stainless steel under a pinhole in the plating would be tolerable (LA-2292).

The first critical experiments with LAPRE I began on February 15, 1956 (LA-2292). The reactor power was raised to a level of 20 kW and held there for five hours. Radioactivity was then detected in the steam line, and shortly thereafter criticality could not be maintained without dropping the temperature. The experiment was terminated with the fuel being transferred to an external tank. After nine days, the reactor was disassembled to determine the cause of the failure. It was found that 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, prompting failure. The corrosion rate observed was unexpectedly high relative to what had been predicted on the basis of laboratory tests (LA-2292). Chemical attack was also noted at imperfections in the plating of the vessel and the boron poison can (LA-2292).

Figure 5-3: Timeline of Operational Events for Omega Site Reactors



Since 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 (LA-2292). This second experiment was conducted on 15 October 1956. The reactor reached a power level of 160 kW and had been held there for approximately 2 hours 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 h^{-1} in the control room (LA-2292). This was thought to be due to gaseous activity released from the end of the steam line and drawn into the building ventilation system (LA-2292). Post-mortem inspection of the reactor determined the failure was again due to the heat exchanger tubes having been eaten away by the fuel solution. Since construction of LAPRE II was already underway at this time, further work with LAPRE I was abandoned (LA-2292).

LAPRE II utilized a different fuel solution than LAPRE I. This new solution had a lower vapor pressure than the LAPRE I fuel, at the expenses 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 (Clark, 1960; LA-2465). The reactor was located in an underground enclosure tank on the south side of the main laboratory building at TA-35. This arrangement provided a prudent means by which to provide 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 was begun in February of 1959 and continued into May of 1959 (Clark, 1960; LA-2465). 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 R h^{-1} were present adjacent to the feed water heater (Clark, 1960; LA-2465). Though it could never be determined for certain, it was suspected that the leakage occurred via containment problems with the heat exchanger, ala LAMPRE I. Dismantlement of LAPRE II began on May 8, 1959 with the transfer of the fuel solution back to the storage tanks (Clark, 1960; LA-2465). The LAPRE program was terminated in 1960.

LAMPRE I

The following was adapted from "Early Reactors" by Merle E. Bunker (Los Alamos Science, Winter/Spring 1983) except where otherwise noted:

The purpose of the Los Alamos Molten Plutonium Reactor Experiment (LAMPRE) program was to explore the issues associated with using plutonium fuel in fast breeder reactors using a reactor fueled with molten plutonium and cooled by molten sodium. While the original design of the LAMPRE I reactor called for a design power level of 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 a 20 megawatt system down to a 1 megawatt test reactor. The LAMPRE I core matrix was such that it 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 megawatt design power for the LAMPRE I allowed it to be placed in an existing building at Ten Site (TA-35). A gas-fired 2-megawatt sodium cooling loop was also 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.

By mid 1963 LAMPRE I had achieved its intended purpose and was shut down. LAMPRE II, which was to be the 20 megawatt system first conceptualized for LAMPRE I, was never funded, with the AEC instead opting to pursue uranium-oxide-fueled reactors rather than plutonium-fueled systems. LAMPRE was in the Ten-Site cell adjacent to the one used for ^{140}La separation. It used molten plutonium contained within dozens of tantalum capsules, located within a sodium-cooled cylindrical core region about 40 cm high by 44 cm diameter. The LAMPRE fuel was transferred to Wing 9 at TA-3 (LA-UR-79-3091). LAMPRE experienced three separate fuel failures during operation; official reports say that these fuel failures did not cause any *operational* problems. [LADC-5936, CONF-258-1 by Robert A. Clark and Review of LAMPP by Argonne NL (PRO-P-1; 4/20/66)]

The Rover Program

In 1955, the United States initiated a program to develop a nuclear rocket engine to be used in defense systems and space exploration (Koenig, 1986; LA-10062-H). The plan was to carry large payloads into deep space, by essentially passing hydrogen through a very high temperature nuclear reactor, where it would expand and be blasted out of the reactor at high velocity. Conducted with NASA, this program was called Project Rover. Los Alamos was given the roles of establishing the basic reactor design and leading the fuel development effort (Koenig, 1986; LA-10062-H). A series of test reactors were designed and built at Los Alamos prior to being tested at the Nevada Test Site. These reactors were intended to

first demonstrate proof of principle, then to establish and test the requisite design considerations. In 1962, Rover was the second largest program at LASL. The Rover 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 new Rover 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, where details for controls and internal structures were worked out. Finally, the completed reactors were assembled and checked out prior to being sent to NTS for testing. Adjustments were made if any deviations from specifications were noted during checkout (Paternoster and Kirk, 1991; LA-UR-91-2434). Each Rover program reactor developed at Los Alamos is listed in Table 5-1 below, along with the date the reactor was tested at NTS (Paxton, 1983; LA-9685-H).

Table 5-1. Rover Program Reactors Developed at Los Alamos

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	May13, 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 and 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. A 1969 waste management plan says that the DP East facility processed new Rover fuel elements containing enriched uranium. Air from the exhaust systems handling radioactive materials was reportedly passed through HEPA filters. All four stacks from these systems were monitored but concentrations were below detectable levels [Repos. No. 113].

UHTREX

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 Technical Area 52, and operated for approximately one year before being shut down in February of 1970 (Salazar and Elder, 1993; LA-12356). The UHTREX was cooled by helium gas in a system consisting of a primary and a secondary loop, and 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 within the main heat exchanger (K-Division, 1967; LA-3556 Revised). Under maximum conditions, the gas temperature at the core inlet was 1600 F, and the exit temperature was 2400 F (Salazar and Elder, 1993; LA-12356). The secondary loop coolant entered the heat exchanger at 200 F and exited at 1000 F (Salazar and Elder, 1993; LA-12356). A regenerative heat exchanger called the recuperator was used to re-heat the primary coolant on its way back to the core. The recuperator also served to lower the primary coolant temperature from 2400 F to 1400 F prior to it reaching the main heat exchanger. The secondary loop rejected heat to the atmosphere in a building outside the main reactor building. This heat dump building housed finned tubes cooled by large fans. The reactor produced no power. The UHTREX utilized 93%-enriched uranium fuel in the form of small spheres of UO_2 coated with 3 layers of pyrolytic carbon and bound in a graphite matrix (K-Division, 1967; LA-3556 Revised). Fuel for the UHTREX was fabricated at the CMR Building (K-Division, 1967; LA-3556 Revised). The UHTREX was designed with a rotating core that allowed the reactor to be fueled while operating. The design thermal power for the UHTREX was 3 MW.

The UHTREX utilized 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 contained in a gas-tight secondary containment provided by the main reactor building (Salazar and Elder, 1993; LA-12356). 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 (to either trap volatile fission products or to delay fission gases to allow for radioactive decay) (K-Division, 1967; LA-3556 Revised). Delay times for the carbon bed were 1.2 h for krypton and 20 h for xenon. Under maximum conditions, 13 kW of decay heat were produced in the charcoal bed. Tritium produced in the primary coolant via the ^{3}He (n,p) ^{3}H 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 high main stack during regeneration of the sieve beds (K-division, 1967; LA-3556 Revised). This process also resulted in the discharge of entrained fission gases (K-Division, 1967; LA-3556 Revised).

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 prior to being exhausted up the main stack (K-Division, 1967; LA-3556 Revised). Stack releases were monitored via a Tracerlab model MAP-1B/MGP-1A combination gas and particulate monitor (K-Division, 1967; LA-3556 Revised). The particulate monitor utilized a moving filter and a plastic scintillation detector. The gas monitor utilized a sodium-iodide detector. A removable charcoal filter was located between the particulate and gas monitors to allow for periodic assay of radioiodine concentrations via gamma-ray spectrometry. The stack monitor did not provide for "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 the UHTREX was loaded into casks and transported by truck to Wing 9 of the CMR Building where it could be evaluated utilizing the hot cell facilities there (K-Division, 1967; LA-3556 Revised). Liquid radioactive wastes were carried by contaminated waste lines to the TA-50 treatment facility. Decontamination and Decontamination (D&D) of the UHTREX site and facilities began in the late 1980s. All radioactively-contaminated solid waste was buried at the laboratory's central waste disposal facility (TA-54) (Salazar and Elder, 1993; LA-12356).

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Chapter 6: Accelerator Operations at Los Alamos

During World War II, accelerators were used to determine the critical masses for each proposed atomic bomb design. Two Van de Graaff accelerators were acquired from the University of Wisconsin, a Cockcroft-Walton accelerator was "borrowed" from the University of Illinois, and a cyclotron was purchased from Harvard (Hoddeson et al., 1993).

The machines supplied neutrons for studying the neutron interactions involved in an explosive fission chain reaction. This was important because these interactions had not been studied at all of the neutron energies relevant to a nuclear explosion., from which fast neutrons are emitted with no slowing down or "moderation" as had been the case in the early graphite reactors. The accelerators also supported the effort to find a way of preventing a "fizzle," or predetonation, in the gun-assembled plutonium bomb. A circular electron accelerator called a betatron was later procured to obtain sequences of images of spheres of mock fission fuel as they were being imploded by surrounding high explosives (Reichelt, 1993, Los Alamos Science No. 21).

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 by the government– 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 Graaff 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 into a variable-energy cyclotron that was used to study the angular distributions of accelerated particles after they scattered off the nuclear of various target elements. (Reichelt, 1993, Los Alamos Science No. 21).

Two electron linear accelerators (linacs) were later built to provide radiographs of the implosion process, in work that led to the 1963 construction of PHERMEX (pulsed high-energy radiographic machine emitting x rays). PHERMEX generates x rays by accelerating an electron beam onto a tungsten target, and the x-ray bursts are sent through model weapons at a remote blasting site to provide three-dimensional images of imploding spheres. (Reichelt, 1993, Los Alamos Science No. 21).

Relatively small accelerators that have been used at Los Alamos include:

- W Building at TA-1 housed a Van de Graaff accelerator. Building W had 2 high-voltage electrostatic generators used to produce variable energy neutrons for cross-section measurements.

Protons were accelerated, hit a target (usually lithium), producing neutrons. Some X rays were also produced. There were also hazards from neutrons and X rays.

- TA-3 Building 16 housed a Van de Graaff accelerator (a.k.a. SM-16). On 24 May 1977, there was a release of up to 800 Ci of tritium from the Van De Graaff accelerator. [Repository Nos. 593, 829]

Accelerator Operations at Technical Area 53

The largest accelerator facility at Los Alamos is the one that is housed at TA-53. Following is a list of acronyms that are used in the discussion of TA-53:

LAMPF = Los Alamos Meson Physics Facility; WNR = Weapons Neutron Research Facility; LANSCE = Los Alamos Neutron Science Center; PSR = Proton Storage Ring; MeV = Million Electron Volt (energy unit); MAP = Mixed Activation Products

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 million electron volt (MeV), 1-milliampere intensity proton linear accelerator. Construction was started on LAMPF in 1968. On June 12, 1972, LAMPF first obtained a full energy beam. Originally constructed to study sub-atomic particles, today LAMPF serves as an accelerator generating intense pulses of neutrons (by sending the protons into targets of high atomic number such as uranium) for scattering research at the WNR and LANSCE facilities. The Proton Storage Ring is used to accumulate protons and provide a short duration pulse of protons for targeting onto uranium and other high atomic number targets for neutron production at WNR.

Today, the complex is called the Los Alamos Neutron Science Center, and includes the linear proton accelerator, the Manuel Lujan Jr. Neutron Scattering Center, and a medical isotope production facility. In addition, the Accelerator Production of Tritium Project Office, including the Low-Energy Demonstration Accelerator, and R&D activities in accelerator technology and high-power microwaves are located at TA-53.

LANSCE Release Summary

LANSCE airborne radionuclide releases consist of short-lived radioactive materials that have been activated from air. These radioactive materials are composed of particulates from activated dust in air and gaseous activation products from air constituent gases. Another source of LANSCE radionuclide

releases is the cooling water used for cooling accelerator components. Non-radioactive releases at accelerators include solvents, which are used in large volumes for cleaning vacuum components.

LANL documents refer to the mix of short-lived materials as Mixed Activation Products (MAP). Some other acronyms seen in documents are G/MAP for Gaseous Mixed Activation Products and P/VAP which are Particulate Various Activation Products. These radioactive 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 (such as targets). These interactions generate neutrons, which subsequently activate the air gases and the dust in air.

Radionuclide releases from LANSCE occur in two ways 1) from the four stacks located in the facility which are monitored for both particulates with filters, and for gases with Kanne chambers and 2) via unintentional pathways of diffuse release via doors and other exit points. For some periods of time, these combined emissions are the source of the highest priority releases to the environment. The radionuclide releases reported at LANSCE are among the highest of all DOE operations nation-wide. The amount of radioactivity released from LANSCE increases proportionally as the power levels and beam-on time increase. Principal gaseous radionuclides constituents released were ^{11}C (20 min), ^{13}N (10 min), ^{15}O (2 min). A trace amount of ^{41}Ar (1.8 h) was also released. The particulate releases are too numerous to mention and are only present in trace levels since these consist of activation products from dust in air or disintegrated target material.

Cooling water that services accelerator components, including targets, also becomes radioactive, and also accumulates corrosion products from the target and magnet systems. This water has been released by the site after decay in concrete walled cooling water ponds that have bentonite clay on the bottom. The cooling water is held until no short-lived radionuclides are observed in the water, after confirmation measurements, the cooling water from these ponds is then released and becomes surface water.

Prioritization of LANSCE Releases

The releases from LANSCE are cataloged in detail by the LAHDRA team in a two calculations (O'Brien 2003a and O'Brien 2003b). Results of the prioritization assessment for airborne radionuclides are presented in Chapter 17. The calculation of Priority Indices (PI) involves dividing the reported annual release by the maximum effluent concentration from 10 CFR Part 20. The result represents the volume of air required to dilute the releases to the maximum permitted value, and therefore permits comparisons for varying amounts of radioactive material from year to year based on the total quantities of air required to dilute the effluent. The maximum effluent concentration value used for MAP is from the International

Atomic Energy Agency (IAEA 1979) and was 2.0×10^{-7} µCi mL^{-1}. The prioritization shows that LAMPF dominates site releases to air since the mid-1970s.

Detailed LANSCE Release Data

The LAHDRA project team has spent many hours finding and reviewing LANSCE records. The project team has identified two key document resource centers within TA-53 that provide substantial quantities of historical effluent monitoring data for LANSCE. Those records cover operations from the early 1970s to the present. The locations are:

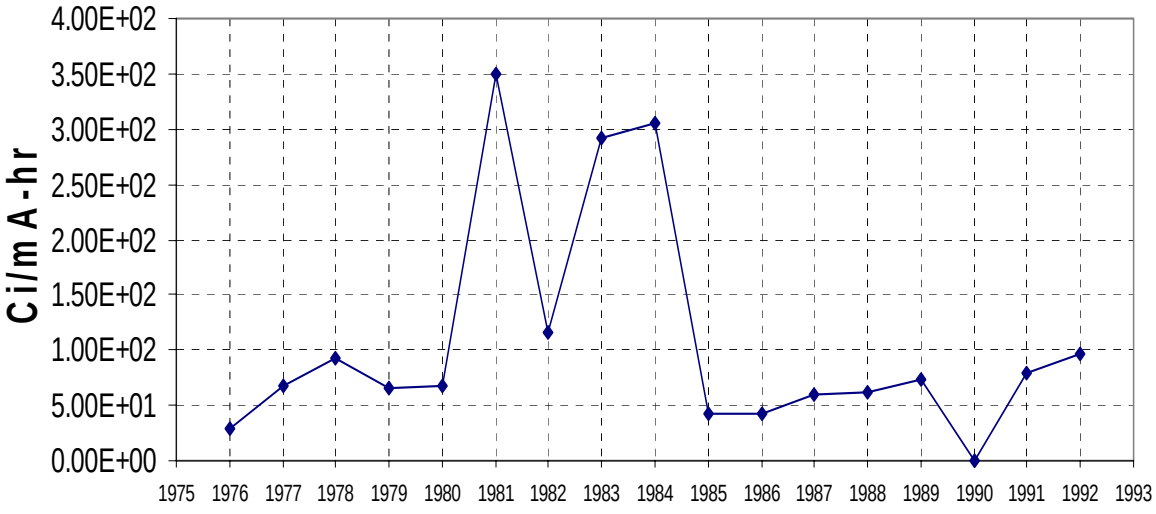
- Building 3, Room 3R-4 (TA-53-3) - Radiological records that contain mostly exhaust stack and water monitoring data for radionuclides.
- Another location for useful records is the operations group in Building 53. Management staff at the accelerator facility generally opted to retain large portions of their records for historical and operational purposes and has stored these records on-site at TA-53.

Monthly and annual air emission reports from 1976 to the present have been located by the LAHDRA team. These reports also present backup information pertaining to how LANL staff performed and collected stack monitoring data and calculated air releases. In related reports, methods for calibration of Kanne "flow-through" ionization chambers and for stack measurements are presented.

Probably the most appropriate method of estimating releases is to use the accelerator operation logs to obtain the milliampere-hours (mA-h) of beam operation, then to use the LAHDRA team's Off-Site Releases (OSR) Database to obtain the curies released annually at TA-53. The accelerator logs were found by LAHDRA analysts and entered into a spreadsheet (LANSCE Effluents.xls) for 1976 to 1992. Periods of accelerator operation are called "cycles" and each cycle is given a sequence number. These data included operations during cycles 3 through 61. Data for cycle 1 and 2 were not found. Data for cycles above 61 are available, but were not captured. In the LANSCE Effluents spreadsheet, beam current was multiplied by beam-on time to calculate mA-hrs for the beam. These values were summed to yield annual values of beam time in mA-h (see Table 6-1). Curies per mA-h are plotted in Fig. 6-1.

Table 6-1. Compiled Annual Beam Current Data for LANSCE

Year	mA-h (from log books)	Annual Activity in Curies (from OSR Database)	Curies per mA-h
1974		1.00E-08	
1975		1.00E-08	
1976	202.66	6.06E+03	2.99E+01
1977	702.27	4.79E+04	6.82E+01
1978	1,259.80	1.17E+05	9.29E+01
1979	1,834.57	1.19E+05	6.49E+01
1980	2,180.00	1.46E+05	6.70E+01
1981	1,010.79	3.53E+05	3.49E+02
1982	2,151.52	2.51E+05	1.17E+02
1983	1,593.71	4.64E+05	2.91E+02
1984	2,420.37	7.37E+05	3.04E+02
1985	3,004.61	1.26E+05	4.19E+01
1986	2,600.06	1.12E+05	4.31E+01
1987	2,534.84	1.50E+05	5.92E+01
1988	1,929.32	1.21E+05	6.27E+01
1989	2,128.43	1.56E+05	7.33E+01
1990	1,966.90	5.00E+02	2.54E-01
1991	721.56	5.75E+04	7.97E+01
1992	744.83	7.19E+04	9.65E+01
1993		2.11E+02	
1994		5.04E+04	
1995		4.37E+04	
1996		1.14E+04	



Fig, 6-1. Ci/mA-h for LANSCE operations 1975-1993

There were some columns in the beam operation logs that were not used in these informal calculations since it was not known how to apply them. One column was for "Duty Factor" and two contained additional beam information "Beam Current 2" and "Beam Hours 2". From verbal conversations with LANL employees it was found that the "Beam Current 2" and "Beam Hours 2" were used only when the beam was run at one current for a certain amount of time and then was run for a second amount of time at a different beam current. Since there were not many times this information was supplied it was ignored for this informal calculation. "Duty Factor" was explained as having something to do with the pulsed nature of the output used sometimes during the operation. Since it was not know how to apply a correction factor for "Duty Factor", the column was not used.

In addition to point release estimates (i.e., exhaust stack releases) LANL began estimating non-point (diffuse) emissions in their annual release and dose estimates. Documents were found for 1993, 1995, 1996, and 1997. The estimates of diffuse releases were 1,418 Ci, 716 Ci, 221 Ci, and 866 Ci for the years listed respectively. These quantities are approximately less than 10% of the annual airborne release values as shown in Table 6-1. The vast majority of these releases were estimated to be ^{11}C.

Repos. No. 1071 mentions that short-lived activation gases were not reported at LAMPF for the 1974 to 1978 time frame. One of the documents abstracted (Repos. No. 441) refers to a letter to the AEC concerning LAMPF airborne emission in 1970, so limited operations may also have occurred prior to 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 ^{7}Be. 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 ^{7}Be.

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 (Repos. No. 503). The magnitude of releases at LANSCE resulted in continuing studies to estimate the off-site impact. One such study was LA-11150-MS, which documented the releases and modeling of the releases for 1985 (Repos. No. 2145). Laboratory measurements have been found for lagoon and cooling pond waters, and for long-lived activity that can be collected on filtering media. The short-lived MAP was assessed with on-line monitoring and through TLDs located at various locations.

Repos. No. 1556 discusses the diffuse releases from LAMPF for 1990, which were 0.21 Ci, a small fraction of the 120,000 Ci of short-lived gases that were reported. The diffuse emissions were comprised of longer lived nuclides (since the diffuse emissions are completely unfiltered) and a comparison of curies alone might be misleading, but the magnitude of diffuse emissions is clearly less significant than that of the primary release points.

The LANL assessment of the impact of radioactive releases from TA-53 has changed in many ways over the years. Prior to 1991, the site assessed the releases taking credit for estimated occupancy and the inherent shielding provided by residences. In 1992, LANL was told by the USEPA that no credit should be taken for shielding and residency time factors (Repos. No. 713). This resulted in a change in methodology for projecting impacts from the releases. Care should be taken when comparing assessments reported by LANL for different periods.

Conclusions Regarding LANSCE Operations

LANSCE is an important major scientific system at LANL. Its operation is important to scientists and researchers from LANL and visiting organizations. Since its inception, LANSCE has been one of the major contributors to airborne releases to the environment. Fortunately, the radionuclides released are short-lived gases or trace amounts of particulates from diffuse emissions. Future iterations that are attempting to create an accurate source term for LANSCE should concentrate on applying the additional beam time corrections, applying the duty factor corrections, locating early operation info (cycle 1 and 2), and ensuring that the curie quantities in the OSR Database are complete and accurate so that Ci/mA-h can be calculated accurately for LANSCE.

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Chapter 7: Tritium Processing at Los Alamos and a Screening Assessment of Public Exposures

The benefits of incorporating tritium into nuclear weapons design was recognized early in the Manhattan Project. Facilities and processes for tritium production were a topic of discussion at LANL at least as early as 1944 (Allison 1944). By this time, tritium production efforts had already begun at the X-10 site (now the Oak Ridge National Laboratory) and there were discussions about large-scale tritium production taking place at Hanford. As of late 1945, LANL had installed equipment for the purification and assaying of tritium. The Lab's CMR Division began using this equipment to supply tritium to groups within P Division and M Division in early 1946. A tritium collection system was being installed in the laboratories of Group P-4 as of March of 1946 (LASL 1946). It is unclear where these operations took place, but small quantities of tritium are reported to have been used in Buildings U, W, and Z in the Original Technical Area (TA-1). As Laboratory operations matured, significant quantities of tritium were released to the atmosphere from facilities in TAs 3, 21, 33, 35, and 41. In addition, tritium was used in some firing site (dynamic testing) activities, at TA-15 for example.

Tritium Facilities at TA-3

The three facilities responsible for the majority of atmospheric tritium releases from TA-3 were the Cryogenics Laboratory (Building SM-34), the Ion Beam Facility (Building SM-16), and the CMR Building (Building SM-29). Both the Cryogenics Laboratory and the IBF used tritium gas generated from uranium tritide[a] beds.

The LANL Cryogenics Laboratory opened in 1955 and is reported to have released 28,000 Ci of tritium from 1976 to 1985 (Morgenstern and Hueske 1995). The Ion Beam Facility (IBF), which housed two Van de Graaff accelerators, began operating in 1951 (Loomis et al. 2005). The accelerators produced neutrons by bombarding tritium gas targets with charged particles. Atmospheric tritium releases for the IBF are reported to have been 14,000 Ci from the 1960s through 1992 (Morgenstern and Hueske 1995). The same reference reports a release of 11,000 Ci of tritium from the CMR Building from when it began operations in 1953. The asserted releases for these three facilities total 53,000 Ci.

[a] A tritide is a hydride (a binary compound formed by the union of hydrogen and one other element) in which hydrogen is in the form of its ^{3}H isotope.

Tritium Facilities at TA-21

TA-21 has housed the LANL Tritium Handling Facility (THF) and the Tritium Systems Test Assembly (TSTA), as well as earlier tritium operations. The THF was also known as the Tritium Salt Facility (TSF). It was expanded in 1984, and subsequently became known as the Tritium Science Fabrication Facility (TSFF). The THF was activated December 5, 1974 as a replacement for obsolete tritide salt processing facilities at TA-35. It was located at DP East Site in Building TA-21-209. The THF consisted of a large dry box system and a gas purification system. Its purpose was to house processes involving metal tritides, specifically, tritium-bearing lithium salts. As of December 12, 1979 the THF had reportedly processed 3.8 million curies of tritium and had released 704.5 Ci to the atmosphere via its local stack (Nasise 1980).

TSTA was a facility for the integrated testing, in full scale, of the processes and safety systems required for the reprocessing and recycling of plasma exhaust gas from a tokamak fusion reactor. The primary material handled was deuterium-tritium (DT) gas. Tritium was first introduced at TSTA on June 25, 1984 (Jalbert 1985).

Tritium appears to have been in use at DP West since at least the early 1950s. In 1952, J. B. Webber of LASL described sampling of effluent streams for tritium oxide from a beaker of tritiated water placed in various locations in DP West Room 326 (Webber 1952). By 1971, a tritium stack monitor had been installed for DP West Room 513 (Johnson 1971).

Tritium Facilities at TA-33

TA-33 was established in 1947 as primarily a test site for atomic bomb initiators (Garcia et al. 2004). Dynamic testing activities took place there involving polonium and other materials. Shots were fired in underground chambers and at the surface. Large guns were used to fire test projectiles into berms. In the early 1950s, facilities were designed and built at TA-33 for the processing of tritium gas (Coffin 1971). The high pressure tritium gas facilities were housed in Building HP-86 and operated there until late 1990 (Garcia et al. 2004). In addition to its function as a high pressure tritium pumping station, HP-86 also had laboratory areas for conducting tests of tritium gas systems and for material compatibility studies (Tuggle 1983). HP-86 had a 75-foot stack as of late 1962, though apparently the stack height had increased from its original design (Deinken 1962).

On an activity basis, HP-86 is believed to be the largest source of atmospheric releases of tritium at LANL. Coffin (1971) stated routine releases to the atmosphere were 2,000 to 6,000 Ci annually and that

60,000 Ci of gas had been released in ten separate incidents dating back 15 years. These accidental releases were in addition to routine releases associated with the evacuation of lines and vessels containing tritium gas and leakage from the gas system overall. The gas system consisted of a process system and a filling system, with the former used to mix and prepare gases for introduction into the latter (Holmes 1965). The filling system was used to fill a desired container with tritium gas at a desired pressure. Coffin (1971) estimated the contributions from routine and accidental releases to the total atmospheric source term to be approximately equal. The LAHDRA document collection contains numerous references documenting accidental releases of large quantities of tritium gas at TA-33.

Tritium Facilities at TA-35

The original tritium salt facility was located in the basement of Building 2 at TA-35. It was constructed in 1953 (Harper and Garde 1981) and was in use until 1974 when the tritium salt operations moved to DP East Site. The TA-35 tritium salt facility was decommissioned in 1979. The facility was used to handle lithium tritide salts containing kilocurie quantities of tritium. It consisted of two glovebox lines and associated equipment, and had its own exhaust stack (Harper and Garde 1981). Tritium operations began in 1955 (Storm 1972) and ended in 1979 with the decommissioning of the facility. Tritium releases from the TA-35-2 facility did not end when operations were relocated to DP East Site. Releases continued to be monitored and reported through the decommissioning process.

The lithium tritide salts were received from Mound Laboratory in a powdered form and were processed and packaged at TA-35 for transfer to Group W-1 (Storm 1972). As of 1972, the frequency of the operation was 6 to 24 weeks per year. Water reacting with the salt compound would result in the release of tritium. This condition was exacerbated by the high moisture content of the glovebox cover gas and the use of water to clean some of the process equipment (Storm 1972). The fact the tritium was released through the water-salt reaction prompted Ellery Storm of LASL to conclude it was probably released in the oxide form.

Tritium Facilities at TA-41

TA-41 was constructed in the early 1950s for weapons development activities (LANL 1988). It was built at the bottom of Los Alamos Canyon, approximately 300 feet below the mesa tops. A central exhaust system and stack were added in 1962. Prior to that time, process effluents were ventilated by local stacks and exhausts serving individual laboratories. TA-41 consists of a number of structures, including an underground vault for the storage of explosives and special nuclear material. The vault, designated Building W-1, is a reinforced concrete structure constructed by tunneling into the north wall of Los

Alamos Canyon. It was built in May, 1949 (LANL 1991). Materials stored in the W-1 vault included pressure vessels containing tritium gas.

It is unclear when tritium operations first began at TA-41. LANL's 1973 estimates of atmospheric tritium releases included estimates for TA-41 dating back to 1967 (LASL 1973). In 1976, LANL was evaluating locating a new tritium handling facility at TA-41 (Barnes 1976) to replace operations at the HP-86 facility at TA-33. It is not clear when these activities began, but it appears they continued until approximately the early 1990s. As of 1983, one of the primary activities at TA-41 was the building and testing of equipment and systems for the storage and transfer of high pressure gases, including tritium (Tuggle 1983). In 1992 the Laboratory determined the cost associated with upgrading the TA-41 facilities to allow resumption of programmatic tritium operations involving quantities greater than 1,000 Ci was not justified (Erickson 1993). Those operations were to be transferred to the Weapons Engineering Tritium Facility at TA-16.

TA-41 was also used for plutonium operations, dating back to at least 1957 (Buckland 1957), and uranium. As of 1983 plutonium and uranium were handled only in sealed containers. Experiments with the containers were conducted inside double containment (Tuggle 1983).

Other Tritium Facilities

As of 2001 the largest tritium inventory at LANL was held at the Weapons Engineering Tritium Facility (WETF) at TA-16. Originally constructed as a replacement for the tritium gas facilities at TA-33 (LANL 1990), WETF houses research and development activities in support of nuclear weapons programs and inertial confinement fusion (DNFSB 2001). Consolidation efforts were at that time underway to relocate all of LANL's tritium processing operations to WETF. WETF is a more modern facility than its predecessors and its tritium releases to the atmosphere are relatively small. Other LANL facilities that contribute to atmospheric tritium releases are waste treatment operations at TA-50 and operations involving tritium-contaminated weapons components at TA-55. There have also been limited tritium operations conducted at a gas boosting test facility housed at TA-9 (Tuggle 1983). With respect to environmental levels, a significant source of atmospheric releases of tritium oxide has been the Lab's central waste disposal facility at TA-54. Buried, tritium-bearing waste materials result in atmospheric releases of tritiated water vapor via evaporation from the soil. These releases are evident on the local ambient air monitoring stations.

Atmospheric Effluent Data for Tritium

LANL did not begin monitoring tritium stack releases until 1971. In 1973, the Lab prepared estimates of atmospheric releases for 1967 through 1970 based on accountability data (LASL 1973). There are no formal estimates of total tritium releases prior to 1967, though the LAHDRA document collection contains effluent monitoring and other tritium release data for some tritium facilities prior to 1967. How complete a picture this information might represent with regard to LANL's total atmospheric tritium releases for the pre-1967 period is currently unknown.

Earlier in the project, the LAHDRA team made a limited effort to compile tritium effluent data from its document collection into a database. Specifically, the focus was on the Lab's formally reported tritium releases for the period from 1967 forward. These data were entered into a database known as the Off-Site Releases (OSR) database. The OSR database was an internal tool used by the LAHDRA project team to support prioritization of historical radionuclide releases from LANL.

Table 7-1 summarizes the atmospheric release data for tritium in the OSR database for TAs 3, 15, 21, 33, 35, and 41 for 1967 through 1991. After 1991, the tritium effluent records used to populate the OSR database began reporting releases on a consolidated basis, that is, releases from multiple TA were combined and reported as a single value. Regardless, the data for the years included in Table 7-1 are believed to encompass the periods of the largest airborne tritium releases from the selected TAs since 1967. In addition, the documents that have been reviewed indicate that these facilities represented the largest contributors to atmospheric tritium releases. In Table 7-1, years for which no data were reported are denoted by "– ". This notation differentiates from the values of 0 for several years for which the database currently shows a release of zero curies.

As the primary charge of the LAHDRA project was information gathering, only limited resources could be dedicated to source term evaluation in support of screening for potential health risks. Thus, the data in the OSR database are known to be incomplete with respect to the totality of tritium release data embedded in the LAHDRA document collection. As an example of the possible magnitude of data not yet captured in the OSR database, compare the total release for TA-3 shown in Table 7-1 (35,414 Ci) with that asserted in 1995 by Morgenstern and Hueske (53, 000 Ci). The latter, which includes releases for the period prior to 1967, exceeds the total from the OSR database by a factor of about 1.5. It should be noted than none of the release totals cited here have been independently verified by the LAHDRA team. All values have been used as reported in the available reference material, without adjustment.

Table 7-1. Airborne Tritium Release Data for Selected TAs from the OSR Database (Ci)

Year	TA-3	TA-15	TA-21	TA-33	TA-35	TA-41	Total
1967	872	3,590	-	11,284	-	12,168	27,914
1968	10,382	-	23	5,512	-	15,782	31,699
1969	172	4,500	3	20,098	-	9,750	34,523
1970	-	11,000	-	670	25,000	438	37,108
1971	-	2,660	-	4,100	3,100	320	10,180
1972	-	1,796	-	2,100	2,500	110	6,506
1973	-	-	4	3,880	2,464	118	6,466
1974	-	-	-	5,916	1,400	-	7,316
1975	22	-	306	3,478	2,394	-	6,200
1976	-	-	95	1,349	1,657	-	3,101
1977	400	-	133	36,950	786	-	38,269
1978	100	-	72	17,780	676	-	18,627
1979	3,015	-	95	10,470	1,300	143	15,024
1980	5	-	106	6,965	25	414	7,515
1981	899	-	108	6,085	-	126	7,218
1982	1,938	-	169	13,600	-	130	15,837
1983	2,277	-	180	4,410	6	974	7,847
1984	1,793	-	802	7,110	206	4,780	14,691
1985	2,119	-	367	4,870	5	1,270	8,631
1986	1,228	-	448	6,660	48	1,320	9,704
1987	851	-	596	1,000	155	470	3,072
1988	8,350	-	528	-	118	1,730	10,726
1989	291	-	455	1,770	18	11,600	14,134
1990	496	-	439	854	0	4,440	6,229
1991	205	-	334	254	0	3,840	4,633
Total	35,414	23,546	5,262	177,165	41,858	69,923	353,168

To ensure a conservative approach to screening, and to account for the fact the tritium release data in the OSR database were incomplete, the maximum annual atmospheric tritium releases for each of the selected TAs were compiled. These are shown in Table 7-2.

Table 7-2. Maximum reported airborne tritium releases from LANL

Technical Area	Maximum Release (Ci)	Year
3	10,382	1968
15	11,000	1970
21	802	1984
33	36,950	1977
35	25,000	1970
41	15,782	1968

For screening purposes, the maximum values should at a minimum be representative of LANL's atmospheric tritium releases for the period 1967 forward, if not bounding in the case of the earlier data derived from accountability data. For the principal contributors to atmospheric tritium releases, all but two of the maximum values were from the period prior to the onset of stack monitoring, that is, they were derived from accountability data. Such estimates are typically conservative with respect to the true release, though it is reiterated that none of the data used in this evaluation have been independently verified.

Chemical Forms of Tritium

One of the most important factors to consider in evaluating atmospheric releases of tritium for potential health risks is the chemical composition of the release. Specifically, one needs to know if the release was in the form of tritium gas or if it was partially or completely in the form of tritium oxide. Tritium is a radioactive isotope of hydrogen. Tritium gas refers to tritium in the form of diatomic HT or T_2 gas, where T is used in place of H to differentiate between atoms of tritium and protium (normal hydrogen). Tritium oxide refers to molecules of water (normally H_2O) in which a tritium atom has been substituted for one or both of the hydrogen atoms to form HTO or T_2O. The difference between tritium gas and tritium oxide is enormous in terms of radiation dose to a human receiver. If inhaled, tritium gas is not incorporated into the body to any appreciable degree, and the only dose consequence is the direct exposure to lung tissue. Tritium oxide, in contrast, behaves as water and is readily incorporated into body tissues. In terms of radiation dose per unit intake, the dose from tritium oxide exceeds that from tritium gas by four orders of magnitude (ICRP 1996). Dose from tritium gas, therefore, is typically negligible. There is no external dose consequence from tritium in either form, but intakes of tritium oxide can result from absorption through exposed skin in addition to inhalation.

Given its application in the weapons program and accelerator operations, tritium at Los Alamos has primarily been used in the form of tritium gas. However, there are some circumstances where an assumption of the oxide form is appropriate, at least for purposes of initial screening. In addition, as of the late 1970s, LANL had installed catalytic converters on its tritium stacks to convert the gaseous effluent to oxide. This allowed the tritium to be efficiently collected on molecular sieves and thus significantly reduce the overall release. However, anything not captured by the sieve system had taken the oxide form. This system for reducing tritium emissions was described in 1973 by R. R. Dube of LASL's GMX-4 group and his colleagues (Dube et al. 1973).

There are other chemical forms of tritium possible in addition to gas and oxide. With respect to tritium operations at LANL, tritium could historically be found in the form of metal (uranium) tritides or lithium tritide salts. Unlike gases, any atmospheric emissions of these materials would be in a particulate form and absorption and retention in the body would depend on the characteristic biokinetic behavior for the specific tritide compound. No information has been noted in the LAHDRA document collection regarding the atmospheric release of tritide compounds, and it is believed to be unlikely that tritides would have been a significant component of LANL's atmospheric tritium releases. From a radiation dose perspective, tritides can represent more dose per unit activity than tritium oxide because they are retained in the body longer. In the case of tritide particulates, with the longer retention characteristics, the dose per unit intake exceeds that for tritium oxide by a factor of 14 (ICRP 1996).

Screening LANL's Atmospheric Tritium Releases for Potential Health Risks

The NCRP Report No. 123 (NCRP 1996) screening method for radionuclide releases to the environment was used to evaluate atmospheric tritium releases from LANL in terms of their potential risk to local residents. The source term used was the maximum release reported for each of the six TAs that represented the largest contributors to LANL's atmospheric tritium releases. These maximum values, shown in Table 7-2, were converted to units of becquerels for input into the NCRP Report No. 123 screening models. The converted values are shown in Table 7-3.

Table 7-3. Maximum reported airborne tritium releases from LANL

Technical Area	Maximum Release (Bq)	Year
3	$3.84\times10^{+14}$	1968
15	$4.07\times10^{+14}$	1970
21	$2.97\times10^{+13}$	1984
33	$1.37\times10^{+15}$	1977
35	$9.25\times10^{+14}$	1970
41	$5.84\times10^{+14}$	1968

The values in Table 7-3 reflect total amounts of tritium released. To ensure a meaningful screening result, they were re-stated in terms of the corresponding tritium oxide activity for each total value. An upper bound for the fraction of a tritium gas source that has converted to an oxide form is 1% (Pan and Rigdon 1996, Mishima and Steele 2002). The small amount of oxide is formed by interactions between residual air in the storage vessel and beta radiation from the tritium. Following a release of tritium gas, additional oxidation occurs slowly, resulting from either additional radiolytic reactions with air (in the case of high activity concentrations) or from photochemical reactions with ultraviolet light. These

secondary oxidation mechanisms result in a conversion rates ranging from approximately 1% per hour, in the case of high activity concentrations, falling off to less than 1% per day as the gas diffuses following release (Mishima and Steele 2002). Tritium gas does not react strongly with water vapor. If there is an ignition, explosion, or similar event involving tritium gas, then an assumption of complete (100%) oxidation is appropriate.

Based on what was known about the processes associated with the maximum atmospheric tritium releases in Table 7-3, conservative assumptions were applied to determine the chemical form of the tritium to be assumed for screening. These are documented in Table 7-4, with tritium oxide being designated HTO.

Table 7-4. Activity and chemical forms of tritium used for screening

Technical Area	Maximum Release (Bq)	Assumed Chemical Form and Basis	Maximum Release as Oxide (Bq)
3	$3.84\times10^{+14}$	1% HTO: principal sources were tritium gas.	$3.84\times10^{+12}$
15	$4.07\times10^{+14}$	100% HTO: assume tritium was expended in detonation events.	$4.07\times10^{+14}$
21	$2.97\times10^{+13}$	100% HTO: assumed releases were the result of water reactions with tritium-bearing salts resulting in an oxide form.	$2.97\times10^{+13}$
33	$1.37\times10^{+15}$	1% HTO: HP-86 was a tritium gas facility.	$1.37\times10^{+13}$
35	$9.25\times10^{+14}$	100% HTO: assumed releases were the result of water reactions with tritium-bearing salts resulting in an oxide form.	$9.25\times10^{+14}$
41	$5.84\times10^{+14}$	1% HTO: operations were similar to those at TA-33.	$5.84\times10^{+12}$
Total	$3.70\times10^{+15}$	--	$1.39\times10^{+15}$

For screening, the maximum release values in Table 7-4 were considered both on an individual and on an aggregate basis (the six values added). Summing the maximum values, which occurred in different calendar years, is believed to provide a source term that is at worst representative of any specific year and is likely bounding. It is reiterated that the maximum release data for TAs 3, 15, 35, and 41 are based on LANL's examination of accountability records, and such assessments are typically conservative with respect to actual releases. On an aggregate basis, the source term in Table 7-4 represents $3.70\times10^{+15}$ Bq (100,000 Ci) of tritium and $1.39\times10^{+15}$ Bq (37,600 Ci) of tritium oxide. The effective oxide fraction for the aggregate source term is 38%.

Screening was performed against a criterion of a 1 in 100,000 added risk of fatal or non-fatal cancer, assuming a risk factor of 6% per sievert (Sv) (ICRP 1990). This corresponds to a dose equivalent of

1.67×10^{-4} Sv. The exposed population selected for each screening assessment was the residential population nearest each release point. The pathways considered for each residential location were inhalation of contaminated air and consumption of contaminated soil and vegetables. Consumption of locally raised meat or milk were not considered.

The first step of the NCRP Report No. 123 screening process is to perform a Level I screening evaluation, which is the simplest and most conservative type of evaluation. The Level I screen does not account for distance from the source to the receiver or the associated atmospheric dispersion. If the Level I screening result exceeds the screening criterion, then one progresses to a Level II approach in which distance to the receiver and atmospheric dispersion are considered. Also, in the Level II screen, the screening criterion is reduced by an order of magnitude to account for uncertainties. If the Level II screening result exceeds the criterion, then a Level III screen is performed. In general, the Level III screen only differs from the Level II in how dose pathways are considered. The approach used here for screening LANL's atmospheric tritium releases was hybridized in that the appropriate pathways were accounted for from the outset, rather than first screening for all pathways and then removing the non-applicable pathways afterward.

A Level I screen was performed for the TA-3 release first, since it was the smallest contributor to the tritium oxide source term. If the Level I screening evaluation for the TA-3 release exceeded the screening criterion, there would be no need to continue with Level I screening for the other releases. As shown in Table 7-5, the Level I screening evaluation for the TA-3 source term exceeded the screening criterion by a substantial margin. Screening therefore proceeded to Level II/III.

Table 7-5. Level I screening for the maximum HTO release from TA-3

			Basis
Total Release =	3.84E+12	Bq HTO	OSR database Rev. 7, 1% HTO
Seconds per year =	3.2E+07		NCRP 123 I-A-2
Annualized Release Rate =	1.2E+05	Bq/sec	(calculated)
Volumetric Flow Rate =	0.3	m^3/sec	NCRP 123 I-A-3
Exhaust vent concentration =	4.0E+05	Bq/m^3	(calculated)
Receiver concentration =	1.0E+05	Bq/m^3	calculated via NCRP 123 I-A-5
Screening Factor =	7.20E-07	Sv per Bq/m^3	NCRP 123 Table B.1 (inhalation + vegetables + soil)
Screening Value =	7.2E-02	Sv	(calculated)
Screening Criterion =	1.67E-04	Sv	1E-05 excess risk at 6% per Sv
Screening criterion exceeded?	YES		

To proceed to Level II screening, the distance from each release point (Technical Area) to the nearest residential area was estimated. Table 7-6 shows the location of the nearest residential area and the approximate distance in meters from each TA.

Table 7-6. Approximate distances from tritium release points to the nearest residents

Technical Area	Nearest Residents	Approximate Distance (m)
3	Western Area	1,740
15	Royal Crest Trailer Park	3,050
21	Town Site Apartments	1,460
33	White Rock	3,750
35	Royal Crest Trailer Park	1,740
41	Town Site Apartments	490

In the Level II screening process, the estimated distances from the release points to the nearest residential locations are used to determine a plume diffusion factor. These factors are determined from plots provided in NCRP Report No. 123. To simplify the process, the bounding value of the diffusion factor was selected for each source-receiver distance. This eliminated the need to account for effective release heights and the possibility of building wake effects. It also added a further degree of conservatism.

Tables 7-7 through 7-12 below show the Level II[b] screening calculations for TAs 3, 15, 21, 33, 35, and 41, respectively. In each of the six Level II screening calculations, the screening criterion has been reduced by an order of magnitude (factor of ten) for an additional degree of conservatism per NCRP Report No. 123. Thus, the judgments as to whether the screening criterion has been exceeded are made against the adjusted, rather than the actual, screening criterion.

The screening evaluations show that only in the case of TA-35, for which the maximum release was treated as 100% HTO, was the adjusted screening criterion exceeded. In no case was the actual (unadjusted) screening criterion exceeded. If all of the screening results are summed, the result (8.17×10^{-5} Sv) is still less than half of the screening criterion of 1.67×10^{-4} Sv. Note that, in addition to the fact the maximum release values are being treated as if they all occurred in the same time span, summing the individual screening values represents the physical impossibility of a hypothetical population of residents simultaneously living at a location nearest each of the individual release points. The screening dose for the aggregate releases would be much lower for any of the individual residential areas.

[b] In reality the Level II screening assessments may be thought of as Level III since only the applicable pathways are being considered.

Table 7-7. Level II screening for the maximum tritium release from TA-3

Total Release =	3.84E+12	Bq HTO	OSR database Rev. 7, 1% HTO
Seconds per year =	3.2E+07	sec	NCRP 123 I-A-2
Annualized Release Rate =	1.20E+05	Bq/sec	(calculated)
Wind Speed =	2	m/sec	NCRP 123 II-bi-7
Distance to receiver =	1740	m	estimated from LAHDRA project map
Dispersion factor =	2.5E-05	m^{-2}	NCRP 123 Fig. 1.4 (limiting value)
Receiver concentration =	3.75E-01	Bq/m^3	
Screening Factor =	7.20E-07	Sv per Bq/m^3	NCRP 123 Table B.1 (inhalation + vegetables + soil)
Screening Value =	2.70E-07	Sv	
Adjusted Screening Criterion =	1.67E-05	Sv	1E-05 excess risk at 6% per Sv, divided by 10 to account for uncertainties per NCRP 123 II-F-5
Screening criterion exceeded?	NO		

Table 7-8. Level II screening for the maximum tritium release from TA-15

Total Release =	4.07E+14	Bq	OSR database Rev. 7, 100% HTO
Seconds per year =	3.2E+07	sec	NCRP 123 I-A-2
Annualized Release Rate =	1.27E+07	Bq/sec	(calculated)
Wind Speed =	2	m/sec	NCRP 123 II-bi-7
Distance to receiver =	3050	m	estimated from LAHDRA project map
Dispersion factor =	9E-06	m^{-2}	NCRP 123 Fig. 1.4 (limiting value)
Receiver concentration =	1.43E+01	Bq/m^3	
Screening Factor =	7.20E-07	Sv per Bq/m^3	NCRP 123 Table B.1 (inhalation + vegetables + soil)
Screening Value =	1.03E-05	Sv	
Adjusted Screening Criterion =	1.67E-05	Sv	1E-05 excess risk at 6% per Sv, divided by 10 to account for uncertainties per NCRP 123 II-F-5
Screening criterion exceeded?	NO		

Table 7-9. Level II screening for the maximum tritium release from TA-21

Total Release =	2.97E+13	Bq HTO	OSR database Rev. 7, 100% HTO
Seconds per year =	3.2E+07	sec	NCRP 123 I-A-2
Annualized Release Rate =	9.28E+05	Bq/sec	(calculated)
Wind Speed =	2	m/sec	NCRP 123 II-bi-7
Distance to receiver =	1460	m	estimated from LAHDRA project map
Dispersion factor =	3E-05	m^{-2}	NCRP 123 Fig. 1.4 (limiting value)
Receiver concentration =	3.48E+00	Bq/m^3	
Screening Factor =	7.20E-07	Sv per Bq/m^3	NCRP 123 Table B.1 (inhalation + vegetables + soil)
Screening Value =	2.51E-06	Sv	
Adjusted Screening Criterion =	1.67E-05	Sv	1E-05 excess risk at 6% per Sv, divided by 10 to account for uncertainties per NCRP 123 II-F-5
Screening criterion exceeded?	NO		

Table 7-10. Level II screening for the maximum tritium release from TA-33

Total Release =	1.37E+13	Bq HTO	OSR database Rev. 7, 1% HTO
Seconds per year =	3.2E+07	sec	NCRP 123 I-A-2
Annualized Release Rate =	4.28E+05	Bq/sec	(calculated)
Wind Speed =	2	m/sec	NCRP 123 II-bi-7
Distance to receiver =	3750	m	estimated from LAHDRA project map
Dispersion factor =	7E-06	m^{-2}	NCRP 123 Fig. 1.4 (limiting value)
Receiver concentration =	3.75E-01	Bq/m^3	
Screening Factor =	7.20E-07	Sv per Bq/m^3	NCRP 123 Table B.1 (inhalation + vegetables + soil)
Screening Value =	2.70E-07	Sv	
Adjusted Screening Criterion =	1.67E-05	Sv	1E-05 excess risk at 6% per Sv, divided by 10 to account for uncertainties per NCRP 123 II-F-5
Screening criterion exceeded?	NO		

Table 7-11. Level II screening for the maximum tritium release from TA-35

Total Release =	9.25E+14	Bq HTO	OSR database Rev. 7, 100% HTO
Seconds per year =	3.2E+07	sec	NCRP 123 I-A-2
Annualized Release Rate =	2.89E+07	Bq/sec	(calculated)
Wind Speed =	2	m/sec	NCRP 123 II-bi-7
Distance to receiver =	1740	m	estimated from LAHDRA project map
Dispersion factor =	2.5E-05	m^{-2}	NCRP 123 Fig. 1.4 (limiting value)
Receiver concentration =	9.03E+01	Bq/m^3	
Screening Factor =	7.20E-07	Sv per Bq/m^3	NCRP 123 Table B.1 (inhalation + vegetables + soil)
Screening Value =	6.50E-05	Sv	
Adjusted Screening Criterion =	1.67E-05	Sv	1E-05 excess risk at 6% per Sv, divided by 10 to account for uncertainties per NCRP 123 II-F-5
Screening criterion exceeded?	YES		

Table 7-12. Level II screening for the maximum tritium release from TA-41

Total Release =	5.84E+12	Bq HTO	OSR database Rev. 7, 1% HTO
Seconds per year =	3.2E+07	sec	NCRP 123 I-A-2
Annualized Release Rate =	1.83E+05	Bq/sec	(calculated)
Wind Speed =	2	m/sec	NCRP 123 II-bi-7
Distance to receiver =	490	m	estimated from LAHDRA project map
Dispersion factor =	2E-04	m^{-2}	NCRP 123 Fig. 1.5 (limiting value)
Receiver concentration =	4.56E+00	Bq/m^3	
Screening Factor =	7.20E-07	Sv per Bq/m^3	NCRP 123 Table B.1 (inhalation + vegetables + soil)
Screening Value =	3.29E-06	Sv	
Adjusted Screening Criterion =	1.67E-05	Sv	1E-05 excess risk at 6% per Sv, divided by 10 to account for uncertainties per NCRP 123 II-F-5
Screening criterion exceeded?	NO		

The NCRP Report No. 123 screening evaluation suggests airborne tritium releases from LANL were unlikely to have been a source of adverse health risks to local residents around Los Alamos. The possibility cannot be ruled out entirely, however, in light of the screening result for TA-35. Further, there are caveats to consider, including the possibility that larger releases could have occurred prior to 1967 (when atmospheric tritium releases were first estimated by LANL) or that some of the releases consisted of a greater fraction as tritium oxide (HTO) than has been considered here. But given the degree of conservatism used in the screening method, it appears the impacts of such effects would have to be substantial before atmospheric tritium releases would have posed a significant health risk.

As a check on the intended conservatism in the screening approach used for atmospheric tritium releases, local environmental monitoring data for tritium oxide (HTO) were compiled for the period July 1970 through December 1979. This period was expected to encompass the largest airborne tritium releases from LANL for the era when environmental monitoring data are available. Table 7-13 shows the maximum annual average concentrations for the on-site and off-site environmental tritium monitoring stations on and around the LANL site for July 1970 to December 1979. The on-site data were included in this evaluation to both be conservative and to allow for the fact that the public historically has had access to many "on-site" locations at LANL.

Table 7-13. Maximum tritium oxide concentrations from the LANL environmental air monitoring stations 1970 – 1979

Year	Maximum On-Site Average		Maximum Off-Site Average		LAHDRA Reference (Repos. No)
	Concentration ($\mu Ci\ mL^{-1}$)	Location	Concentration ($\mu Ci\ mL^{-1}$)	Location	
1970*	1.80×10^{-11}	unknown	3.50×10^{-12}	"Community"	2178
1971	2.40×10^{-10}	Array 156-9.4	1.20×10^{-10}	Array 42-3.1	2155
1972	1.80×10^{-10}	Array 156-9.4	4.40×10^{-11}	Array 164-8.5	887
1973	1.51×10^{-10}	TA-21	2.70×10^{-11}	Fuller Lodge	2161
1974	1.41×10^{-10}	TA-33	3.60×10^{-11}	Fuller Lodge	2157
1975	1.74×10^{-10}	TA-52	9.30×10^{-11}	Fuller Lodge	2158
1976	3.30×10^{-10}	TA-54	5.10×10^{-11}	Los Alamos airport	2159
1977	1.87×10^{-10}	TA-54	5.10×10^{-11}	Los Alamos airport	2069
1978	5.70×10^{-11}	TA-54	2.60×10^{-11}	Los Alamos airport	953
1979	4.00×10^{-11}	TA-33	6.70×10^{-12}	Royal Crest Trailer Park	2190

*July – December 1970

The elevated HTO concentrations at TA-54 are the result of evaporative losses from soil containing buried, tritium-contaminated wastes. Tritium oxidizes slowly in the environment at a rate of less than 1% per day (Mishima and Steele 2002). The fact the TA-54 sampling station is the location of the maximum measured on-site HTO concentrations for some years shows the importance of TA-54 as a source of

airborne releases of tritium oxide relative to other sources. The tritium oxide concentration for the TA-54 environmental monitoring station for 1976 was the largest of all of the on-site annual averages for July 1970 through December 1979. The largest off-site annual average for this period was at the location designated Array 42-3.1 for 1971. It is difficult to discern the precise location of this monitoring station in the reference, but it appears that it might be at or near the Fuller Lodge location.

From Table 7-13, the maximum annual average airborne tritium oxide concentrations reported by the LANL environmental air monitoring network for July 1970 through December 1979 were 3.3×10^{-10} µCi mL^{-1} (12.2 Bq m^{-3}) and 1.2×10^{-10} µCi mL^{-1} (4.4 Bq m^{-3}) for on-site and off-site locations, respectively. One can gauge what these concentrations imply in terms of dose to human receivers by applying screening factors for tritium oxide from NCRP Report No. 123. For the on-site locations, the appropriate factor to use is that for inhalation alone. The combined factors for inhalation and consumption of contaminated vegetables and soil are appropriate for the off-site locations. These screening factors are 1.4×10^{-7} Sv per Bq m^{-3} for inhalation and 7.2×10^{-7} Sv per Bq m^{-3} for the combination of inhalation and consumption of contaminated vegetables and soil.

Multiplying the inhalation screening factor by the maximum on-site concentration value (in consistent units) gives a screening dose equivalent value of 1.7×10^{-6} Sv, or 0.17 mrem. Note this calculation requires the extremely conservative assumption of 100% occupancy at the on-site location. The same calculation for maximum average off-site concentration, using the combined factor for inhalation and vegetables, gives a screening dose equivalent of 3.2×10^{-6} Sv, or 0.3 mrem. Including the vegetation pathway results in a higher screening dose than the on-site location despite the lower average air concentration. Nonetheless, both of these values are well below the screening criterion of 1.67×10^{-4} Sv (16.7 mrem).

As with the screening assessment performed using atmospheric release data for tritium, measured values of tritium oxide concentrations in the local environment around Los Alamos also suggests that airborne releases of tritium from Los Alamos are unlikely to have resulted in any adverse health risks to the local residents. However, as with the effluent data, the environmental monitoring data have been used as reported without any adjustments or verification, and they do not consider the period prior to 1970.

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Chapter 8: Hot Cell Facilities and Operations at LANL

Beginning with early operations, LANL processed highly radioactive material, such as fission products, to meet the production and research needs of the Lab and the federal government. Much of the work on radioactive materials at the laboratory was carried out in specialized, shielded enclosures called "hot cells" that provided protection for the workers by reducing their radiation exposures. Remote manipulators, also called mechanical hands, were used to handle the isolated radioactive materials inside the hot cells. The hot cells also provided some level of control in helping to reduce releases of radioactive material to the environment.

In 1944, LANL began receiving its first shipments of multiple curies of ^{140}Ba for use in extracting ^{140}La, a radionuclide used as a tracer for hydrodynamic explosive tests conducted during the Radioactive Lanthanum ("RaLa") program. Due to the high gamma energy and radiation fields associated with these materials, LANL designed and built its first hot cell facility in order to safely extract the ^{140}La for further processing. Over the course of many years, LANL built several additional hot cell facilities to meet the growing needs of the federal government and other customers and by the early 1980s had approximately 36 hot cells in operation.

In addition to ^{140}Ba/^{140}La operations, hot cells were used for (Wilson et al. 1979):

- handling and manufacturing of nuclear reactor fuels and fuel assemblies,
- chemical separation and analysis of irradiated reactor fuels,
- radionuclide analyses, such as with fission products, supporting nuclear weapon tests,
- accelerator-based production of radionuclides for medical and research applications,
- fabrication and testing of fuels associated with the Rover nuclear propulsion and the Ultra High-Temperature Reactor Experiment (UHTREX) projects,
- storage and processing of materials with high tritium concentrations, and
- chemical separation, isotopic analysis, treatment and volume reduction, and storage of high-level radioactive waste in support of a variety of laboratory and other governmental programs.

LANL's hot cell facilities were used in the handling of large quantities of fission products, and to a lesser extent plutonium, uranium, and other heavy elements. Because of the higher radioactivity handled in these facilities, the project team collected information on hot cell operations to support potential prioritization of associated releases in the future. This chapter is intended to provide an overview of LANL's hot cell operations and highlight those that may warrant further investigation. In the preliminary

prioritization analyses that have been performed, fission products were found to be less important than several other classes of other radionuclides. However, the analyses performed to date have been largely dependent on release estimates put forward by LANL, and waste streams associated with hot cell operations appear to have not always been among the top priorities within programs for monitoring and estimation of releases to the environment. Several comments have been made during past LAHDRA public meetings that indicate a belief among some members of the public that releases from hot cell operations have not been adequately disclosed, characterized, or quantified. Some believe that releases of radioiodine and other fission products could have been significantly larger than has been disclosed, and that an independent evaluation of associated historical activities is warranted. A summary of LANL hot cell operations is presented in Table 8-1 at the end of this chapter.

Over 8,000 documents or sets of documents that are included in the LAHDRA project information database were searched by team members for information pertaining to hot cell and associated operations. A summary of related information that has been extracted is presented below.

The RaLa Program

Chemical extractions of lanthanum during the initial years of the program for testing the implosion process (1944-1950) were performed using 1.5- to 2- m high, shielded shipping casks and were carried out in a wooden building located in Bayo Canyon, TA-10 (Wilson 1979). Operators located approximately 27 m from the casks using electric cranks, cabling, and remote tongs, along with telescopes and mirrors for viewing, lowered reagents into casks to complete the chemical separation of barium and lanthanum. One hundred and fifty sources of ^{140}La ranging in source strength from 40 to over 3,000 Ci were prepared and used in explosives tests from September 1944 to July 1950. The crude remote handling facility that was used at TA-10 was modest by today's standards for hot cell design and performance, but it served its purpose until it was phased out of operations in the early 1950s.

In 1947, LANL began construction of a new hot cell facility at Ten Site (TA-35) to process the barium and lanthanum. Completed in 1951 at a cost of nearly $3 million, the facility consisted of two 3-m by 6-m by 2.5-m high hot cells. A crane and trolley system was used to move radioactive materials in and out of the cells. The trolley housed a rotatable spindle with pins on one end to mate with bayonet slots of various tools, vessels, and equipment components inside the hot cells for handling and processing of materials. An operator's view inside a hot cell was accomplished through shielded glass windows (such as leaded glass) and a series of mirrors and retractable periscopes. A large auxiliary building was used to handle and purify air and house liquid filtration and treatment equipment. Believed to have been the first modern hot cell design to handle high-level radioactive materials, the TA-35 facility contained innovative

features such as exterior, contamination–free lighting, cell wash-down sprays, collimated ports for experiments, and hydraulic rams for opening and handling shipping casks. LANL later added concrete caves with a zinc bromide window above the hot cells to provide flexibility in packaging lanthanum sources. In 1963, these operations terminated after processing about 2 million curies from the Chemical Processing Plant at the Idaho Falls (Wilson 1979).

Hot Cells Associated with LANL Reactors

A series of research and production reactors were operated at Los Alamos dating back to 1943. These reactors were largely used in fuel and neutron experimentation and for research and production of fission products and activation products (Wilson, 1979). The first of these reactors were the Water Boiler series reactors– LOPO, HYPO, and SUPO– as described in Chapter 5. The Clementine reactor, located at Omega Site (TA-2) at the bottom of Los Alamos Canyon, was commissioned in November 1946 and was the first reactor to use ^{239}Pu as its fuel. Hot cells were used to test the fuel and reactor components following neutron irradiation experiments. Corrosion of steel cladding began to release considerable alpha contamination into the mercury coolant which led to the shutdown and decommissioning of the reactor in 1952. According to LANL employees at the time, no detectable radioactivity was released to the environment during these fuel rod failures (Wilson 1979).

The Omega West Reactor was built at the same location where Clementine existed and was operated from 1956 to 1994 to support a variety of research programs. Irradiated fuel from Omega West was transferred to hot cells for chemical processing and testing. In some cases, isotopes were extracted to support or research programs.

LANL used a series of compact reactors that were assembled and tested at Ten Site in the 1950s and 1960s to test new technologies used in reactor and fuel assembly designs. These were called the Los Alamos Power Reactor Experiment (LAPRE) and used plutonium dissolved in phosphoric acid. LAPRE I was a forced-convection, high pressure, water-cooled reactor that was later drained and decommissioned. LAPRE II used natural convection. This operated for short time and then shut down. Irradiated fuel and reactors components and equipment were tested inside the TA-35 hot cells. Typical processes involved chemical separation, analytical measurements of radionuclides, and preparation for waste disposal. A third reactor known as the Los Alamos Molten Plutonium Reactor Experiment (LAMPRE) was operated within the Ten Site hot cell adjacent to the one used to extract ^{140}La in the RaLa program. The fuels from these reactors were eventually transferred for storage to the CMR Wing 9 hot cell facility at TA-3 for further processing and waste disposal (Wilson 1979).

General Purpose Hot Cells

Since 1951, LANL has operated 36 general purpose hot cells in four separate on-site facilities. These are described as general purpose cells because their designs permitted considerable flexibility for storage, processing, and handling of radioactive materials. This section presents a description for each of these facilities. Hot cell operations are active, or have been active, at the following LANL facilities:

- TA-3, CMR Building, Wing 9 Operations,
- TA-21, DP West Site, Building 4, Room 401,
- TA-48, Radiochemistry Laboratory,
- TA-50, Contaminated Waste Treatment Facility,
- TA-52, UHTREX Facility, and
- TA-53, LAMPF/LANSCE Facility.

TA-3; CMR Building Wing 9 Hot Cells

The CMR Wing 9 hot cell facility began operations in December 1961. The facility was used to support the civilian power reactor program from 1961 to 1967, the Rover Nuclear Propulsion Project from 1961 to 1973, and the Liquid Metal Fast Breeder Reactor (LMFBR) from 1967 to the early 1980s. The facility has also provided assistance to numerous LANL programs by performing various experiments involving high levels of gamma radiation associated with irradiated fuel and fission product samples. The facility still supports a variety of LANL programs, including transuranic (TRU) waste treatment and packaging for disposal at the DOE WIPP site in Carlsbad, New Mexico (LANL 1999).

The Wing 9 hot cell facility consists of sixteen 2-m by 2-m by 3.6-m high hot cells arranged in two groups of eight cells separated by shielded corridors. Fig. 8-1 represents a cutaway drawing of the Wing 9 hot cell facility. The ferro-phosphorus walls and leaded-glass windows shield up to 30,000 Ci of mixed fission products or 50,000 Ci

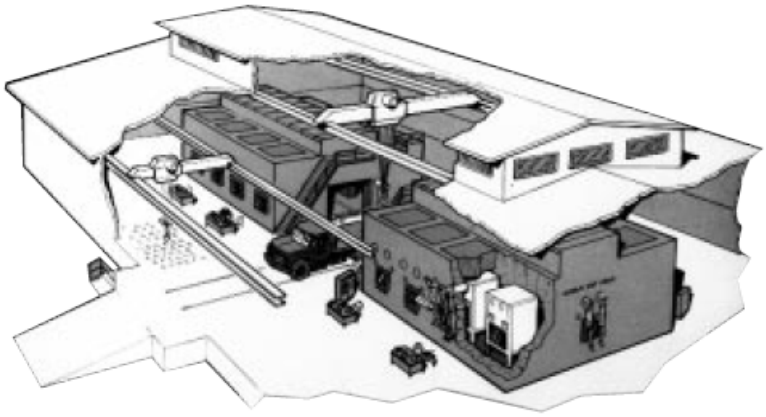

Fig. 8-1. Wing 9 hot cell facility at TA-3's CMR Building (LANL 1999)

of 1 MeV gamma radioactivity (Wilson 1979; Valentine et al. 1968). A storage area consists of 364 shielded holes that are cooled and maintained at negative pressure. Areas within the facility are designed for decontamination activities, mock-up runs, machine shop, manipulator repair, cold laboratory, dark room, and staff offices. Fig. 8-2 is a photograph that shows the exterior work stations and the shielded glass viewing windows, manipulator arms, and control panels for a group of four Wing 9 hot cells located in the CMR Building.

Fig. 8-2. CMR Building Wing 9 hot cells

Airborne effluents from the CMR Wing 9 hot cells are filtered and monitored for particulates and radioiodine with fiber and charcoal filters, respectively. Air from three monitored compartments is discharged at a rate of 176,840 ft^3 min^{-1} through a 56 ft tall stack. Air samples are collected on a 24-h basis and analyzed for ^{235}U, ^{238}U, ^{239}Pu, ^{241}Am, fission products, and ^{131}I. Sampling results and details of the sampling program are reported in LANL reports and were reviewed by the LAHDRA team. Early effluent monitoring results are published in monthly Health Division reports and special reports that present monitoring results for non-routine releases and discussion of general issues related to stack monitoring and airborne emissions and their impact in the environment. Monitoring results are also published in LANL's Annual Environmental Surveillance reports for the years 1970 to the present.

Stack sampling and filtering of effluents for the Wing 9 hot cells began at the start of operations and underwent of number of changes and improvements over the years. In a 1970 memorandum, LANL reports that the CMR stack sampling was not isokinetic, results were therefore not representative of quantities actually discharged, and improvements were needed in order to generate reliable release estimates (Meyer 1970, Enders 1970). Upgrades and new procedures were implemented to improve the exhaust filtration and monitoring program as highlighted in numerous Health Division reports and memorandums (Lawrence 1970). Efforts to reduce emissions were also being emphasized during this period because of the forthcoming reductions in AEC release limits for radioactive isotopes. Other reports also depict LANL's efforts to improve monitoring and control of airborne releases from other CMR wings and exhaust stacks (LASL 1975).

Solid radioactive waste from these and other hot cell operations were disposed of at the former TA-21 and TA-54 burials grounds. Waste was often treated or consolidated and packaged into a variety of containers (such as 55-gallon metals drums) and transported to the burial grounds for shallow-land burial. Land burial at LANL began during the 1940s and continued up through recent years.

Small volumes of liquid waste from hot cell operations that contain plutonium, americium, uranium, and fission products along with reacted sodium and sodium potassium solutions were placed in 3.8 L or smaller containers and then packed in 7.8 L cans with dry vermiculite for shaft burial at the burial grounds. Other waste containing higher levels of radioactivity were transported to TA-50 for treatment (LASL 1975).

T-21; DP West Site Room 401 Hot Cells

Construction of four hot cells began in 1958 in Building 4 at TA-21. These cells were designed to handle kilogram quantities of irradiated plutonium that possessed kilocuries of gamma activity and to support evaluation of plutonium fuel reprocessing schemes up through 1967. The facility then remained idle for the next three years until the cells were used to perform in-depth, post-irradiation examinations of reactor fuel elements. The 2-m by 2-m by 6.5-m high cells were interconnected by a 3-m by 10-m, shielded corridor with rolling steel doors and 22 storage wells located on the floor that are 1.5 m deep. The cells were equipped with manipulators for remote processing, and radioactive material was moved in and out via a transfer can system. This facility was partially decommissioned in the 1980s and has been under a maintenance and preservation program since. The future plans for many of the buildings at TA-21 are currently under review by the laboratory.

The Room 401 hot cells were designed with a negative pressure water circulating system. If there was a breach in the system, air would leak into the system rather than letting water leak into the cells. This minimized the chances of a nuclear criticality accident and reduced the potential for a large of amount of contaminated water that would have otherwise flooded the cells. This design did, however, create airborne emission concerns.

As reported in two 1961 Health Division memos regarding the DP West Room 401 Hot Cells, LANL recognized that process air concentrations and releases of ^{131}I had become a concern and needed to be addressed through the use of improved source control and exhaust vent and stack filtration (Dummer 1961). Fig. 8-3 provides an example report of air concentrations above the maximum permissible concentrations (MPCs) that highlighted those concerns. The elevated air concentrations were due to dissolution and analysis processing of an 82-g plutonium foil that had been irradiated in the Omega West

Reactor. The reports suggest that this was not a one time occurrence and that greater attention was required to reduce these airborne emissions in the future.

TABLE I
401 DRYBOX EXHAUST I^{131}

Date Collected	$d/m\text{-}M^3$ on Filter Corrected for Decay	$d/m\text{-}M^3$ Corrected for Filter Paper Efficiency*	% MPC**
6-2-61	3.8×10^5	3.8×10^8	130
6-5-61	3.8×10^5	3.8×10^8	130
6-6-61	4.2×10^5	4.2×10^8	140
6-7-61	9.0×10^5	9.0×10^8	300
6-8-61	6.6×10^5	6.6×10^8	230
6-9-61	5.2×10^5	5.2×10^8	180
6-12-61	6.6×10^5	6.6×10^8	230
6-13-61	3.4×10^5	3.4×10^8	120
6-14-61	2.2×10^5	2.2×10^8	76

Fig. 8-3. DP West hot cell ^{131}I air sample results (from Dummer 1961)

LANL also stated in memos that, before another sample was run, some effort to prevent iodine dispersal should be made– that is, charcoal filters should be installed at the drybox exhaust ports (Dummer 1961). Fig. 8-4 depicts the layout of the DP West, Room 401 hot cell facility and represents the sequence of air samplers and exhaust air filters in relation to the exhaust stack.

TA-48 Radiochemistry Hot Cell Facility

The TA-48 Radiochemistry Hot Cell Facility became operational in 1959 and was designed for evaluations and experiments with irradiated fuel and fission products. The facility was also used for other programs such as actinide chemistry experiments, isotope separation and production for medical and research uses, in-depth fuel analyses, and fission product and fuel testing of samples collected following nuclear weapon detonation tests (Wilson et al 1979). The first cell utilized three work stations and was design to store and handle hundreds of curies of radioactivity. TA-48 hot cells are still in use today for processing, testing, and storage of radioactive materials (Hyder 1992).

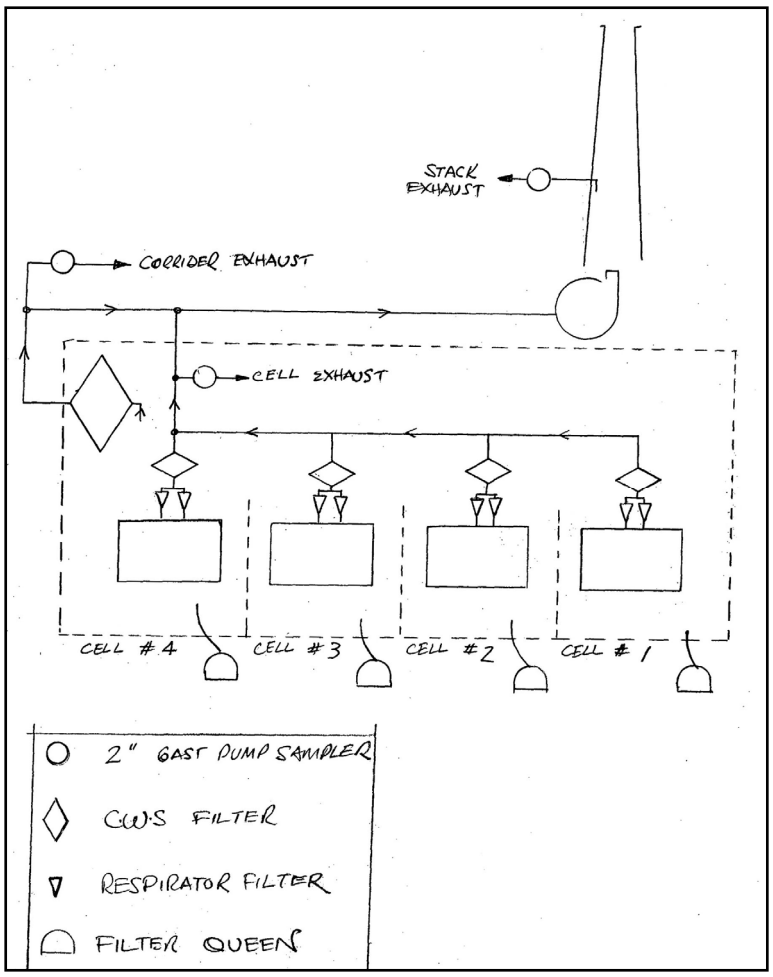

Fig. 8-4. DP West hot cell layout showing monitoring and filters (Dummer 1961)

In 1963, twelve more cells were built in an adjacent building at TA-48 for dissolution and evaluation of graphite fuel used in the Rover program. The cells are 1.5-m by 1.7-m by 2.7-m high and arranged in two rows of six separated by a shielded corridor. The Rover project ended in 1973, and some of the cells were later modified to handle uranium, plutonium, transuranics, and fission products. Releases of ^{131}I and other fission products gained the attention of LANL staff. While it is unclear how rapid LANL's response to the issue was, it is clear that Health Division staff published their concerns about the issue during early operations.

Fig. 8-5 presents an example of a LANL document that highlights radioiodine releases and concerns about off-site emissions from the TA-48 hot cells. Much of their concerns focused on residents living in a nearby trailer court (Royal Crest Trailer Park) located approximately 1000 m from the TA-48 exhaust stack. Hot cells at TA-48 were used to experiment with a variety of less commonly used radionuclides such ^{227}Ac, ^{76}Br, ^{77}Br, ^{82}Br, and ^{237}U (Dummer 1979a, b).

LOS ALAMOS SCIENTIFIC LABORATORY
UNIVERSITY OF CALIFORNIA
LOS ALAMOS, NEW MEXICO

OFFICE MEMORANDUM

TO : Distribution

DATE: Oct. 14, 1964

FROM : Carl Buckland, Leader, General Monitoring Section, H-1

SUBJECT: SUMMARY OF I^{131} CONCENTRATIONS FOUND IN AND FROM NEW CELL ADDITION AT TA-48

SYMBOL : H-1

For my own benefit, I felt a need to summarize Don's I^{131} data at TA-48 to determine how we stand (reference his 10-12-64 report). If I have my figures correct, the following conclusions may be drawn:

Room breathing air - No individual air sample exceeded the MPC for occupational exposure. Highest was one-third MPC on October 5 thru 6, Room 334. It should be pointed out, however, that the sampling time included 8 hours in which no work took place (diluted mathematically by additional air flow).

Stack - Highest individual sample, 4.9×10^{-2} $\mu c/M^3$, Exhaust 4, October 5 thru 6, same dates as highest room sample, is about 500 times MPC for non-occupational exposure. Although this appears high, the highest average over a previous 13 week period was only 2.3×10^{-4} $\mu c/M^3$ (twice MPC non-occupational).

Environmental - As I understand, Chapter 0524 or something I read, if the non-occupational MPC over a 13 week period is exceeded at the point of discharge (stack), samples have to be taken at the perimeter fence. Although the sampling is meager, the non-occupational MPC was not exceeded 500 feet in a NE direction from the building. If there was a skip over this sampling point, we have only two H-6 charcoal filter samplers to fall back on, both of which are not in a northeasterly direction from TA-48 (located at SM-43 and TA-50). The highest level for one month when adding the findings for the whole month, was 8.1×10^{-12} $\mu c/cc$, well below the non-occupational MPC of 1.0×10^{-10} $\mu c/cc$ on top of SM-43.

All MPC's for air were taken from Chapter 0524 and converted to 9×10^{-3} $\mu c/M^3$ occupational, 1×10^{-4} non-occupational soluble I^{131}.

You may want this type of thing for the Progress Report, if my conclusions and calculations are correct. If so, it can be reduced further as a brief summary.

CB/es
Distribution:
Dean Meyer, H-1
Donald McKown, H-1
Sixto Maestas, H-1

Fig. 8-5. 1964 H-Division memo addressing airborne iodine releases at TA-48 (Buckland 1964)

LANL took steps to reduce these iodine releases by adding additional charcoal filters to exhaust air systems. They also improved their stack sampling and monitoring systems and practices over time so that results more accurately quantified releases to the environment (Maestas 1967).

Process air from TA-48 hot cells and surrounding areas was consolidated and exhausted through two main exhaust plenums, designated as FE-38 and FE-48, and then vented to the outdoor atmosphere through an elevated stack (Maestas 1969; Maestas 1970; Maestas 1971). The Maestas references cited here are sample reports selected from a series of weekly Health Division reports located in the LAHDRA database.

TA-50 Contaminated Waste Treatment Plant Hot Cell Facility

As part of the Chemical Waste Treatment Plant at TA-50, a hot cell facility became operational in 1963 to handle high levels of beta-gamma emitting radioactive material. The hot cell facility was primarily used to neutralize liquid waste and package the treated and consolidated waste for long-term storage and disposal. The facility consisted of a cask unloading dock, transfer and storage area, and one 2-m by 3-m by 4-m high hot cell.

TA-52 UHTREX Hot Cell

This hot cell was built in 1965 to provide a properly-shielded place to exchange fuel assemblies and perform testing of irradiated fuel. The facility was shut down in 1968 along with the UHTREX project.

Fast Reactor Core Test Facility

Construction of this facility began in 1963 and was completed in 1966. The project and associated use of the hot cell facility for handling plutonium fuel was terminated before any of the systems or structures were tested or used.

TA-53 LAMPF/LANSCE

The accelerator complex at TA-53 contains two hot cells with four work stations. These hot cells have been in operation since 1976. The cells are used for radiochemical experiments and medical and research isotope production and separation. Isotope separation was also performed inside the hot cells at Wing 9, CMR Building at TA-3.

Hot Cell Decontamination and Waste Disposal

The largest amount of radioactive waste generated by hot cell operations came from the hot cells located at TA-3 (Wing 9), TA-21 (Room 401), TA-35 (Ten Site Laboratory), TA-48 (Radiochemistry Laboratory), and TA-50 (Waste Treatment Plant). Methods used to decontaminate, treat, and dispose of liquid and solid waste from LANL's hot cell operations varied according to the levels of radioactivity and types of radioactive materials processed in a given project. Much of the removal, treatment, consolidation, and disposal of highly radioactive residues and wastes generated inside hot cells involved the use of remotely-operated, jet spray washing and dry and wet vacuum systems (Dummer, 1965; LANL 1974). Treatment of highly radioactive liquid waste was performed at the Contaminated Waste Hot Cell facility located at TA-50

Removal and collection of contamination and subsequent treatment of the radioactive waste for on-site disposal for a typical LANL hot cell involved the following procedures:

- Removable contamination was spray-washed from containment structures, such as bench tops and laboratory exhaust hoods, and from equipment and tools and then vacuumed into holding containers.

- Spray washing to remove loose contamination was repeated until levels allowed personnel to enter the hot cells for short periods to apply more aggressive measures such as acid washing and scrubbing to lower contamination to acceptable levels.

- Soaking highly contaminated, smaller equipment and tools in containers filled with a mixture of CH_2Cl_2 (dichloromethane or methylene chloride), detergents, and hot water. This was an effective means of removing radioactive residues. The foaming action of the mixture carried off much contamination in precipitates that were collected for treatment and/or disposal.

- Dry solid residues and debris were vacuumed with in-cell vacuum systems and collected in containers. Recovered material considered to be of value was sent for further separation, analysis, and recycle.

- At Ten Site (TA-35 hot cells), highly radioactive residues were evaporated to dryness, placed in a pressure-sealed, aluminum containers, and loaded into uranium casks. The casks were then loaded on trucks and transported to the TA-21 disposal area for burial in 2-ft diameter by 15 ft

deep holes in the ground. When burial activities at TA-21 ceased, LANL began using the burial grounds at TA-54 to meet their disposal requirements for these wastes.

- Highly radioactive solid waste was loaded into aluminum or stainless steel containers and placed in uranium casks for burial at the TA-21 disposal area. In later years, these wastes were transported to the burial grounds at TA-54. During the early period of the 1950s and 1960s, liquid wastes were mixed with concrete and vermiculite and buried as solid waste.

- At the Wing 9 facility (TA-3 hot cells), cells dedicated to uranium and plutonium fuel work used open containers inside the hot cells. Dry debris and dust generated from cutting, crushing, and drilling the fuel were collected with an in-cell vacuum system equipped with a cyclone separator, a CWS filter, and a charcoal adsorption bed. Liquid and solid wastes were collected, treated, and consolidated for land burial using similar methods as those described above.

- By the 1970s, liquid wastes with recoverable amounts of radioactive materials were sent to hot cells at TA-50 for separation (such as cation exchange processing), analyzed, and returned to Lab generators for reuse and/or further analyses. Waste contents with 10^{-3} µCi mL^{-1} alpha and/or 10^{-2} µCi mL^{-1} beta concentrations were disposed of as low-level radioactive waste. If concentrations were above these values, the waste was placed in portable stainless steel tanks and delivered to the TA-50 Waste Treatment facility for recovery and consolidation (LANL, 1974).

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Table 8-1. Hot Cell Operations at Los Alamos National Laboratory (Wilson et al. 1979)

TA	Purpose	Dates	Radionuclides/Chemicals
1	Radiochemical and radiotracer separation (including RaLa operations) and neutron source preparation. Most of these operations took place in H Building.	1944 -1957	^{140}Ba, ^{140}La, ^{90}Sr,. ^{210}Po, ^{226}Ra, Be
3	CMR Building Wing 9 Hot Cell Facility. Used to evaluate irradiated plutonium and uranium fuel and fission products testing and separation and post detonation debris radiochemical analyses. Operations occurred largely in Wing 9 of CMR Building. The facility contained 16 general purpose cells 2m by 2m by 3.6m high.	1961-present	^{239,238}Pu, ^{234,235,238}U, mixed fission products, mixed activation products, TRU
10	Early RaLa sources were prepared in Bayo Canyon and later in facilities at Ten Site (TA-35). RaLa explosive experiments were completed in Bayo canyon. Remote handling, telescopes, and mirrors were used to aid in the separation and preparation of the ^{140}La. A few hundred thousands curies were handled during almost 20 y of RaLa explosive testing. Some batches of La reached upwards to 5,000 Ci. Single sources for test shots ranged from 40 to over 3,000 Ci.	1944-1951	^{140}Ba, ^{140}La, ^{90}Sr,. ^{210}Po, ^{226}Ra, Be
18	Rover Program - Hot Cell facility	1955-1973	Pu, U, and fission products
21	Examination of irradiated Pu and enriched uranium from Omega reactor (such as ^{235}U impregnated with graphite and ^{239}Pu in stainless steel casing and a tantalum sheath) and separation of irradiated fuel and fission products. The facility had four primary hot cells that were designed primarily to evaluate plutonium reprocessing schemes. Fuel reprocessing experiments and tests were discontinued in 1967. In the 1970s, the hot cells were used to evaluate irradiated fuel elements associated with the LMFBR program. Operations occurred largely in Bldg 4, Room 401. Rooms 403 through 407 contained gloveboxes used for metal preparation of ^{238,239}Pu. High exposure rates during material transfers to hot cells. After tests were completed, irradiated fuel was transferred from hot cells to the “hot dump.” On 26 May 1961, special fiberglass filter papers were placed in cell, corridor, and stack exhaust lines in Room 401 to sample air for fission products.	1958 - 1978	^{3}H, ^{239,238}Pu, ^{234,235,238}U, mixed fission products
33	Tritium handling facilities that contained hot cells for source handling and processing.		^{3}H
35	Radiochemical and radiotracer separation (RaLa operations), neutron source preparation, and fuel separation. Starting in 1956, the Chemical Processing Plant at Idaho Falls provided purified ^{140}Ba. Almost 2 million Ci were processed at Ten Site by 1963 when the RaLa program was terminated. Irradiated fuels from the LAPRE I and II and LAMPRE reactors were also evaluated in hot cells located at Ten Site. First hot cell design after WWII for handling high-level radioactive materials.	1951-1963	^{140}Ba, ^{140}La, ^{90}Sr,. ^{210}Po, ^{226}Ra, mixed fission products, Be
48	Radiochemistry Hot Cell Facility. Used to perform actinide chemistry and isotope production/separation. Facility also used to analyze samples collected from nuclear weapon test shots. In 1963, another hot cell facility was built in an adjacent structure to evaluate and dissolve samples of graphite fuel from the Rover Program. The Rover Program ended in 1973.	1959-present	Pu, U, TRU, mixed fission products, and mixed activation products
50	Contaminated Hot Cell facility. This facility was designed to handle high-level beta and gamma emitting wastes from several groups at LANL. The hot cells were part of the Contaminated Waste Treatment Plant. The cell was primarily used to neutralize liquid waste and package it for permanent storage.	1963-present	Pu, U, TRU, mixed fission products, andmixed activation products
52	UHTREX high-level remote handling area consisted of one hot cell for fuel element changing and examination.	1961-1968	Pu and U
53	LAMPF and LANSCE facilities contain two hot cells used for radiochemical experiments of irradiated targets, isotope production, and mixed activation products.	1976-present	^{3}H, mixed activation products

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Chapter 9: Operations with Other Radionuclides

Uranium

As discussed in numerous places in this report, uranium, at various levels of ^{235}U enrichment, has been used in a wide variety of applications at Los Alamos.

Uses of Uranium in Weapons

To develop and build gun-assembled weapons, Los Alamos personnel initially experimented with use of enriched uranium (^{235}U) and plutonium as the fissionable material. The gun-assembled uranium weapon was carried into production, and some implosion-assembled weapons that came along later included uranium as a fissile material. In addition, heavy metals such as uranium were used as "tampers" that confined the explosion, reflected some neutrons that would otherwise escape, and thereby decreased the "critical mass" of fissile material required to achieve an atomic explosion (Serber et al. 1992).

Uses of Uranium in Reactors

Uranium was also used in liquid and solid forms as fuel in various forms of nuclear reactors. More details can be found in Chapter 5. The first Water Boiler reactor was assembled in late 1943 at Omega Site (TA-2), using the nation's total supply enriched uranium as its fuel in the form of 14%-enriched uranyl sulfate. The Plutonium Fast Reactor (Clementine) used plutonium fuel that was surrounded with a 6-inch thick natural uranium reflector, and reactivity control was achieved via insertion of uranium fuel rods. The LAPRE I reactor experiment studied the use of phosphoric acid solutions of high-enriched uranium in a high-temperature reactor fuel, as did LAPRE II. The Ultra High Temperature Reactor Experiment (UHTREX) used 93%-enriched uranium fuel in the form of small spheres of UO_2 coated with pyrolytic carbon and bound in a graphite matrix. That fuel was fabricated at the CMR Building in TA-3. A 1969 waste management plan says that the DP East facility processed new Rover fuel elements containing enriched uranium.

Facilities that Handled Uranium

From 1948 to 1960, DP West Site's Building 4 housed laboratories for production of enriched uranium hydride. In 1960, the hydride equipment was removed so that a hot cell could be added for the examination of irradiated plutonium and enriched uranium fuel elements.

Facilities at the Original Technical Area (TA-1) that housed uranium operations included:

- C Building– housed a normal machine shop with a uranium machine shop in southeast section. Became operational in October 1943.
- D-Building– a facility designed to carry out chemistry and metallurgical experiments on plutonium and uranium. Other activities included design of tampers and polonium initiators and development of various refractory materials.
- G Building– housed the uranium and graphite "Sigma Pile", plus leak-testing of radium sources. Removed 6/59.
- HT Building– heat treatment and machining of normal and enriched uranium.
- HT Barrel House– contained storage areas for ^{239}Pu and ^{235}U.
- M Building– housed processing, metallurgy, and recovery of enriched uranium.
- Sigma Bldg– housed casting, machining, powder metallurgy of normal and enriched uranium, thorium (eastern part was normal; western part was enriched).
- TU Building– housed machining of normal uranium ("tuballoy").
- TU-1 Building– housed recovery of enriched uranium.
- V Building– contained the original machine shop; uranium and beryllium were machined there.

The Sigma Complex in TA-3, built in the 1950s and 1960s, has housed extensive laboratory areas for materials synthesis, and processing, characterization, and fabrication of materials such as beryllium, uranium, thallium, and aluminum alloys. These activities have included large-scale metallurgy and fabrication of normal and fully enriched uranium. As of 1969, the CMR Bldg, except for its Wing 9, was used for laboratory work on small quantities of uranium and plutonium. Wing 9 contained hot cells for handling of irradiated uranium and sometimes plutonium (see Chapter 8).

Uses of Uranium in Explosive Testing

LASL staff estimated in 1971 that between 75,000 and 95,000 kg of uranium had been expended in experimental shots at the Lab from 1949 through 1970 (Drake and Eyster 1971). Normal uranium was used until 1954, after which depleted uranium was used exclusively. A 1952 AEC report states that test shots at LASL routinely dispersed 300 lbs of uranium per month and 200 lbs of barium per month (English 1952). Between 1944 and 1948, eight firing sites (A-H) were established at TA-15 (R-Site). Experiments using from 50 lb up to 2 tons of HE were conducted at these firing points. Firing points E and F were the most active. Up to 65,000 kg of uranium and 350 kg of beryllium were expended at these two firing sites. Hazardous materials, including uranium, beryllium and lead, were largely left in place at these sites where after they were deposited by the explosion (LANL 1992).

The Bayo Canyon Site (TA-10) was used between 1944 and 1962 for experiments using conventional high explosives, radioactive lanthanum (RaLa), and in some cases depleted or natural uranium. The explosions resulted in the dispersion of uranium, ^{140}La and ^{90}Sr in the form of aerosols and debris to the atmosphere and onto the ground.

Use of Uranium at LAMPF / LANSCE

Originally constructed to study sub-atomic particles, the Los Alamos Meson Physics facility (LAMPF) includes an accelerator that has been used to generate intense pulses of neutrons by sending protons into targets of high atomic number such as uranium.

Accidents and Incidents Involving Uranium

In addition to routine, operational releases of uranium, some of the accidents and incidents that are described in LANL documents involved uranium and could have been associated with airborne and/or waterborne releases to the environment. Some of the documented accidents that that have involved uranium are summarized in Table 9-1.

Evaluation of Potential Health Risks from Atmospheric Releases of Uranium

As summarized above, the main areas where uranium has been used in machining or fabrication include the original technical area (TA-1), TA-3, and TA-21. Considerable quantities of uranium have also been expended in firing site activities conducted at TA-15, TA-36, and others. LANL's operations have involved a wide range of uranium enrichment, from depleted (primarily ^{238}U, with very little ^{235}U) to highly enriched (primarily ^{235}U).

To gauge what impact LANL's atmospheric uranium releases may have had in terms of human health risk, the NCRP Report No. 123 screening model was applied to airborne uranium source term information for a given year (NCRP 1996). The year selected was 1972, for which LANL reported a relatively large release of 1,200 µCi of U-234/U-235 from TA-21 (LASL 1973).

The 1972 uranium release was screened against a criterion of a 1 in 100,000 added risk of fatal or non-fatal cancer, assuming a risk factor of 6% per sievert (Sv). This corresponds to a dose equivalent of 1.67×10^{-04} Sv (16.7 mrem). The exposed population selected was the residential area nearest the release point. In the case of TA-21 this was the residential apartments within the townsite, at an estimated distance of 1,460 m. The pathways considered for the residential location were inhalation of contaminated air, plume immersion, irradiation from contaminated ground, and consumption of

Table 9-1. Some accidents and incidents at LANL that involved uranium

Date	Description	Repos. No.
2/1/1951	On February 1, 1951 there was a criticality incident involving 2 cylinders of U-235. The cylinders weighted 24.4 kg and 38.5 kg of 93% U-235. The 2 cylinders were in a water reflected system. There was slight oxidation of the uranium. 10^{17} total fissions were involved.	6206
12/9/1952	On December 9, 1952 in S-104 uranium in a furnace caught fire and was contained in the furnace. Clean-up of S-104 was conducted on December 11 and 12.	3495
6/26/1953	On June 26, 1953 there was a small fire in a flask containing uranium hydride in D-151.	3491
12/5/1953	On December 5, 1953 a glass furnace in a vacuum hood exploded releasing 40g of uranium.	3491
3/9/1955	Uranium was released into the hood of Room 121 at TA-46 on March 9, 1954.	2383
5/12/1955	On May 12, 1955 a small furnace erupted releasing an unknown quantity estimated at less than one kilogram of uranium in Room 102 of Sigma Building.	2374
7/21/1955	On July 21, 1955 some normal uranium caught fire in Room 1131.	1184
8/19/1955	On August 19, 1955 an employee dropped a test tube containing one gram of normal uranium in Wing 2 of CMR Building.	3489
3/9/1956	On March 9, 1956 a spill of uranium flowed into the bottom of the furnace in Room 21 of the Sigma Building.	2383
9/27/1957	On September 27, 1957 rags contaminated with sodium and uranium caught fire in Room 133 at Ten Site. Fire was quickly extinguished with CO2.	2414
4/1/1959	During processing of irradiated U-235 at TA-48 uranium oxide was blown out of the hood when a sample can was opened.	2514
12/3/1959	On December 3, 1959, a fire broke out in the duct work of Room 313 of DP West where uranium materials are incinerated. The damage was limited to the duct work.	2494
6/17/1960	On June 17, 1960 there was a criticality incident involving ~48 kg U-235. Uranium cylinders in thick graphite (9-in.) reflected before complete assembly, resulting in trivial damage. 6×10^{16} total fissions were involved.	6206
8/7/1961	On August 7, 1961 a container with a uranium fuel element leaked. Contamination products were detected in the parking lot and around the building. No decontamination was done.	2524
4/8/1963	On April 8, 1963 there was a uranium spill at TA-46.	2536
1/10/1964	On January 10, 1964 in SM-66 depleted uranium residue ignited in a drum. The material was allowed to burn out.	2812
4/22/1964	An explosion occurred following a fire in Room 313 DP West from uranium contaminated rags on April 22, 1964. The fire spread from the drybox to the adjoining hood.	2505
6/1/1965	At DP East the gas purge line to a recovery furnace became plugged. The operator in charge removed a rubber hose connected to the unit, and uranium-containing dust was blown out into his face and onto his clothing.	NA
11/16/1966	The air cleaner at one of the enriched uranium shops developed a pin-hole leak, which resulted in high surface contamination of the surrounding area.	NA
1/15/1969	A glovebox explosion occurred in the uranium recovery operation at DP West, during the incineration of U-235 metal turnings.	NA
4/3/1970	On April 3, 1970 a furnace containing uranium exploded releasing dust in SM-35 Room 104.	4261
11/2/1971	On November 2, 1971 an explosion in test cell furnace blew uranium contamination onto floor.	1417
5/4/1979	A stainless steel pot containing uranium tritide was overheated in a laboratory at the Cryogenics Building and ruptured on May 4, 1979. tritiated water escaped into the laboratory because of inadequate air flow in the hood. Some tritium was released to the atmosphere.	4484
11/2/1982	On November 2, 1982 approximately 50-100 L of waste liquid escaped from a tank vent at TA-21-257 contaminating the building roof, walls, and surrounding area with low levels of plutonium, americium, and uranium.	NA

contaminated soil and vegetables. Consumption of locally raised meat or milk were not considered. The applicable NCRP 123 screening factors for the selected pathways were 0.31 Sv per Bq per m^3 and 0.33 Sv per Bq per m^3 for ^{234}U and ^{235}U, respectively. Inhalation is the dominant contributor to both factors, being 93% of the total for ^{234}U and 80% for ^{235}U. For simplicity the release was screened as 100% ^{235}U. A bounding value for the air diffusion factor was selected based on the source-receiver difference. This was conservative and avoided the need to account for effective release height and building wake effects.

The NCRP Report No. 123 screening evaluation for the 1972 airborne uranium release from TA-21 gave a screening value of 1.7×10^{-6} Sv (0.17 mrem), much smaller than the screening criterion. The screening dose was also compared against screening criterion reduced by a factor of ten, as recommended by NCRP 123 to account for uncertainties. This gives an adjusted screening value of 1.67×10^{-5} Sv (1.67 mrem), still much larger than the screening dose. Thus, a significant human health risk (relative to the selected risk criterion) is not indicated for the relatively large uranium release reported for TA-21 for 1972. It should be noted the release value was used as reported by LANL and has not been adjusted in any way or independently verified. Adjustments for biases such as sample line losses or counting losses from the material being buried in the collection media would increase the amount of material released, but not by enough in this case to exceed the screening criteria.

A screening evaluation was also performed for depleted uranium (DU). The effluent data for 1973 were used, with a release of 640 kg of DU from TA-3 (LASL 1974). On an activity basis, this equates to a release of 2.11×10^{5} μCi, assuming the material was 100% ^{238}U (specific activity = 0.33 μCi/g). The airborne DU release reported for TA-3 was assumed to have originated from the Sigma Complex. The Sigma Complex consists of the Sigma Building (SM-66) and other facilities involved in uranium operations. The nearest residential area was determined to be the Western Area at a distance of about 1,040 m. As with the screening for TA-21, a bounding value of the diffusion factor at that distance was used for simplicity. The NCRP 123 screening factor for ^{238}U for the applicable pathways is 0.29 Sv per Bq per m^3.

The NCRP 123 screening evaluation for the 1973 airborne DU release from TA-3 gave a screening value of 4.4×10^{-4} Sv (44 mrem). This value exceeds the screening criterion without adjusting it to account for uncertainties, indicating further investigation into potential health risks is warranted. As with the evaluation for TA-21, the release value was used as reported by LANL and has not been adjusted in any way or independently verified.

It seems counterintuitive that DU releases would screen so much higher than ^{235}U, but that result reflects the large quantities of DU processed at Los Alamos over its history. DU was also expended in substantial quantities in dynamic experiments at firing sites such as TA-15 and TA-36.

To follow-up on the result of the DU screening, the maximum average air concentration values reported by LANL's ambient environmental air monitoring network for 1973 were evaluated in terms of the screening dose they represented. The maximum annual average reported for offsite locations was 0.2 ng m^{-3} (LASL 1974). This value was seen at three of the 26 off-site and perimeter monitoring stations: Acorn Street, Bandelier headquarters, and White Rock. The maximum annual average for the on-site monitors was 0.3 ng m^{-3}, measured at TA-52 (LASL 1974). Assuming the measured air concentration values reflected ^{235}U activity (the conservative choice), applying the NCRP Report No. 123 screening factor for ^{235}U to the maximum offsite average for 1973 (in consistent units) gave a screening dose of 5.4×10^{-6} Sv (0.54 mrem). This is well below the screening criterion of 1.67×10^{-4} Sv even if the order of magnitude adjustment is applied to account for uncertainties. Treating the measured concentration as ^{238}U would give an even lower screening dose.

The above evaluations do not paint a clear picture of the potential for health risks to Los Alamos residents from historical atmospheric releases of uranium. NCRP Report No. 123 screening evaluations have indicated enriched uranium releases were not significant in terms of potential risk relative to the 1 in 100,000 criterion selected, and showed releases of depleted uranium warranted further investigation. The ambient air monitoring data for 1973 did not suggest significant risk. None of these evaluations, however, consider releases from earlier in LANL's history. Earlier releases may have been much larger than those from the 1970s forward for which atmospheric effluent data are conveniently summarized.

Beyond the need to compile data from a large volume of individual references, asserting uranium releases from the earlier years is further complicated by the fact much of the available effluent data were reported in terms of gross alpha or beta activity, rather than for specific isotopes. These data would need to be evaluated using process knowledge to assign the gross measurements to specific isotopes. Further, the fact uranium releases were a chronic source of exposure involving a material strongly retained in the human body may warrant a more detailed evaluation than can be achieved through the screening methods used here. Thus, further investigation would be needed before a more conclusive assessment could be made of the potential for health risks to local residents from atmospheric uranium releases from Los Alamos.

Radioactive Lanthanum (RaLa) Operations

Barium/lanthanum is a mixture of ^{140}Ba and its daughter product ^{140}La . ^{140}La is the isotope that was used by LANL in the years between 1944 and 1962 as an aid in "hydrodynamic tests" conducted primarily to perfect the implosion process. ^{140}La has a 40-h half-life, a strong gamma emission, and "grew into" the ^{140}Ba that was produced in large quantities in the Clinton Pile at X-10 Site in Oak Ridge (Widner 2000, Widner and Flack 2002) and later at the Idaho National Engineering Laboratory. RaLa was used in implosion testing from 21 September 1944 through 6 March 1962 (Dummer et al. 1996). All RaLa implosion tests were conducted in Bayo Canyon (TA-10), which is shown in Fig. 9-1. Fig. 9-2 depicts the location of the buildings and firing points within TA-10.

Fig. 9-1 . Bayo Canyon Site, TA-10, in 1950. View is toward the west.
Photo ERID-018982 courtesy of LANL

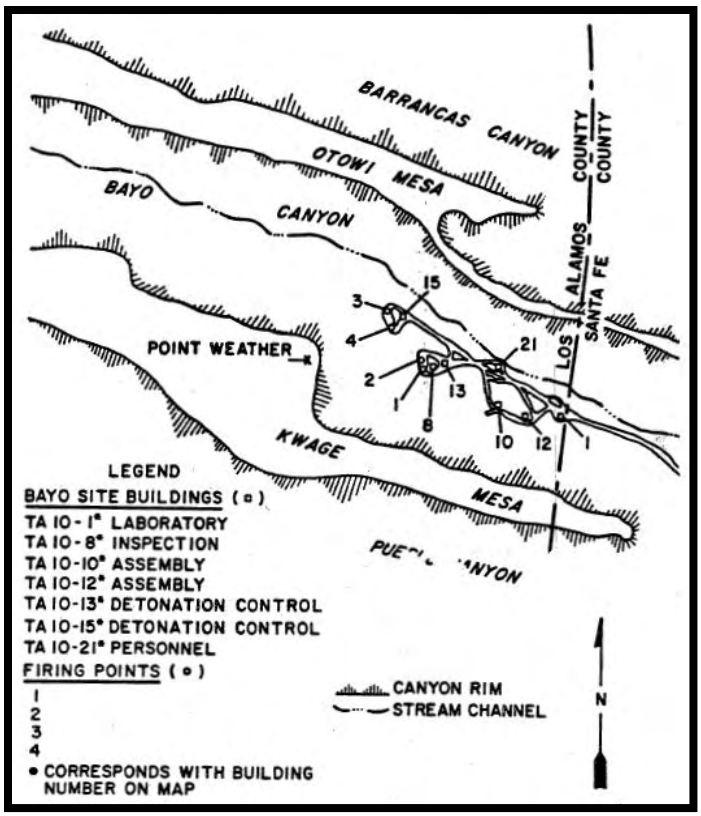

Fig. 9-2. Layout of TA-10, Bayo Canyon

From 1944 to 1950, the RaLa sources were prepared at the TA-10 Chemical Processing Building. Preparation of the RaLa sources was moved to TA-35 ("Ten Site") for the period of 1951 through 1963 and operated by group CMR-10. The ^{140}La sources were placed in shielded containers and trucked to the firing site where they were remotely loaded to the explosive test assemblies.

In order to obtain data on implosions, laboratory personnel had previously conceived a procedure by placing a gamma ray source at the center of a spherical implosion assembly. The emitted gamma rays would travel outward radially, through both the collapsing shell and the high explosive. The increased compression of the metallic shell during implosion would cause the gamma rays to be increasingly absorbed. The gamma rays would monitored by detectors set around the high explosives. The monitored data would provide data on the density changes in the collapsing shell, the time of collapse, the degree of compression, and symmetry by comparing the gamma rays intensity in different directions. A mixture of ^{140}Ba and ^{140}La would be used as the gamma ray source. Due to the potential post-experiment radioactive problems, ^{140}Ba was removed from the mixture.

^{140}La was initially provided by Oak Ridge as a mixture of ^{140}Ba and ^{140}La. Chemists at the TA-10 Chemical Process Building prepared RaLa sources by separating a solution containing the parent barium-

140 and other impurities such as ^{89}Sr and ^{90}Sr. The separated RaLa, along with unavoidable small amount of barium and strontium, was then encapsulated as specified by each experiment—sometimes in a metal sphere no larger than a match head (a pure 1,000-Ci ^{140}La source weighs 0.8 mg).

The explosive test assemblies used surrogate materials with mechanical properties similar to plutonium. Uranium, although used, had the disadvantage of being a strong gamma-ray absorber. Metals such as iron, copper, or cadmium were used, and most of the early shots employed cadmium (Dummer et al. 1996). The implosion assembly was surrounded initially by a number of ionization chambers (see Fig. 9-3) and later by scintillation detectors.

Fig. 9-3. Ionization chambers surrounding a RaLa shot on 13 May 1947

Table 9-2 lists, by year, the number of test shots and the amount of RaLa involved. A total of 254 tests were conducted between 1944 and 1962, with RaLa sources ranging in size from about 25 Ci to 7,090 Ci. The explosions resulted in the dispersion of the metallic shell (uranium or other material such as cadmium) and the radioactive RaLa and residual impurities such as ^{140}Ba and ^{90}Sr, in the form of aerosols and debris to the atmosphere and onto the ground.

The preparation of the RaLa conducted at TA-10 generated liquid and radioactive wastes which were disposed of in subsurface pits and leaching fields at the site. Almost 2 million curies of ^{140}Ba had been handled at TA-10 and TA-35 by the time the RaLa program was terminated in 1963. The TA-10 site was decommissioned by 1963 and transferred to Los Alamos County on July 1, 1967 (Mayfield et al. 1979). In addition to the release of RaLa, about 226 mCi of Strontium-90 was reported released; over 80% of the 226 mCi was released in seven shots in 1945 (Dummer et al. 1996). 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. The calculated dose for those who were in Los Alamos during the experiments ranges from 110 mrem to 450 mrem (Mayfield et al. 1979, Dummer et al. 1996, Kraig 1997). None of these dose assessments have been independently critiqued by the LAHDRA team.

Table 9-2. Annual quantities of radioactive lanthanum used in RaLa shots at Bayo Canyon

Year	Quantity of RaLa Used (Ci)	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

During March and early April 1950, the Air Force sought to conduct independent studies of airborne radioactivity (Dummer et al. 1996). They selected three of the 254 RaLa experiments (Shots 147, 148, and 149) and used a B-17 aircraft to track and measure radioactivity in the cloud resulting from them. In July 1950, LANL provided the Air Force with a static 400 Ci RaLa source for additional analysis. The source was transported to an area near Abiquiu, about 22 air miles north of Los Alamos, and seven passes were made by an airplane over the stationary source (Dummer et al. 1996).

Polonium Operations

Polonium was used in atomic bomb initiators, utilizing the (α,n) reaction of ^{210}Po and ^{9}Be to generate neutrons. In February 1945, schedule for polonium delivery from Monsanto to the Original Technical Area was increased to 100 Ci per month by June and 500 Ci per month by December (Hoddeson et al. 2004). At TA-1, polonium was handled in D Building, H Building, and Gamma Building. DP East Site began operation in September 1945 and contained Buildings 151, 152, and 153. Building 155 was

completed in December 1949. It is reported that "the well-designed DP polonium plant went into operation sooner than did the plutonium plant" [DP West site; TR 6704, Box 6 of 8]. The DP East Site facilities were used to process polonium and actinium and to produce initiators.

At DP East, Building 21-153 exhausted air from the main buildings at DP East, was constructed similarly to Building 12, and was in service until March 1970. The primary radioactive contaminant of this filter house was ^{227}Ac. Bldg. 153 had transitional plenums and filter housings for electromatic filters, two blowers, and two stacks. Stack monitoring data for DP East Site have been located in CMR-12 monthly progress reports starting in August 1945. The data are presented as average counts per minute per liter over each month for DP East Stack 1 and Stack 2. These data are for alpha-emitting radioactivity, with no isotopic composition indicated through at least 1949 (CMR-12 Progress Reports 1945-1949).

Polonium was also expended in explosive testing at Los Alamos. For example, TA-33 (Hot Point or HP) Site was developed in 1947 for the Laboratory's weapons testing group as a substitute test site for experiments that were being conducted at Trinity Site in southern New Mexico (McLain et al. 2001). These tests used conventional high explosives as well as uranium, beryllium, and polonium radiation sources. Experiments that were conducted primarily to verify designs of nuclear weapon initiators were performed in underground chambers and on surface firing pads. Additional tests were carried out at TA-33 firing sites equipped with large guns that fired projectiles into earthen berms. The documents associated with LAHDRA Repository Numbers 2375, 4519, 6523, and 7021 provide details of events at TA-33 that resulted in releases of polonium from tests at TA-33 in the 1950s.

On 8 January 1953, it was discovered that a mock fission source containing polonium and beryllium had ruptured at Pajarito Site (TA-18) and contamination had spread to the housing area (Shipman 1953). Possibly as much as 2 Ci of polonium was lost, that greater part of which was thought to have remained in and around the laboratory at Pajarito Site. However, "significant amounts [of polonium] were found in a number of homes." Among the items found to be contaminated in a "large number" of homes were shoes, clothing, floor coverings, vacuum cleaners, children's toys, and baby diapers. Rugs and upholstered furniture presented serious problems with decontamination.

On 3 August 1955 a Po:Be neutron source ruptured, resulting in the contamination of 150 staff members in Building SM-40 (Shipman 1955). A mock fission polonium source containing 25.2 Ci of polonium exploded in the basement of the Physics Building, and contamination was spread through out the building. It was 5 days or more before most personnel could return to work. The report states that air

samples for the area never exceeded "3 times tolerance." Although it was said that no activity reached homes or personal vehicles, a "few" government vehicles were contaminated.

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