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Final Project Report
TA-2 Water Boiler Reactor Decommissioning Project

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TA-2 Water Boiler Reactor Decommissioning Project

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FINAL PROJECT REPORT
TA-2 WATER BOILER REACTOR
DECOMMISSIONING PROJECT

by

Gilbert M. Montoya

ABSTRACT

This final report addresses the Phase II decommissioning of the Water Boiler Reactor, biological shield, other components within the biological shield, and piping pits in the floor of the reactor building. External structures and underground piping associated with the gaseous effluent (stack) line from Technical Area 2 (TA-2) Water Boiler Reactor were removed in 1985-1986 as Phase I of reactor decommissioning.[1] The cost of Phase II was approximately $623K. The decommissioning operation produced 173 m^3 of low-level solid radioactive waste and 35 m^3 of mixed waste.

1.0 INTRODUCTION

1.1 Los Alamos National Laboratory

Los Alamos National Laboratory (formerly Los Alamos Scientific Laboratory) was established in 1943. It has been operated by the University of California since then as a government-owned, contractor-operated (GOCO) facility for the Manhattan Engineering District of the US Army, the Atomic Energy Commission, the Energy Research and Development Administration, and now the Department of Energy. The primary mission of the Laboratory is research and development to support the nation's nuclear weapon program. Although weapons activity has always been and remains the largest single activity, the Laboratory has become a versatile and broadly based multiprogram research and development institution.

The Laboratory is located in north-central New Mexico about 60 air miles north of Albuquerque. Physical facilities include 50 sites, or technical areas, spread over 43 square miles.

1.2 History of the Facility

In the urgent wartime period of the Manhattan Project, research equipment was being hurriedly commandeered for Los Alamos from universities and other laboratories. This equipment was essential for obtaining data vital to the design of the first atomic bomb.

Enrico Fermi advocated construction at Los Alamos of what was to become the world's third reactor (the first two were Fermi's "pile" at Chicago's Stagg Field and the X-10 graphite reactor at Oak Ridge), the first homogeneous liquid-fuel reactor, and the first reactor to be fueled by uranium enriched in uranium-235. Eventually three versions were built, all based on the same concept. For security purposes, these reactors were given the code name "Water Boilers." The name was appropriate because, in the higher power versions, the fuel solution appeared to boil as hydrogen and oxygen bubbles were formed through decomposition of the water solvent by the energetic fission products.

The first Water Boiler was assembled late in 1943 in a building that still exists in Los Alamos Canyon, TA-2-1. Fuel for the reactor consumed the country's total supply of enriched uranium (14% ^{235}U). To help protect the material, two machine-gun posts were located at the site.

The reactor was called LOPO, for low power, because its power output was virtually zero. This feature simplified its design and construction and eliminated the need for shielding. The liquid fuel was contained in a 1-foot-diameter stainless steel sphere shell surrounded by neutron-reflecting blocks of beryllium oxide on a graphite base (Fig. 1). On the day that LOPO reached criticality, in May 1944, after one final addition of enriched uranium, Fermi was at the controls.

LOPO served the purposes for which it had been intended: determining the critical mass of a simple fuel configuration and testing a new reactor concept. LOPO was dismantled to make way for a second Water Boiler, HYPO (high power), that could be operated at power levels up to 5.5 kilowatts and thus could provide the strong source of neutrons the Laboratory needed for various measurements and studies. A massive concrete shield was built to surround the core and the large graphite thermal column that radiated from it. The reactor became operative in December 1944. Many of the key neutron measurements needed in the design of the early atomic bombs were made with HYPO. Figure 2 is a simplified cross section of HYPO.

By 1950 higher neutron fluxes were desirable. Consequently, extensive modifications were made to permit operation at power levels up to 35 kilowatts. This version of the Water Boiler was named SUPO, for super power. Completed in March 1951, the conversion from HYPO to SUPO included the following modifications.

- Three 20-foot-long stainless-steel cooling coils were installed in the 1-foot-diameter fuel vessel.
- The enrichment of the uranyl nitrate soup was increased from 14% to 88.7% ^{235}U.
- The beryllium oxide portion of the reflector was replaced with graphite to permit a more rapid and complete shutdown of the reactor.
- A gas recombination system was connected to the fuel vessel.

SUPO was operated almost daily until its deactivation in 1974.

1.3 Purpose of the Project

The purpose of the TA-2 Water Boiler Reactor Decommissioning Project (WBRDP) was to decontaminate and decommission (D&D) the Water Boiler Reactor inside Room 122 to provide reusable space at the TA-2 site and to eliminate the hazard of accidental intrusion into a contaminated structure.

1.4 Description of the Water Boiler Reactor (SUPO)

The reactor was used primarily as a source of neutrons rather than as an experiment in reactor design. The Water Boiler was an 88.7% enriched uranium homogeneous reactor consisting of a 1-ft-diameter stainless steel sphere (Fig. 3) filled with a water solution of uranyl nitrate and surrounded by a graphite neutron reflector.[2] Other major components included various shielding materials, a concrete biological shield 15 ft x 15 ft x 11 ft high,

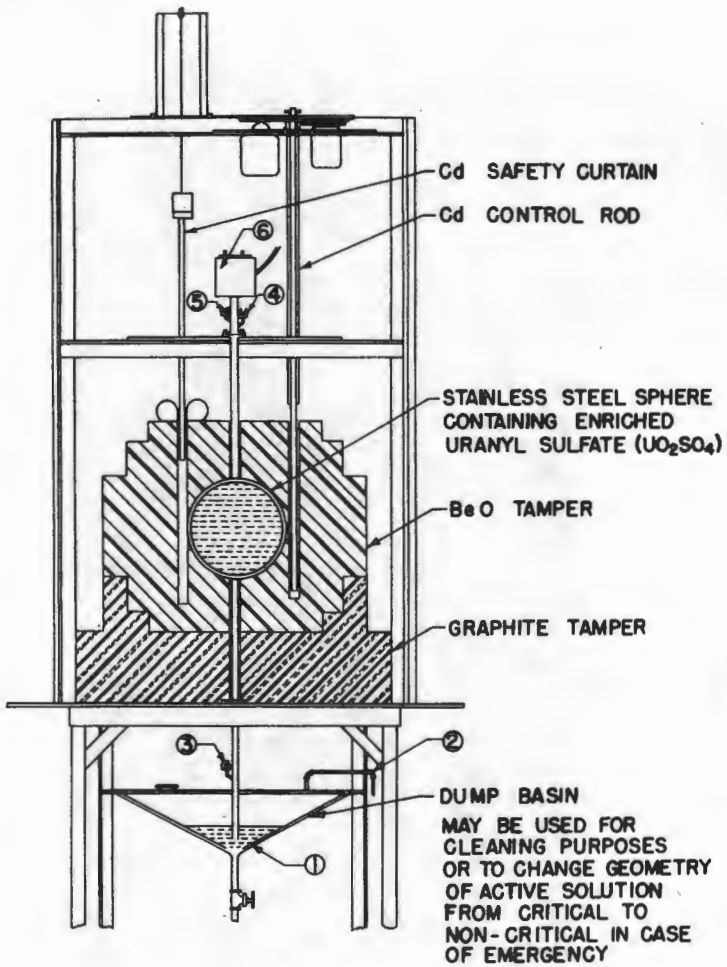

Figure 1. LOPO reactor.

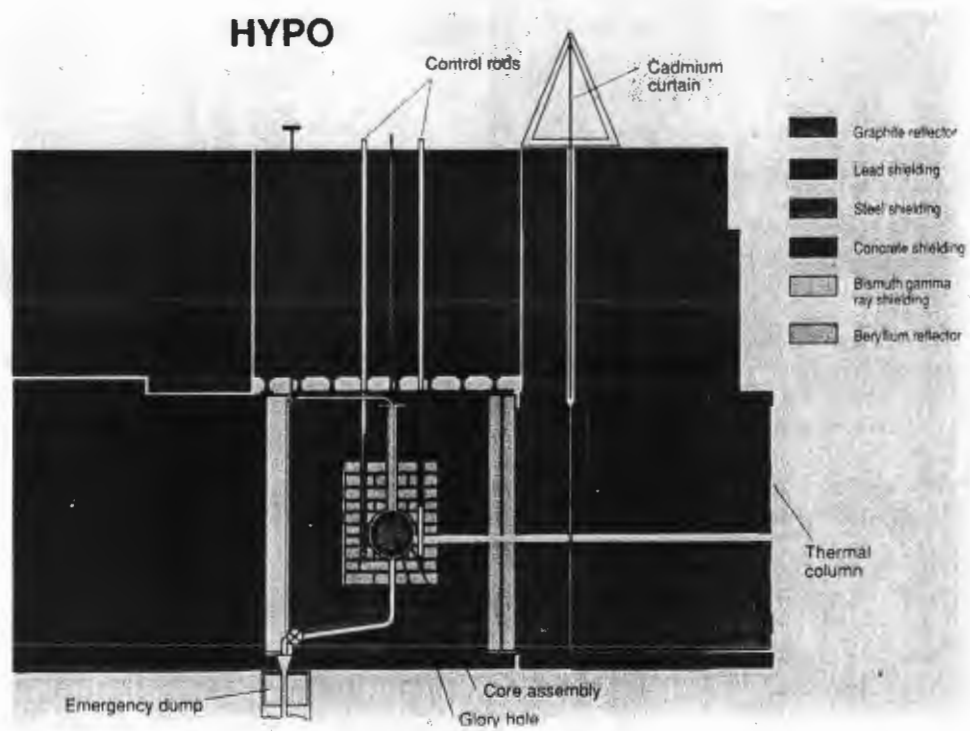

Figure 2. HYPO reactor.

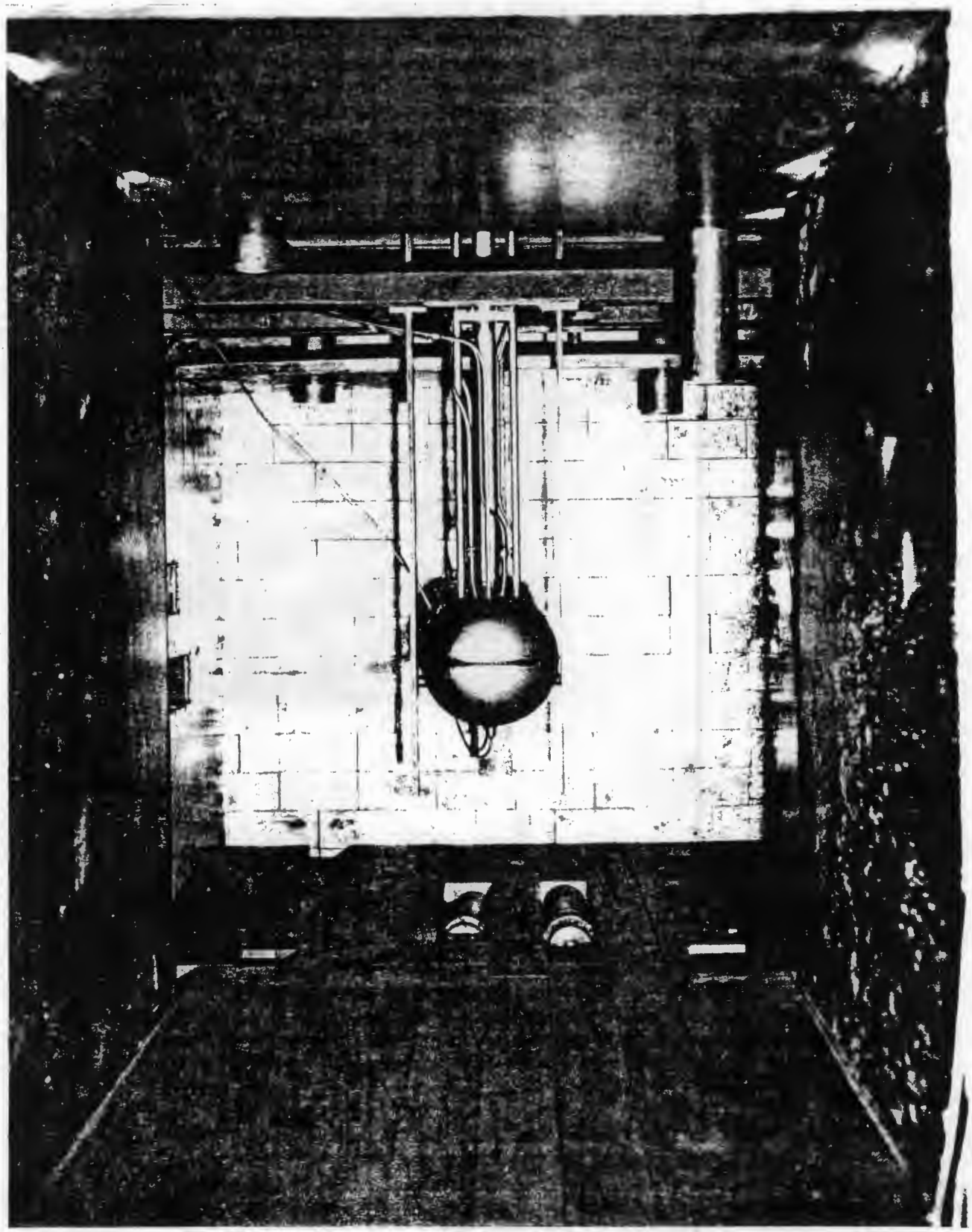

Figure 3. Stainless steel sphere.

two thermal columns (north and south), various access ports, and a gas recombination system. Photographs and cross sectional views of the reactor are shown in Figures 4-7.

1.5 Technical Objectives

The technical objectives of the WBRDP were to do the following:

- o demonstrate the safe and cost-effective dismantlement of a highly contaminated and activated nuclear-fueled reactor;
- o optimize the use of a dedicated subcontractor labor crew to induce a transfer of decommissioning experience; and
- o provide for technology transfer by generating project performance data and documenting the decommissioning experience for use in future decommissioning projects.

1.6 Project Summary

Conceptual and detailed engineering to lay the groundwork for the physical decommissioning for the project began in July 1988 and was completed in June 1989. World Services, formerly Pan Am World Services, is the on-site subcontractor to Los Alamos National Laboratory and was therefore the subcontractor for decommissioning operations. The Waste Management Group, HSE-7, and the Radiation Protection Group, HSE-1, provided site-specific health and safety indoctrination training and specific training on all reactor-related components. Physical decommissioning began in June 1989.

The general decommissioning approach was to do site characterization work that provided a thorough physical, chemical, and radiological assessment of the contamination at the site. This step was followed by removing the contaminated filter plenum and unstacking the graphite thermal columns and the removable shielding, including an 8-1/2-inch bismuth pier in both the north and south thermal columns; 1/2-inch boron carbide $(B_4C)^+$ concrete, and borax paraffin cans; paraffin; and 4-inch lead. Next the recombiner assembly, reactor vessel, and remaining shielding materials, including the concrete biological shield, were removed. Remedial action activities and final restoration were then completed. Physical decommissioning was completed in April 1990 and the room released to the Isotope and Nuclear Chemistry Division.

1.7 Primary Participants

US Department of Energy - WBRDP was a project under the Assistant Secretary for Nuclear Energy with program responsibilities assigned to the Division of Facility and Site Decommissioning Projects in the Office of Remedial Action and Waste Technology at the Headquarters of the Department of Energy (DOE-HQ). An on-site DOE Project Manager was responsible for project execution, implementation, and on-site administration.

Decommissioning operations subcontractor (DOS) - World Services was the DOS to the Laboratory, which provided all craft support in the decommissioning effort.

Other on-site organizations - Figure 8 shows organizational relationships among the project's major participants.

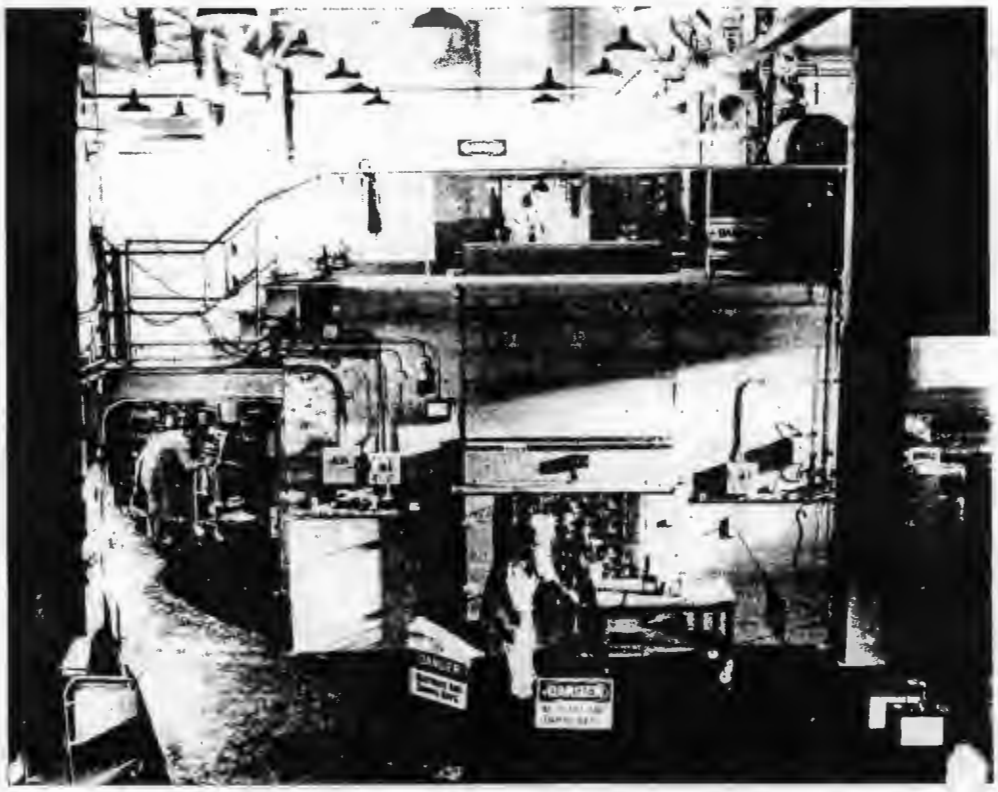

Figure 4. South face of the Water Boiler Reactor.

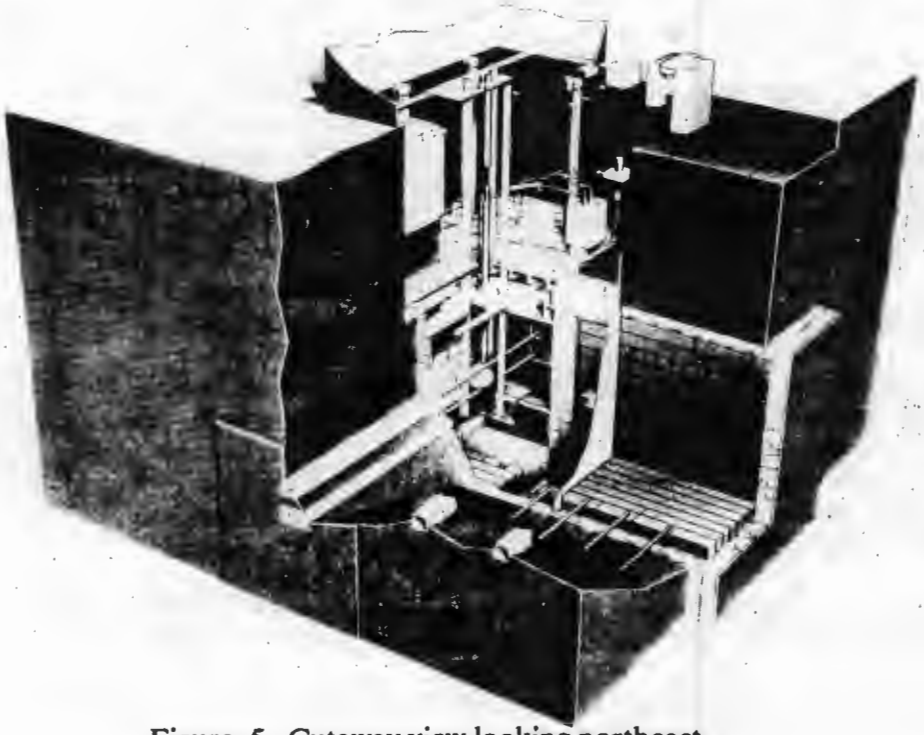

Figure 5. Cutaway view looking northeast.

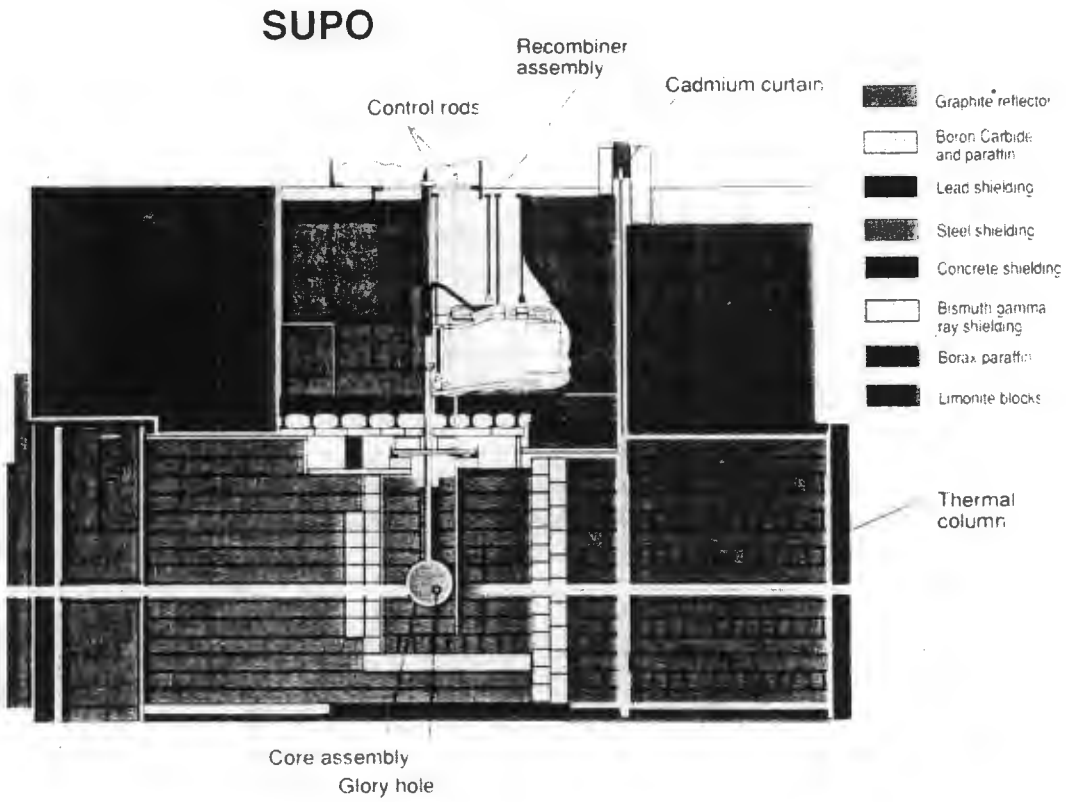

Figure 6. North-south cross section of the reactor.

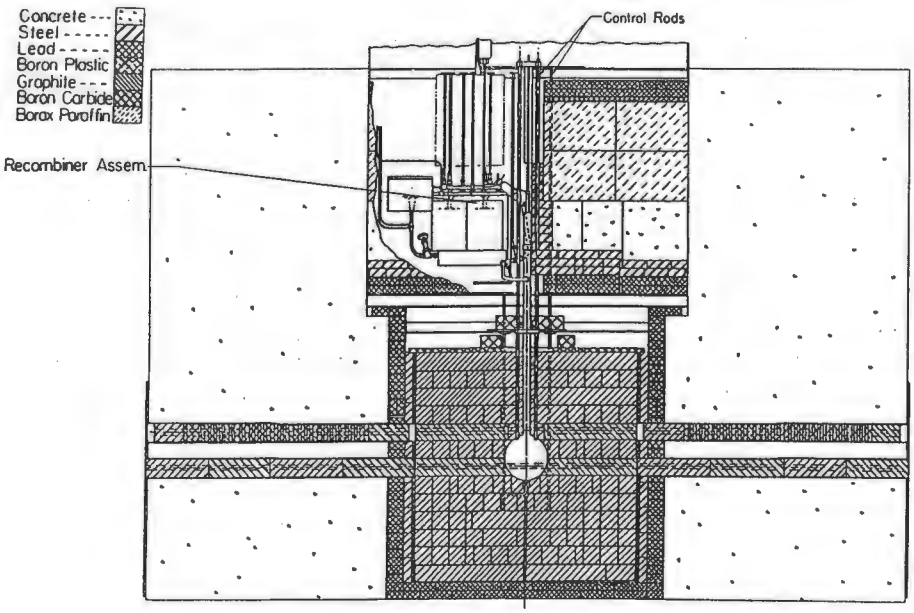

Figure 7. East-west vertical cross section.

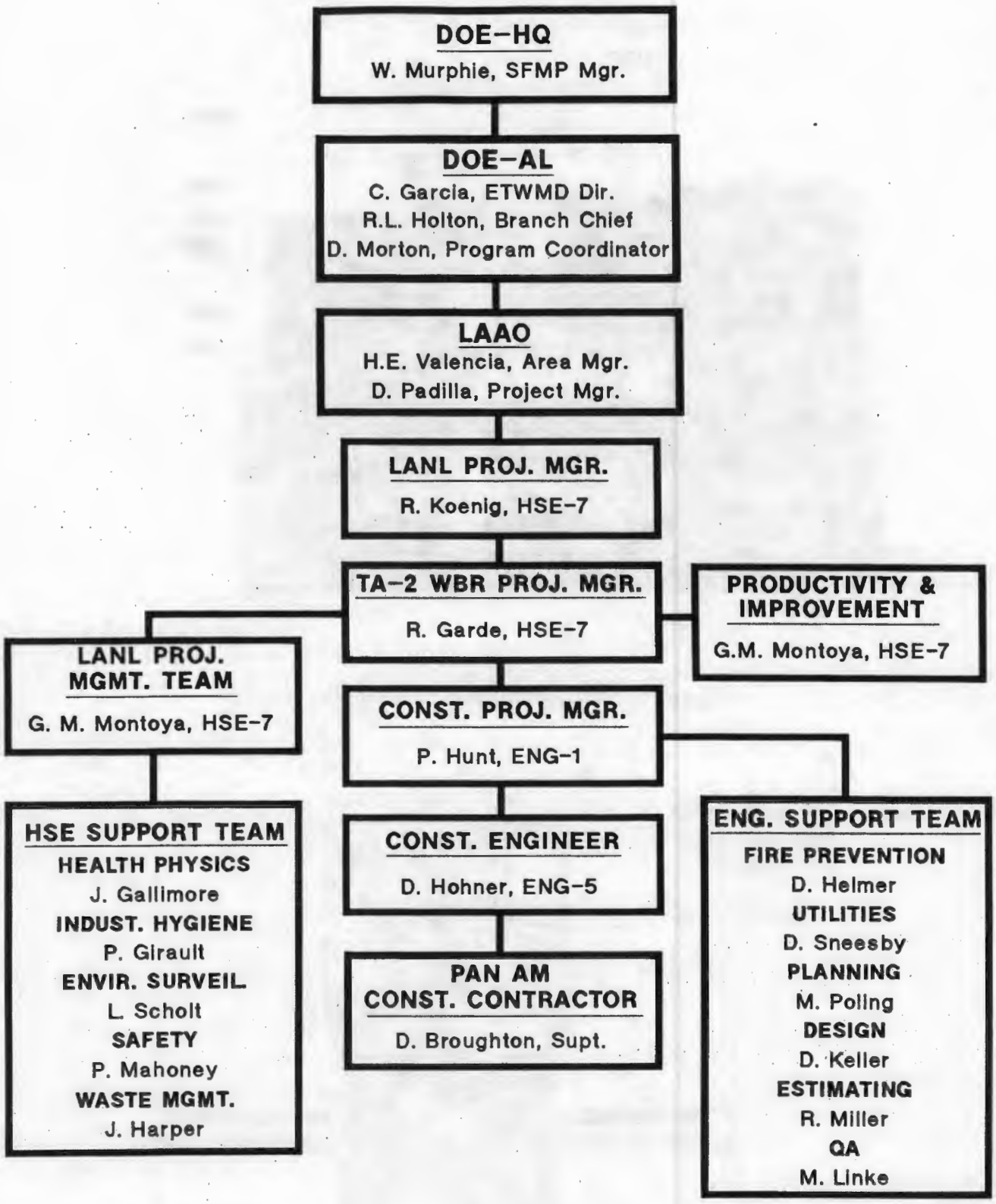

Figure 8. Project organization chart.

2.0 FACILITY DESCRIPTION AND RECOGNIZED HAZARDS

2.1 Description of TA-2-1-122

Figure 9 shows the location of TA-2, Omega Site. Figure 10 shows the layout of Building 1. TA-2 is isolated from the rest of the Laboratory because of its location in Los Alamos Canyon. No direct access to the site from other technical areas is available except through the Los Alamos Canyon Road. Room 122 houses the Water Boiler Reactor. The reactor and its biological shield structure and control room were housed in a frame building approximately 60 ft x 60 ft x 26 ft.

2.2 Recognized Hazards

Contamination from fission products was distributed throughout reactor-related systems. Neutron activation of the reactor vessel and nearby components ranged from 1 R/h to 150 R/h. Radiation surveys of floor tunnels indicated radiation fields to be less than 1 mR/h in accessible areas.

In addition to the common industrial hazards of fall, electrical shock, crushing, rotating machinery, and the like, another hazard in the facility was lead. Lead shot, brick, and plates were used for radiation shielding. A waste regulated under the Resource Conservation and Recovery Act (RCRA), the lead was disposed of under regulations of the state and the Environmental Protection Agency (EPA).

3.0 PROJECT MANAGEMENT

3.1 Project Cost and Schedule

WBRDP used DOE's Cost and Schedule Control System Criteria as the basis for complete integration of cost and schedule objectives and plans for the duration of the project. WBRDP also applied DOE Order 4700.1, Project Management System, which provided a uniform project control system for both Laboratory and the subcontractor and allowed for a totally integrated projectwide system.[3]

Project summary schedule - The overall project summary schedule was based on an operations schedule planned to begin in June 1989 and end in October 1989. Because of higher-than-anticipated radiation fields, the actual completion date for the operations was April 1990. Physical decommissioning took place over an eleven-month period.

Project costs - The total estimated cost was $500K. Because of higher-than-expected radiation fields, final costs were over budget by $123K for a total of $623K. Figure 11 shows an overview of major physical decommissioning activities costs. Table I shows the elements of the work breakdown structure (WBS). Table II shows project costs by WBS.

Figure 12 shows project costs and percent of total by elements of the WBS.

3.2 Radiological Controls

Radiological control program - Strict compliance with radiological control procedures was essential to minimize occupational radioactivity exposure to levels as low as reasonably achievable (ALARA) and to prevent spreading contamination to adjoining rooms.

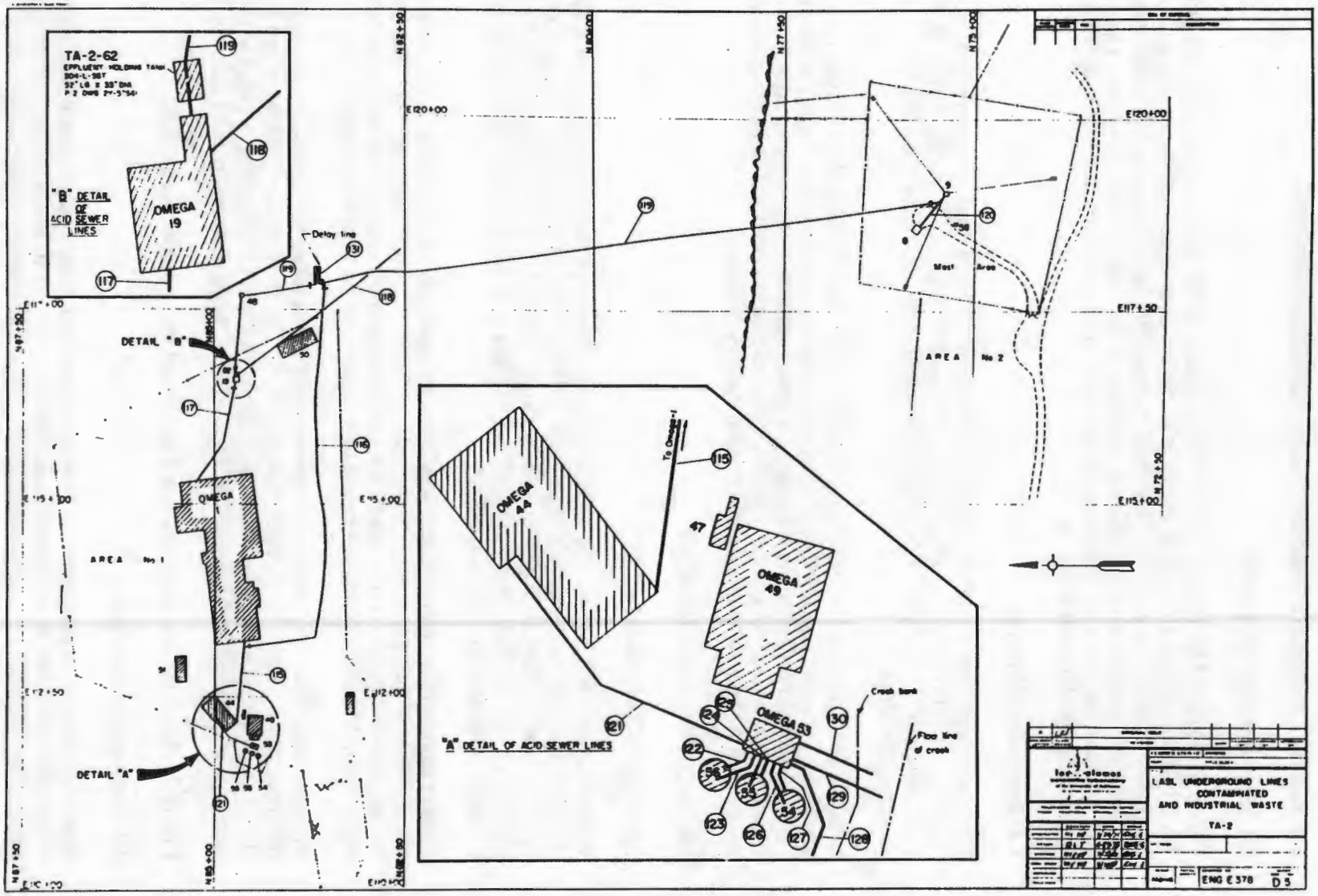

Figure 9. Site plan of TA-2.

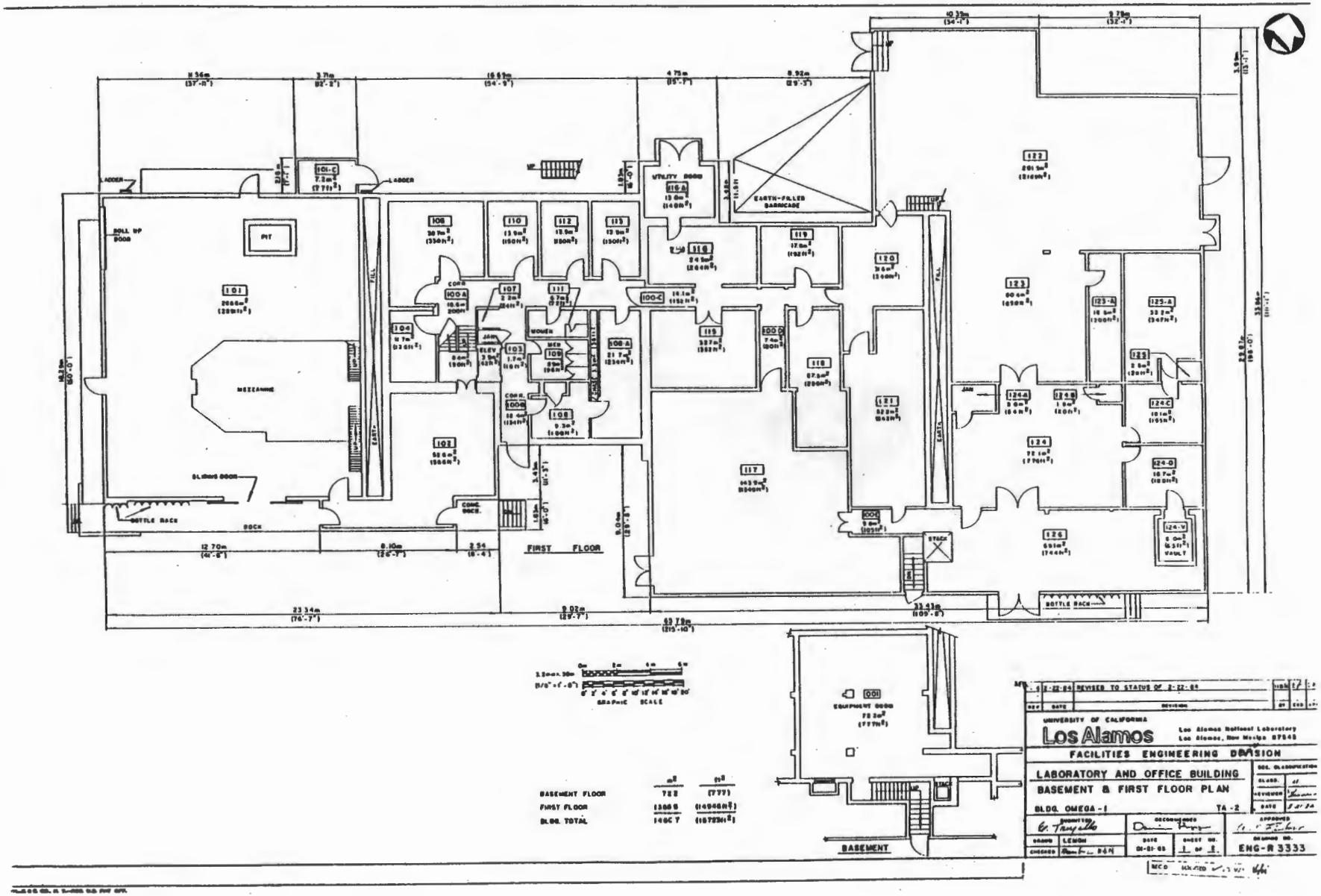

Figure 10. Layout of TA-2-1.

COST OF MAJOR PHYSICAL D&D ACTIVITIES
$K

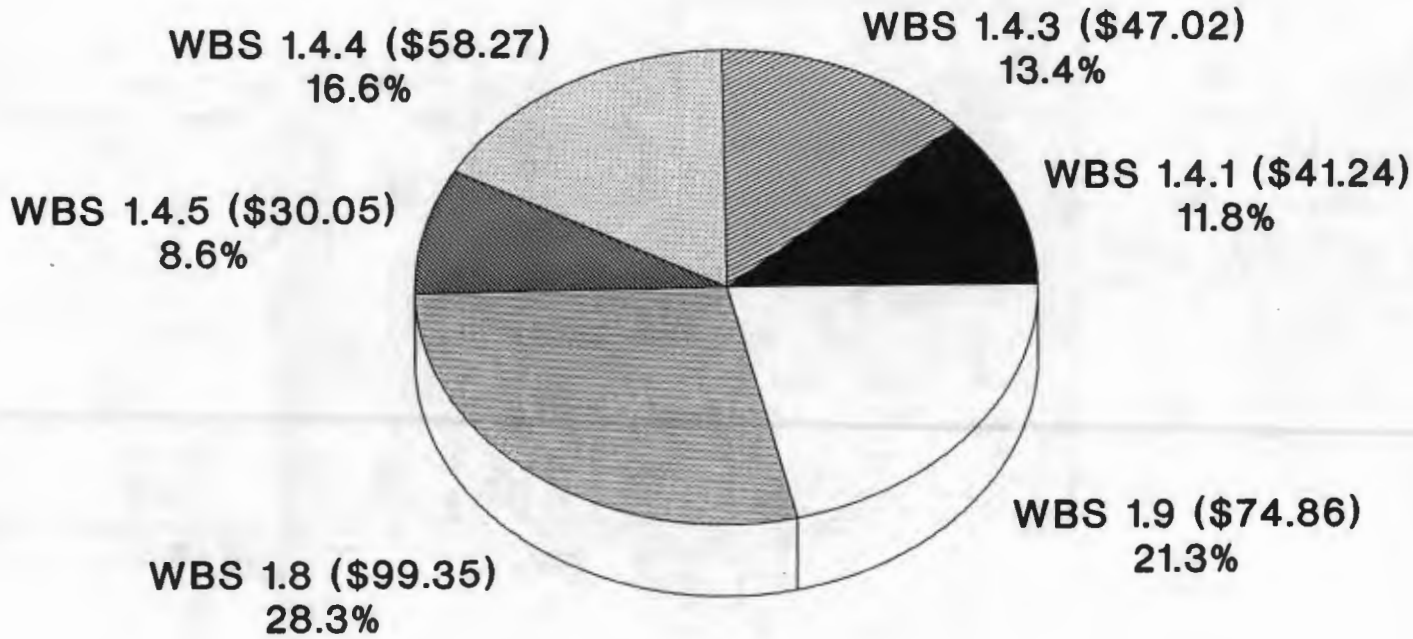

Figure 11. Cost of major physical D&D activities.

Table I. Project Work Breakdown Structure.

Level 1	Level 2	Level 3
1.0 Operations	1.1 Project support	1.4.1 Prepare for operations
	1.2 Engineering	1.4.2 Remove support system
	1.3 Procedure preparation	1.4.3 Unstack removable shielding
	1.4 Dismantlement	1.4.4 Remove reactor vessel and associated components
	1.5 Waste disposal	1.4.5 Demolish biological shield
	1.6 Health physics	1.4.6 Construction support
	1.7 Change control	
	1.8 Decontamination	
	1.9 Restoration	
	1.10 Closeout	
	1.11 Management reserve	

Table II. Project Costs by Work Breakdown Structure ($K).

WBS	ACTIVITY	FY89	FY90	TOTAL
1.1	project support	58.13	50.10	108.23
1.2	planning and engineering	3.80	0.00	3.80
1.4.1	preparation for operations	35.50	5.74	41.24
1.4.2	materials and equipment	50.15	29.85	80.00
1.4.3	unstack and remove shield	36.41	10.61	47.02
1.4.4	remove reactor and components	58.27	0.00	58.27
1.4.5	demolish biological shield	30.05	0.00	30.05
1.4.6	construction support	19.65	28.86	48.51
1.5	waste disposal	0.00	0.00	0.00
1.6	health physics	25.77	6.30	32.07
1.8	decontamination	0.10	99.25	99.35
1.9	restoration	0.05	62.81	62.86
1.10	closeout	0.00	12.00	12.00
Actual cost of work performed (ACWP)		**317.88**	**305.52**	**623.40**

PROJECT COSTS AND % OF TOTAL BY WBS
$K

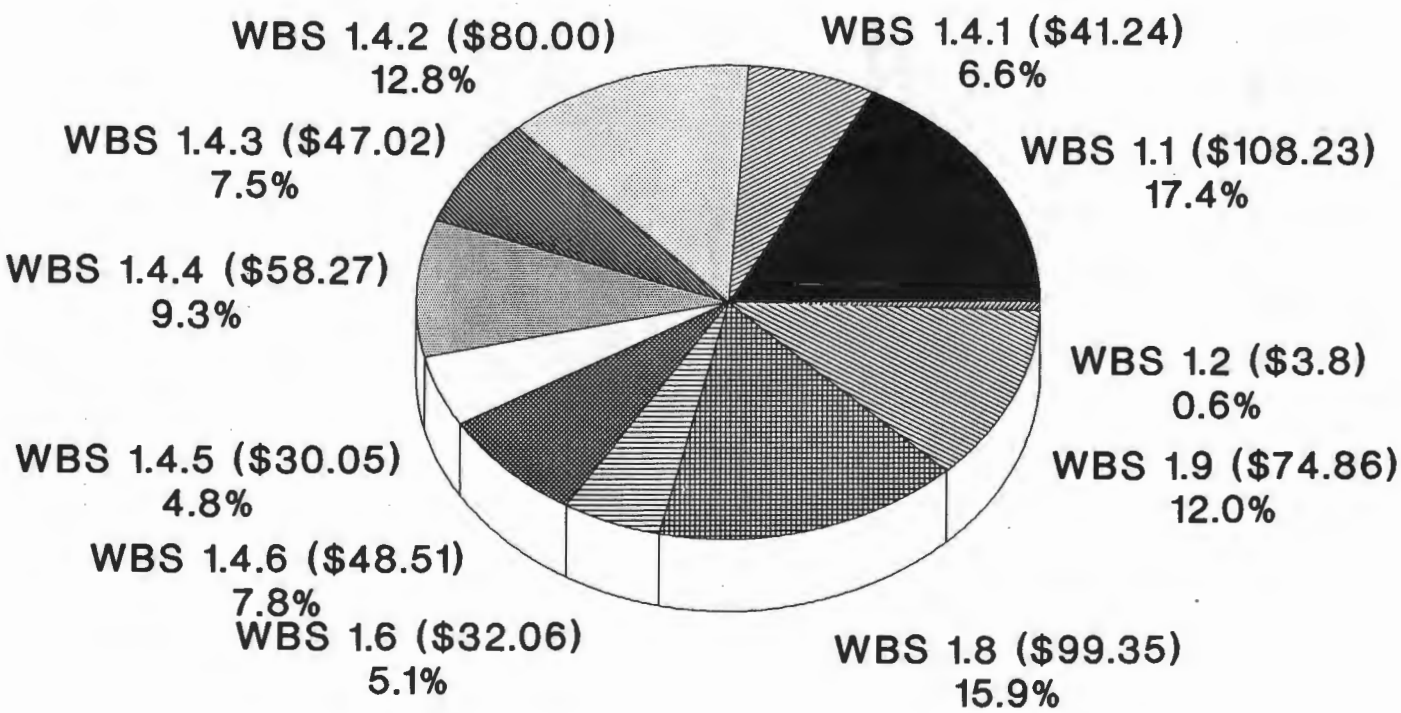

Figure 12. Project costs and percent of total by WBS.

A trained health physics technician (HPT) from the Radiation Protection Group, HSE-1, provided continuous surveillance of all decommissioning activities associated with the Water Boiler Reactor.

Special requirements for radiation protection of workers were specified under the Laboratory practice of issuing a Special Work Permit (SWP) for radiation work. See also Administrative Requirement (AR) 1-3, "Standard Operating Procedures and Special Work Permits," and AR 3-1, "Personnel Radiation Exposure Control" in the Environment, Safety, and Health (ES&H) Manual.[4,5] After reviewing expected conditions, the project management team initiated the Radiation Work Permit (RWP), and HSE-1 personnel received and approved it.

Work was monitored to ensure that the procedures were followed. HPTs surveyed and monitored the materials generated during the work. Exposure records, surveys, and work conditions were reviewed daily. The need for changes in procedures or radiological controls were evaluated on the basis of these reviews.

The HPTs used portable survey instruments to measure loose surface contamination, the general area and contact radiation levels, and airborne contamination concentrations. HPTs also ensured that personnel from World Services worked in a radiologically safe manner. Other routine tasks, including surveying, used protective clothing and source calibrating of instruments.

All personnel doing contaminated work wore protective clothing: rubber gloves, cloth coveralls, shoe covers, and hoods. When levels of contamination were high, a second set of protective clothing was required and supplemented with plastic or rubber apparel.

Personnel also wore full-face respirators when exposure to airborne activity was possible. The Industrial Hygiene Group, HSE-5, fitted each worker with respirators. The Laboratory is required to maintain a respirator program in accordance with standards of the Occupational Safety and Health Administration (OSHA). Engineered systems, such as high-efficiency particulate air (HEPA) -filtered ventilators and/or enclosures, kept airborne concentrations below limits established by the Laboratory's Health, Safety, and Environment Division and the ES&H Manual.

Personnel monitoring included monthly radiation badge dosimetry, pocket and finger ring dosimeters, bioassay analysis of urine specimens, and annual in vivo counting. Air in the work area was continuously sampled because of the significant potential for airborne contamination. Daily air samples were sent to the Health Physics Analysis Laboratory (HPAL) in HSE-1 for analysis of gross alpha and gross beta/gamma activity.

Nasal smears were taken after operations involving removal of any reactor-related component and were checked for beta/gamma activity.

WBRDP was completed without a release of radioactive material from the operations area or any worker overexposure. All personnel exposures were maintained within federal quarterly and annual limits. The ALARA principle, an operating principle that encourages keeping exposure to toxic materials and radiation to the lowest reasonably achievable level, was enforced in daily operations. Actual exposures received by D&D workers are discussed below.

No significant radiological impacts to the environment were caused by decommissioning work. Key factors in these achievements were the following:

- o management overview,
- o strict procedural controls,
- o prudent deployment of RWPs,
- o ongoing surveys,
- o employee training,
- o using dosimetric devices for exposure controls, and
- o daily task planning.

Occupational doses - The Project Management Plan (PMP) estimated a total dose over the life of the project of 27.3 man-rem. The actual total dose over the life of the project was 4.35 man-rem. This successful record was the result of using principles of ALARA, good planning, and coordination.

ALARA - Project policy was to maintain personnel exposure at ALARA levels. This practice is required in DOE Order 5480.11, "Environment, Safety, and Health Program for Department of Energy Operations": Chapter XI, Requirements for Radiation Protection, Edition 4(f).[6]

As a major management practice for ALARA, special attention was given to reviewing procedures, perfecting existing techniques, and observing work practices with an awareness of methods to reduce personnel exposure.

Preplanning of work tasks by the project management team and World Services included detailed work procedures with estimates of personnel exposures. The project management team reviewed critical operations. Observations by management personnel and HPTs ensured that procedures were followed, that radiological control practices were followed properly, and that changing conditions were properly addressed. Post-work reviews tracked accumulation of exposure for various activities to ascertain where improvements could be made and where experience obtained could be applied to related work. Work in potentially high exposure areas was preceded by several classroom and simulation training sessions so that workers became familiar with their predetermined tasks before entering the exposure area.

Key lessons learned in the application of ALARA at the Water Boiler Reactor Decommissioning project were the following:

- o to include requirements for ALARA and man-rem estimates for tasks with potential for significant exposure;
- o to review all procedures carefully; and
- o to monitor compliance of work with the procedures in the project management plan.

3.3 HSE Oversight

The Health, Safety, and Environment Division (HSE) administered implementation of industrial safety and hygiene procedures; provided personnel training; and ensured

compliance with health, safety, and environmental requirements of DOE orders and the Environmental Surveillance Group, HSE-8.

Safety - World Services Safety and the Safety and Risk Assessment Group, HSE-3, were responsible for the safe working conditions of the workers. The safety program included reviewing planned work procedures, surveillance of actual work practices, training, and technical support. World Services Safety provided first-aid training, job-specific training, safe lifting and rigging procedures, and procedures for accident prevention and investigation.

Industrial Hygiene - The Industrial Hygiene Group, HSE-5, provided technical support to the decommissioning effort in asbestos removal, lead removal, and dust and carbon monoxide sampling.

Environmental Protection - Environmental protection at the WBRDP consisted of controlling hazardous and radiological contaminants at the site and monitoring of the site perimeter by the Environmental Surveillance Group, HSE-8, to verify that there were no significant radiological effects. Objectives of environmental protection were to

- ensure that the WBRDP complied with applicable regulations and that exposures were ALARA and
- verify that any contaminants released to the environment did not pose a significant risk to the public and were representative of the concentrations expected.

3.4 Engineering

Engineering objectives for the WBRDP included applying safe, cost-effective decommissioning practices to fulfill the objective of the project. Engineering activities included establishing project work practices by developing project instructions, detailed procedures, administrative procedures, technical operations practices, engineering design activities, technical specification preparation for the task list, and input for the project schedule.

WBRDP Project Instructions - The project management team prepared and issued project instructions during special operations. These instructions provided the subcontractor with the daily project activities not otherwise covered in detailed technical procedures such as the project management plan and standard operating procedures (SOPs). Examples of project instructions are operational safety requirements, communication control during critical operations, and ALARA review.

Detailed procedures - The project management team developed the SOP "Removing, Packaging, and Transporting Contaminated Components Associated with the Water Boiler Reactor," which covered safety and engineering requirements.[7]

World Services Safety Plan - The subcontractor developed for its workers a health and safety plan specifically for the WBRDP. The contents of the plan were Scope, General Plan, Organization, Emergency Procedures, Accident Reporting, Fire Prevention and Protection, Traffic Control, Sanitation, Housekeeping, Environmental Protection, Personal Protective Equipment, Electrical Safety, and Specific Health and Safety Requirements. Details of the plan appear in "Health and Safety Plan for the TA-2 Water Boiler Reactor Decommissioning Project," World Services PSFT-1646.[8]

3.5 Quality Assurance

The quality assurance (QA) program was structured to conform with ANSI/ASME NQA-1, Quality Assurance Program Requirements for Nuclear Facilities, and DOE Order AL 5700.6B, "Quality Assurance."[9,10] To ensure the requisite quality of the overall project, the QA plan for the WBRDP established measures, procedures, and instructions for accomplishing the decommissioning activities. The QA plan ensured that the appropriate activities were done to establish and organize the program and that the following elements were included:

- o document control;
- o inspection and test control;
- o identification and control of items;
- o control of nonconforming items and services;
- o corrective actions;
- o control of measuring and test equipment; and
- o establishment and maintenance of quality assurance records.

Requirements and guidelines for these activities are specified in the Los Alamos Quality Assurance Manual for Engineering and Construction, which complies with the requirements of DOE AL 5700.6B.

3.6 Site Security

Security objectives were to control on-site entry into Room 122 by all persons and to prohibit unauthorized removal of government property.

Compliance with security requirements was enforced by security guards, who checked identification badges and deterred and reported any security violations. All personnel were required to comply with security requirements. Vehicles and personal property were subject to search before entering or leaving the site.

4.0 DECOMMISSIONING PROJECT ACTIVITIES

4.1 Goals

The goal of the TA-2 WBRDP was to decommission the Water Boiler Reactor safely and cost-effectively. The project was funded by the DOE Surplus Facilities Management Program (SFMP). The project was conducted under the requirements of the SFMP as stated in the SFMP Resource Manual 85-4 and SFMP Five-Year Plan 85-2.

4.2 Site Preparation

Site preparation work supported the safe and expeditious dismantling and removal of the Water Boiler Reactor. This work included the following:

- o setting up the World Services office;

- o installing support facilities for site workers;
- o establishing emergency readiness according to the Omega Site Emergency Plan; and
- o addressing safety concerns (alarms, paging system, ventilation, etc.).

Setting up the subcontractor office - Room 120 next to the Water Boiler facility was modified to provide temporary office space and support facilities to World Services.

Installing support facilities for site workers - A self-contained mobile decontamination unit accommodated the various crafts personnel involved. The unit was a change-out and showering area. A dining trailer was also acquired for all crafts personnel assigned to the decommissioning project.

A craft entry structure was provided as an access control point near Room 122. The area was a radiation monitoring checkpoint for all crafts personnel leaving the facility.

Establishing emergency readiness - Because TA-2 was occupied and the Omega West Reactor (OWR) was still operating, the Omega Site Emergency Plan was posted and in effect during all D&D activities. The objective of the plan was to minimize personnel injury and property damage in an accident or other emergency, such as fire, explosion, OWR excursion, or radioactivity release. The evacuation route and assembly point were well marked.

Safety concerns - Safety concerns in health physics and industrial safety required ongoing dialogue between project management and subcontractor personnel. Radiation and fire alarms were tested as part of the regular building maintenance program.

To control employee exposure to airborne contamination, fresh, clean air was circulated by a portable HEPA-filtered blower to replace the area's stale or contaminated air. The Industrial Hygiene Group, HSE-5, in cooperation with other groups in HSE Division, determined the ventilation needs for the workers assigned to the WBRDP.

4.3 Scope of Work for Decommissioning

The decommissioning of the Water Boiler Reactor consisted primarily of removing the FE-22 filter housing; the reactor vessel and its associated recombiner assembly and plumbing; two thermal columns; and various shielding materials, including bismuth, paraffin, steel, lead, and concrete, which were contained in a 5-ft-thick concrete biological shield. Contaminated concrete and soil beneath the biological shield and related utility tunnels were also removed. See also Subsection 3.5.

Removing the FE-22 filter housing - Excess gas that appeared in the recombiner system, whether internally generated or externally injected, was automatically bled into an exhaust (or "stack") line that ran underground to the top of an adjacent mesa and terminated in a 150-ft-high stack. Small amounts of radioactive gas escaped the reactor's biological shield and stack line and were collected and filtered with an exhaust arrangement (FE-22) that discharged the gas into the atmosphere above the reactor building. The filter housing was removed (Fig. 13) and disposed of at the Laboratory's solid waste disposal site.

Removing miscellaneous shielding materials - Shielding materials removed and disposed of included the following:

Figure 13. Demolition of FE-22 filtered exhaust arrangement.

- o limonite cans;
- o the 8-1/2-in. bismuth pier in the north and south thermal columns;
- o 1/2 in. of B_4C^+ paraffin; and
- o steel, lead, and a 5-ft thick steel reinforced concrete biological shield structure.

The graphite neutron reflector was also unstacked. Smears from shielding materials, primarily from ^{137}Cs, were > 100,000 dpm/100 cm^2. To contain contamination on shielding materials that were being removed, special plywood-silicone, airtight sealed containers were fabricated.

Removing the recombiner (catalyst) - The catalyst was a stainless steel rectangular can with inside dimensions of 6-1/8 in. x 6-7/8 in. x 5 in. (Fig. 14). Its primary function was to improve heat distribution, which in turn reduced radioactive off-gas velocity and kept both the reactor and stack line below the explosive concentration of gaseous fission products. The dose rate at contact on this component was 30 R/h. Removal was difficult because all the shielding materials encompassed the disconnection points. Personnel used lead blankets as spot shielding and long-handled tools so that they could work for extended periods. The recombiner was placed inside a 20 in. x 20 in. x 13 in. "suitcase cask" that contained 2 1/2 in. of lead shielding and weighed approximately 3 tons. Contact reading after packaging was 10 mR/h. The recombiner was taken into a hot cell at TA-3-29 where lead shielding was removed remotely before final disposition.

Removing the circulating blower - The blower kept static pressure negative to the stack to prevent radioactive gas leaks into the reactor room (Fig. 15). The dose rate at contact on the blower was 20 R/h. The blower was placed inside a 55-gallon drum and encased in concrete for disposal. Contact reading after packaging was 900 mR/h.

Removing the entrainment wool trap - The wool trap was located ahead of the blower to stop any entrained liquid carried over (Fig. 16). It consisted of a 3-1/2 in. x 3-1/2 in. x 17 in. rectangular stainless steel box filled with stainless steel wool. The wool trap had a contact dose rate of 150 R/h. Each step of disassembly was done quickly. With lead shielding and specially designed long-handled tools, personnel exposure was not a problem.

A disposal container measuring 6 in. x 8 in. x 32 in. was fabricated. The container was constructed of 3/8-in. steel plate, in box form, and lined with 4 inches of lead to reduce the exterior contact reading to approximately 15 mR/h.

Removing the after-condenser - The design requirements of the after-condenser were that it should simultaneously reduce the temperature of gas flowing through it and condense water (Fig. 17). The contact dose rate on the condenser was 20 R/h. The container for the condenser and related piping was constructed of corrugated metal pipe (CMP) measuring 3 ft in diameter by 6 ft long, with a CMP insert 2 ft in diameter by 4 ft long as the cavity. The outer CMP was filled with a 6-in. cold plug of concrete and 6-in. walls filled with concrete for shielding. The outside contact reading was 200 mR/h.

Removing the reactor vessel - The 1-ft-diameter sphere was formed by welding together two hemispheres of type 347 stainless steel. Inside the sphere were cooling coils where cooling water passed. The vessel also had a glory hole that enabled an operator to measure the neutron flux. The contact dose rates were 17.5 R/h on the top side, and 22 R/h on the bottom. A battery magnet with a load capacity of 5000 lb. was used to remove large sections of steel shielding around the vessel area. Two 6-ft extensions for a drill bit and

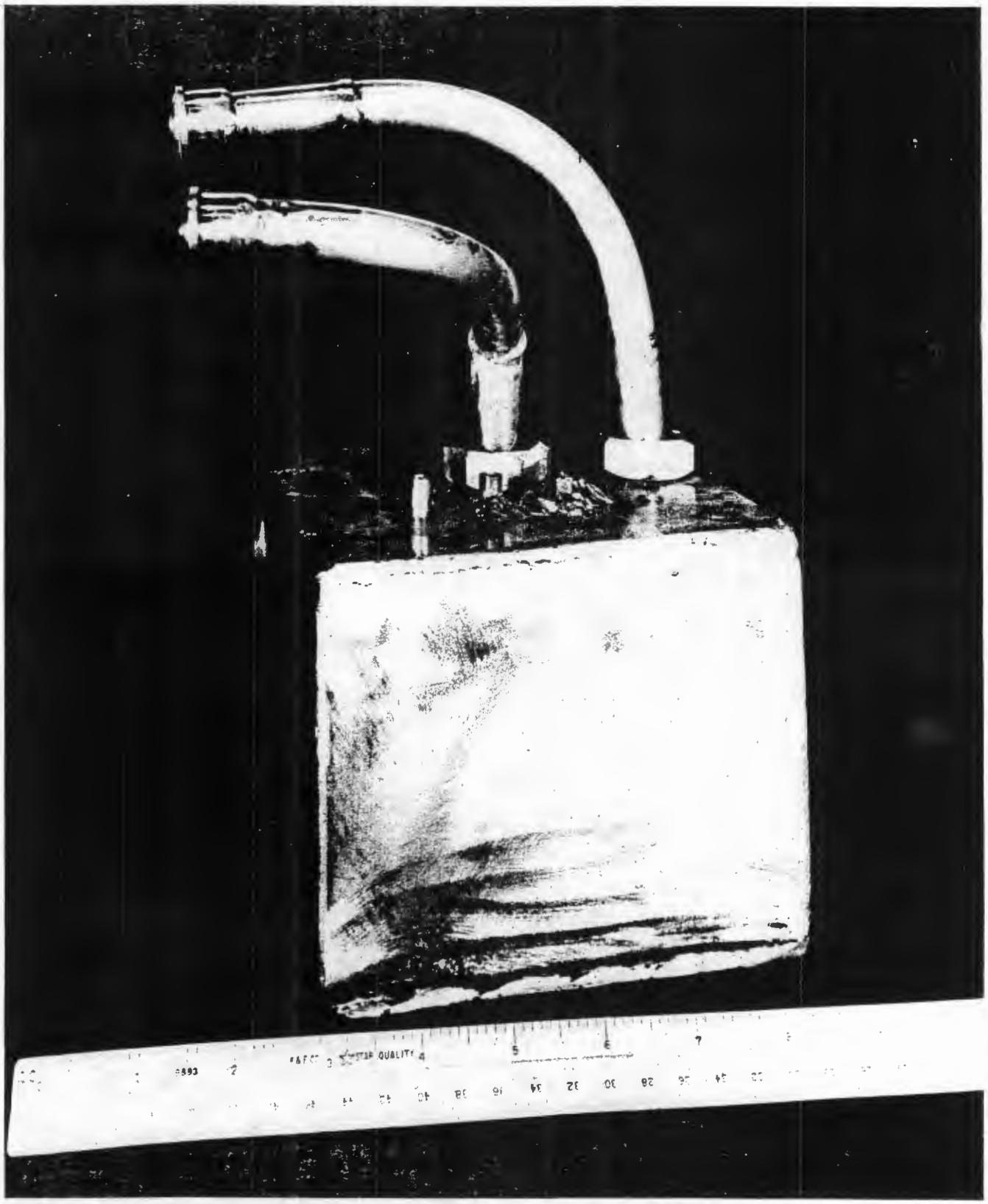

Figure 14. Stainless steel recombiner.

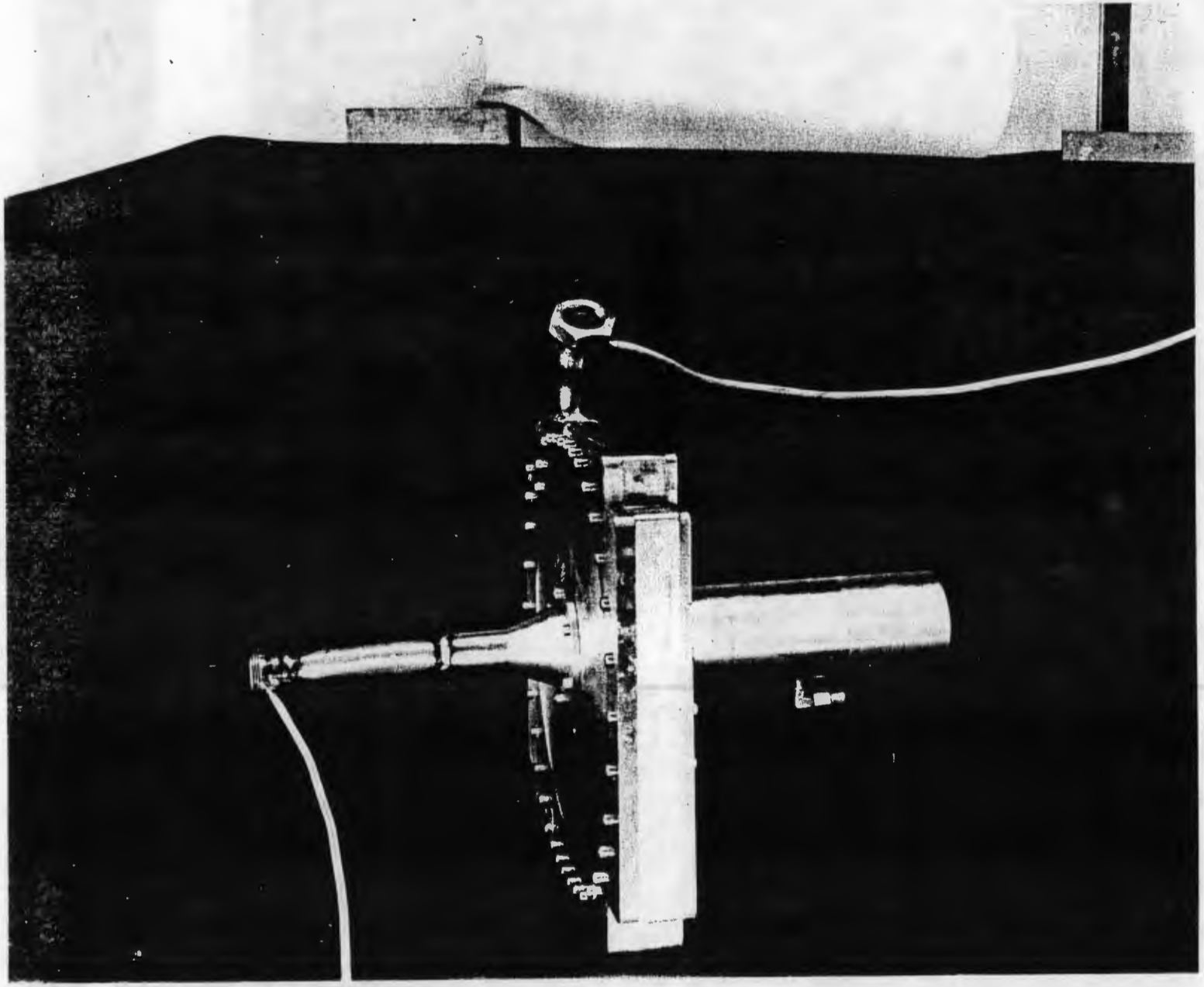

Figure 15. T[illegible]irculating blower.

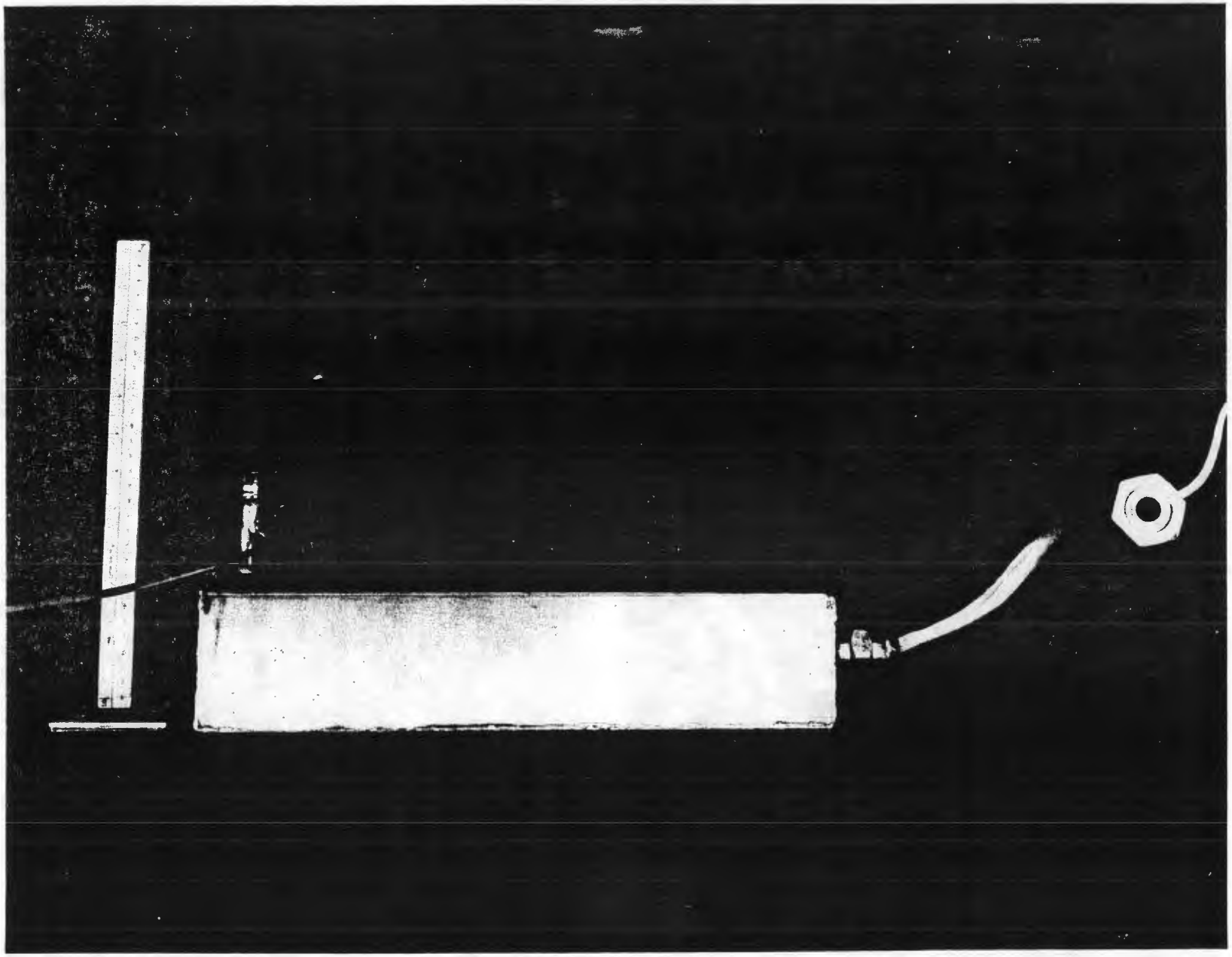

Figure 16. The entrainment wool trap.

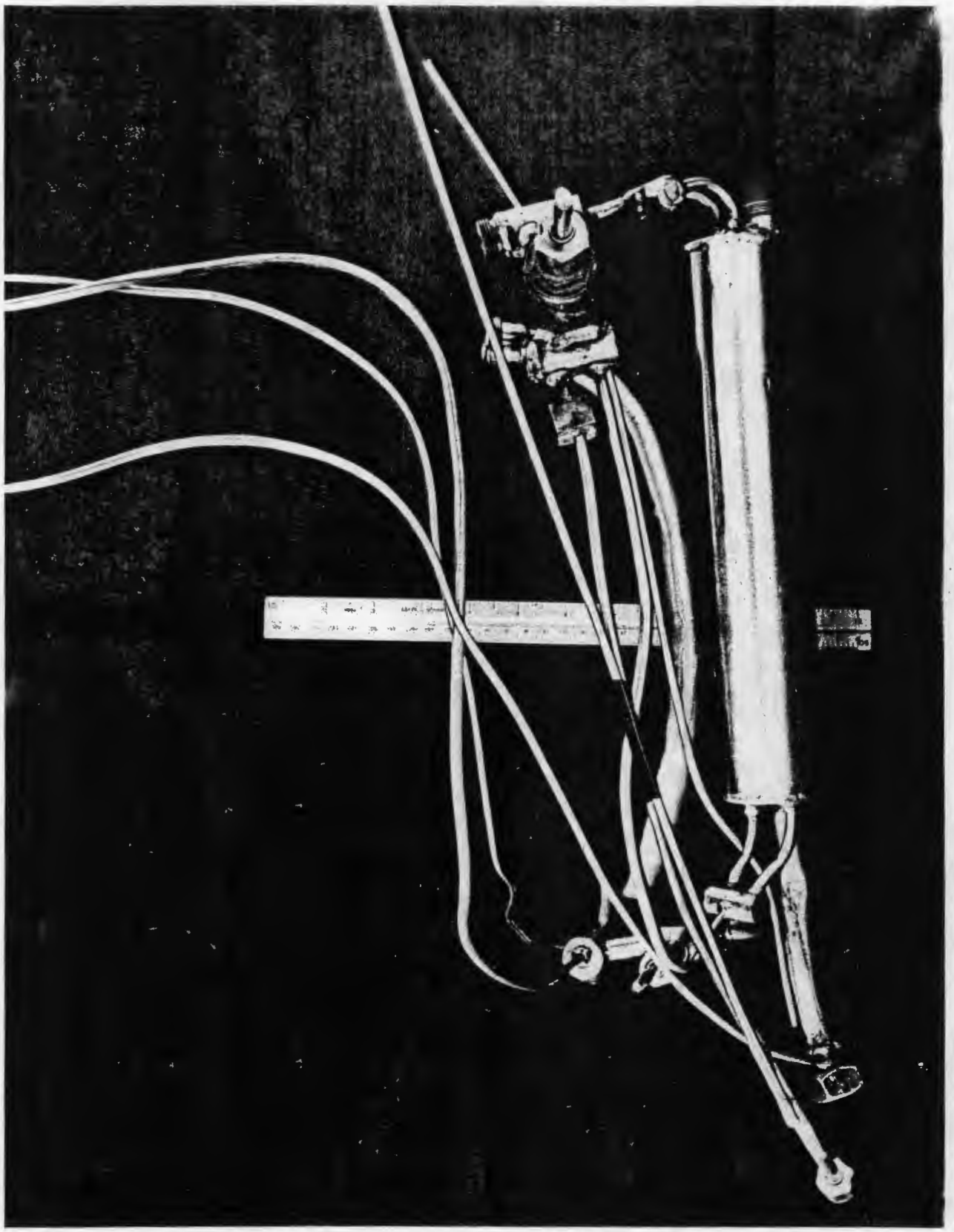

Figure 17. The after-condenser.

fabricated for remotely removing graphite that completely encircled the reactor vessel. The extensions were operated with a 1/2-in. variable speed drill. This procedure demonstrated a useful technique in reducing unnecessary personnel exposure. A 6 ft x 6 ft x 8 ft 35-ton steel cask was used to transport the vessel to the Laboratory's solid waste disposal site (Fig. 18).

Removing the 15 ft x 15 ft x 11 ft concrete biological shield - An attempt was made to remove the 5-ft. thick steel-reinforced concrete biological shield without creating unnecessary dust. A star drill was used to bore holes at systematic intervals; holes were filled with "s-mite," an expanding medium, so that the concrete would be broken. This attempt failed because of the considerable amount of reinforced steel used in the concrete at the time of construction. The alternative consisted of using three jackhammers to break up the concrete shield (Fig. 19). Airborne contamination was kept at a minimum by painting all accessible surfaces inside the biological shield, and using a light spray of water during the jackhammering. This method was labor intensive and time consuming but the only alternative. A major cleanup of contaminated dust and debris followed.

Removing the asbestos floor tile - Approximately 2000 ft^2 of asbestos floor tile was removed as part of the activities for post-remedial action. The subcontractor provided all site-specific training of personnel in asbestos removal.

4.4 Specifically Designed Tools and Techniques Used to Remove Highly Activated Components

Specially designed tools were fabricated on-site to safely and remotely remove highly activated components. Conventional tools with extensions were also used for remote operation. The tools enabled craft personnel to work for greater periods without unnecessary exposure from the high radiation field. Portable lead shielding was also used during the removal of the recombiner assembly.

Numerous proven techniques to keep personnel exposure at acceptable limits were used:

- lead blankets;
- specially designed waste containers that provided the necessary shielding;
- fixed rigging (steel chokers, ropes, and nylon straps) placed on components upon removal to facilitate disposal; and
- an overhead crane and a magnet with a 5000-lb. lifting capacity to enable the crew to remove the 200-lb. steel plates that exposed the top of the reactor vessel.

4.5 Packaging, Transportation, and Disposal of Wastes

All radioactive solid wastes were packaged and labeled to comply with the requirements of HSE-7, Waste Management, as described in the Laboratory's *Environment, Safety, and Health Manual* and in the *On-Site Transportation Manual*.[11]

Packaging - Contact-handled waste packages were limited to a maximum surface dose rate of 200 mR/h. Because of the highly activated components, up to 150 R/h, associated with the WBRDP, special approval from the Hazardous Material Packaging Section of the Safety and Risk Assessment Group, HSE-3, was requested and approved. The radiation limits were raised to 1 R/h at contact with packaging.

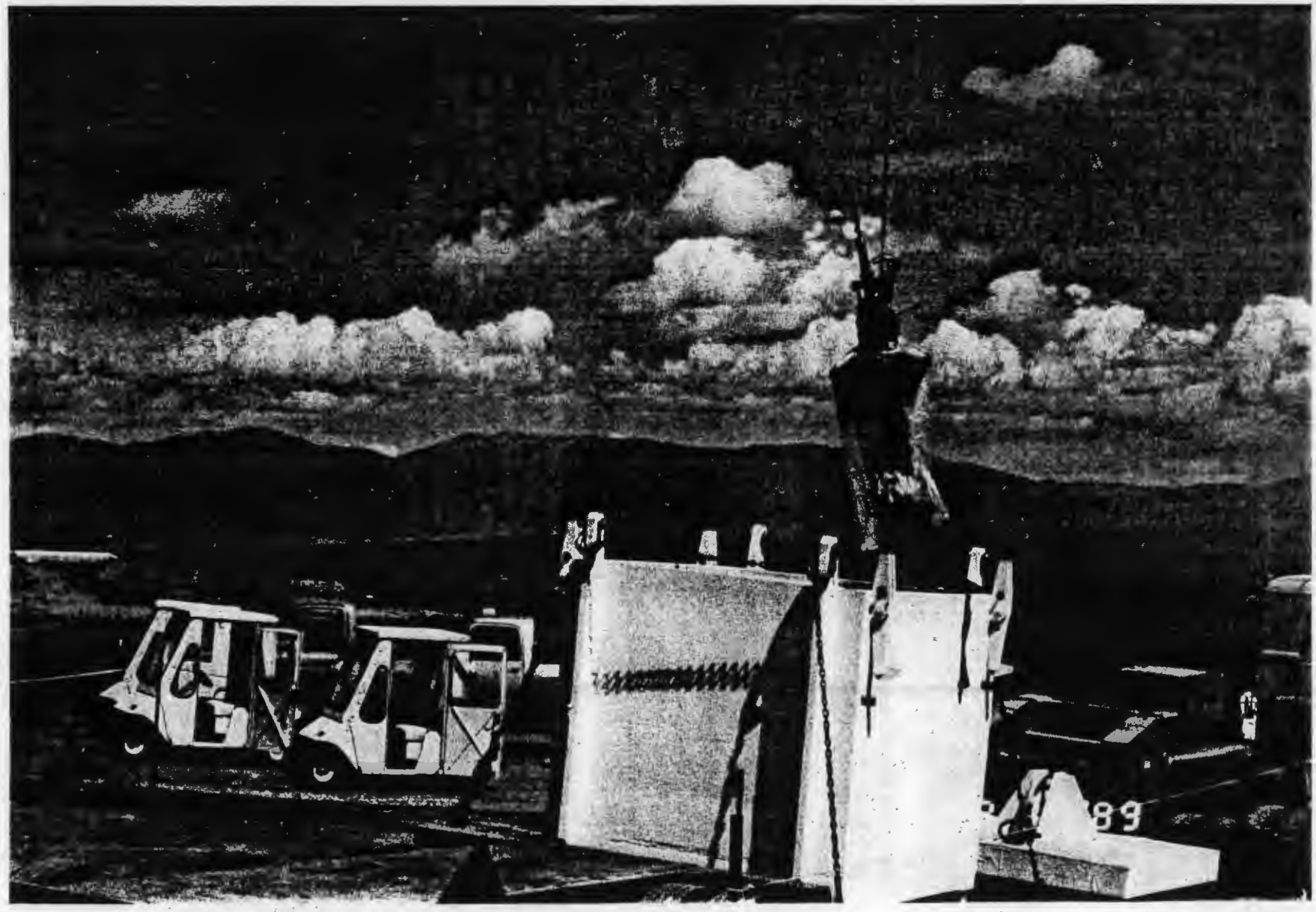

Figure 18. Steel transport cask.

Figure 19. Concrete biological shield broken with jackhammers.

Highly activated components, such as the recombiner assembly, reactor vessel, and associated piping, were placed inside specially fabricated metal containers consisting of either steel, lead, or concrete or a combination of these (Fig. 20).

Transportation - All waste loads were secured and covered for shipment to the waste disposal site, TA-54, Area G. The HSE-1 health physics surveyor (HPS) signed the Radioactive Waste Disposal Form only after approving the loading and securing of the waste load. Waste was sent to TA-54 only during hours when traffic was not expected to be heavy. An official HSE-1 escort vehicle was used when transporting highly activated components to the waste disposal site.

Disposal of wastes - Low-level radioactive solid waste generated by the WBRDP was either buried in pits or placed in shafts at TA-54, Area G (Fig. 21 and 22). Burial in pits consists of covering the waste in the pits with a meter of uncontaminated soil and revegetating the disposal area. Disposal in shafts consisted of lowering the waste package down a 65-ft shaft.

All mixed waste was stored at TA-54, Area G, in accordance with applicable regulatory requirements. See also AR 10-3, "Chemical, Hazardous, and Mixed Waste," in the Laboratory's *Environment, Safety, and Health Manual.*[12]

5.0 SITE RELEASE PROGRAM

To release a successfully decommissioned facility or site from the SFMP, it is necessary to verify and, in some cases, certify that the decontamination has been completed according to the criteria established for the project.

For complete details of post-remedial activities, refer to G. M. Montoya, "Post-Remedial Action Report for the Water Boiler Reactor, Los Alamos, New Mexico."[13]

5.1 Remedial Action Guidelines

The upper-limit concentration guides were derived to ensure conformance with the requirement that no member of the operating group (INC-5, Research Reactor Group) receives more than 100 mrem/y total effective dose commitment above background because of exposure to residual contamination. Every effort was made to ensure that actual doses to the room occupants were as far below the basic limit as is reasonably achievable. As low as reasonably achievable (ALARA) is the policy of reducing personnel radiation exposures to the lowest levels commensurate with sound economics and operating practices. The Environmental Surveillance Group, HSE-8, developed appropriate guidelines based on scenarios suggested by SFMP in *A Manual for Implementing Residual Radioactive Material Guidelines.*[14]

The guidelines for upper-limit concentration used in the WBRDP were as follows.

Surface contamination criteria - Analysis of concrete and soil samples by the Health and Environmental Chemistry Group, HSE-9, determined that 75% of surface contamination at the Water Boiler Project was attributed to ^{137}Cs, which would have an average allowable total surface contamination of 5000 dpm/100 cm^2 (average); 15,000 dpm/100 cm^2 (maximum); and 1000 dpm/100 cm^2 (removable). See Appendix F in the SFMP Resource Manual. The remaining 25% was attributed to additional radionuclides identified, including ^{152}Eu, ^{60}Co, and ^{90}Sr. Because ^{90}Sr guidelines differ from ^{137}Cs guidelines (Appendix B, Table II), the 75%-25% ratio was considered. Thus, the guidelines used for all surfaces were as follows: 2500 dpm/100 cm^2 (average); 7500 dpm/100 cm^2 (maximum);

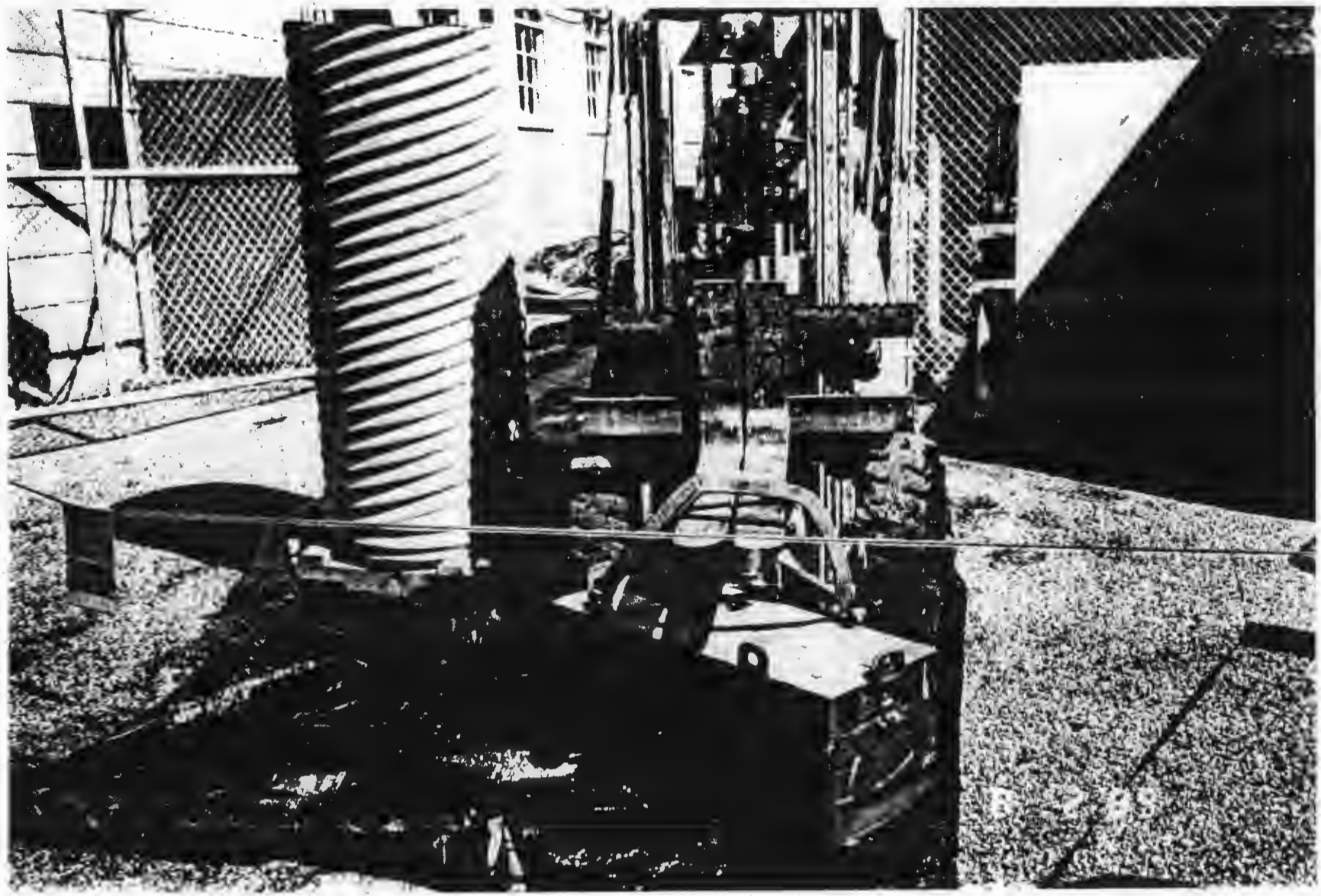

Figure 20. Specially fabricated waste transport containers.

Figure 21. Waste being emplaced in a disposal pit.

Figure 22. Highly activated waste emplaced in a disposal shaft.

all surfaces were as follows: 2500 dpm/100 cm^2 (average); 7500 dpm/100 cm^2 (maximum); and 500 dpm/100 cm^2 (removable). The Laboratory's Health and Environmental Chemistry Group, HSE-9, provided and maintains information that supports the derived values, for example, gamma spectroscopy and ^{90}Sr results.

Soil contamination - Based on field surveys, ^{137}Cs is the predominant radionuclide in the soil; thus, the cleanup criteria for soil exposed beneath the slab inside Room 122 were developed primarily for this radionuclide, though ^{152}Eu and ^{90}Sr were also present. The code for residual radioactive materials guidelines (RESRAD) for ^{137}Cs yielded a cleanup guide of 70 pCi/g, assuming no cover on the contaminated area. Attenuation of direct gamma photons by a new 4-in. poured concrete floor would increase this guide even more. The survey team from Oak Ridge Associated Universities (ORAU) also identified ^{152}Eu and ^{90}Sr in soil samples collected during the final independent verification survey. See also L. Soholt, "Plan for Environmental Sampling, Removal of Contaminated Soil Associated with the Water Boiler Reactor, TA-2, Los Alamos National Laboratory, Los Alamos, New Mexico." Table III includes data for all radionuclides that were identified inside Room 122.

5.2 Remedial Action

After the determination that the Water Boiler Reactor should be decommissioned and decontaminated, the reactor was designated for remedial action. Because the Water Boiler Reactor was known to be contaminated with radioactive materials because of program activities by the Office of Nuclear Energy (NE), the facility was accepted into the SFMP. Radiological surveys determined that Room 122 had isolated areas that would require remedial action. Surface contamination was heavy on the floor surface where the biological shield was removed, an area of approximately 250 ft^2. The soil in one area, the utility trench (sand trap), was found to be contaminated with ^{137}Cs in concentrations greater than 850 pCi/g. Furthermore, a utility trench inside Room 122 was found to contain many lead plates and required the removal of approximately 2 m^3 of soil (Fig. 23).

Remedial action activities - Three types of remedial action were done at the Water Boiler Reactor to remove radioactive contamination.

The first was decontaminating the floor surfaces having removable contamination where the biological shield was removed. The floor surfaces were vacuumed with a high-efficiency filtered vacuum cleaner or cleaned with a wet cloth.

The second was decontaminating floor surfaces having fixed contamination by scabbling and jackhammering the areas of contamination (Fig. 24). In some places, the concrete was saw-cut along joints or cracks to remove all residual contamination.

The third involved removing contaminated soil with a shovel at various locations, including the reactor pit; sand trap; utility tunnel, which was also contaminated with lead residual; and various locations throughout the biological shield area.

Waste from all these remedial action activities was placed in 55-gal. steel drums for disposal or proper storage. All the water generated from the remedial action activities was placed in an approved 250-gal. tank and transported to the liquid waste treatment plant, TA-50-1, for treatment.

Contamination control during remedial action - During remedial action operations, measures were taken to prevent the spread of contamination and to control exposure rates of the workers. Measures were taken to monitor airborne radioactivity resulting primarily

Table III. Soil Concentration Guidelines Based on a Radiation Standard of 100 mrem/y Total Committed Effective Dose Equivalent.

Parameter	Surface	Subsurface[a]
	(pCi/g above Background)	
^{60}Co	10	80
^{137}Cs	70	5000
^{152}Eu	30	100
^{90}Sr	90	1000

[a]Subsurface soils are considered to be below the first 0.15 m.

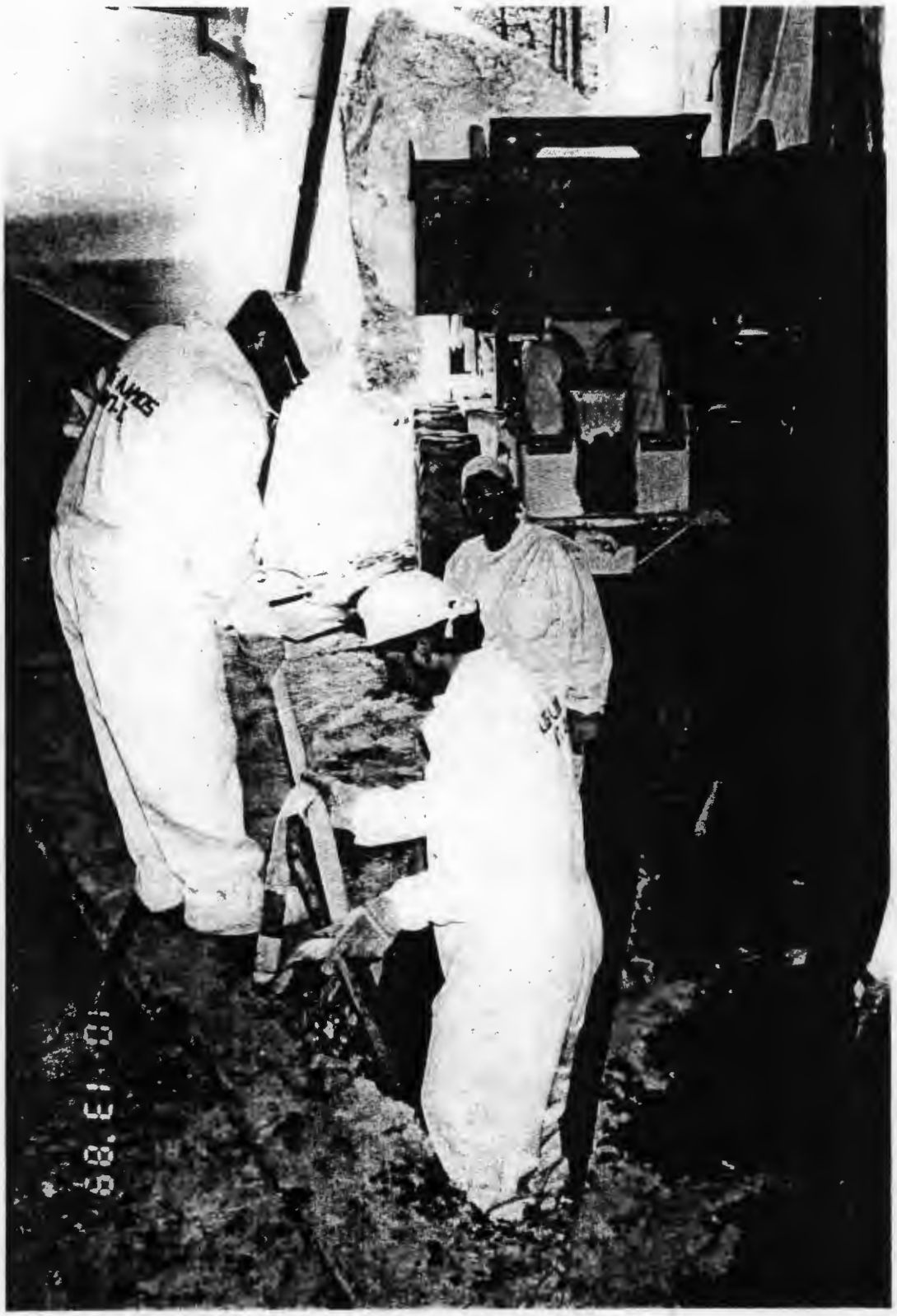

Figure 23. Removal of lead plates.

Figure 24. Monitoring the floor surface.

from the dust and to limit personnel exposure from carbon monoxide exhaust gases from various pieces of engine-driven equipment.

The following contamination control measures were implemented during remedial action at the Water Boiler Reactor.

- o Water kept the dust down in all scabbling and jackhammering activities. Plastic on the walls and ceiling protected the room from the dust created during concrete removal. A portable high-efficiency filter system was used to exhaust the room.
- o All personnel wore respiratory protection when working around an operation that could produce contaminated dust or harmful exhaust gases.
- o The room was isolated from the rest of the building by a partition constructed of sheets of plastic and wood.
- o A controlled area was established outside the east entrance to Room 122. This controlled area was the access and egress area from the contaminated zone, where all personnel and equipment leaving the area were checked for contamination.

Air was sampled in the room to ensure the success of these measures to control contamination.

5.3 Post-remedial Action Measurements

After decommissioning and decontamination were completed, the Radiation Protection Group, HSE-1, did the final surveys of Room 122.

The quantity of surface contamination left on the walls and ceiling in Room 122 is well below the residual activity guidelines based on the ^{90}Sr:^{137}Cs activity ratio of 25:75.

Fixed and removable contamination measurements were made at five locations in each 2-m grid block. The maximum and average were compared with the residual activity guidelines.

After remedial actions were completed, most of the floor, except for isolated areas, was below residual activity guidelines. The highest reading was taken over a 2-meter grid on the floor surface. The average maximum beta/gamma fixed-activity reading in this area was 261,000 dpm/100 cm^2. Because the entire floor area was capped with four inches of concrete after completion of floor restoration and any residual radioactivity was entombed, the Water Boiler Project Management Team has concluded that the concrete will provide adequate protection, giving due consideration to health and safety, the environment, and costs. An exception is not considered appropriate in this case.

The Radiation Protection Group, HSE-1, surveyed the grid to determine what the average maximum beta/gamma fixed-activity reading was after the concrete pour. The average of five readings was 418 dpm/100 cm^2. In a weekly instrumentation survey of the TA-2 facility, the Radiation Protection Group looks for readings exceeding 0.1 mrem/h. A monthly swipe survey is also done throughout the site, including Room 122.

Three surveys were performed after post-remedial action activities were completed: a fixed-contamination survey, a removable-contamination survey, and a soil-sampling survey.

Fixed-contamination survey - A 1-m^2 grid was used on surfaces most likely to contain the highest levels of contamination, the floor and utility tunnels. Readings were taken at the center and at four other points midway between the center and the corners of a grid block (Fig. 25).

A 1-m^2 grid was used on the walls up to a height of 2 m. Readings were taken at the center of each grid block.

The maximum beta/gamma fixed-activity reading in Room 122 was on the east steel support beam used for the overhead bridge crane, which, after paint removal and sanding, read approximately 900,000 dpm/probe area, which corresponds to 5,850,000 dpm/100 cm^2. Although the contamination in this area is a point source, fixed and remote (7 m above floor grade), a 4-in.-square, 1/4-in. steel plate was welded over the source to entomb and eliminate the fixed direct reading.

Personnel used an Eberline ESP-1 with HP-260 pancake GM probe for beta/gamma (15 cm^2 probe area). The minimum detectable activity counting 1 minute with the ESP-1 is approximately 380 dpm/100 cm^2, assuming that activity 20% above background can be detected.

Swipe survey (removable contamination survey) - Samples for removable contamination were taken using the same grid-mapping outlined in "Fixed Contamination Survey," above.

Swipe surveys included swipes of the floor, walls, utility tunnels, bridge crane, lamps, windows, and remaining electrical equipment.

The highest swipable beta/gamma activity in Room 122 was 207 dpm/100 cm^2, below the limit of 500 dpm/100 cm^2. The swipe survey for removable activity was conducted by a standard dry Nucon smear over an area of 100 cm^2 or greater. Swipe samples were subjected to gross alpha/gross beta-gamma analysis at the Los Alamos Health Physics Analysis Laboratory (HPAL).

Spectrographic analyses of selected swipe samples from Room 122 have shown ^{137}Cs to be the predominant fission product remaining. Other radionuclides identified are ^{152}Eu, ^{90}Sr, and ^{60}Co.

Soil sample survey - Soil samples were taken from a grid laid out on the floor at 2-m intervals. Samples from each exposed wall were taken at the same interval. The characterization of residual ^{137}Cs and final cleanup required 21 samples inside Room 122. Concentration of ^{137}Cs was determined by a NaI deep-well counter configured to count the appropriate part of the gamma spectrum. Three samples were collected from the excavated material to determine whether hazardous substances regulated under RCRA were present. These samples were submitted to the Health and Environmental Chemistry Group, HSE-9, for analysis by methods approved by the Environmental Protection Agency. Analysis showed that no hazardous substances were present in the soil.

Post-remedial action status - Measurements taken after removing radioactive materials indicated that no areas of concern exist. Under the Radiological Site Assessment Program, ORAU independently assessed the remedial action done at the Water Boiler Reactor. The assessment verifies the data supporting the adequacy of remedial action and confirming that radiological conditions at the Water Boiler Reactor comply with the guidelines established for this project.

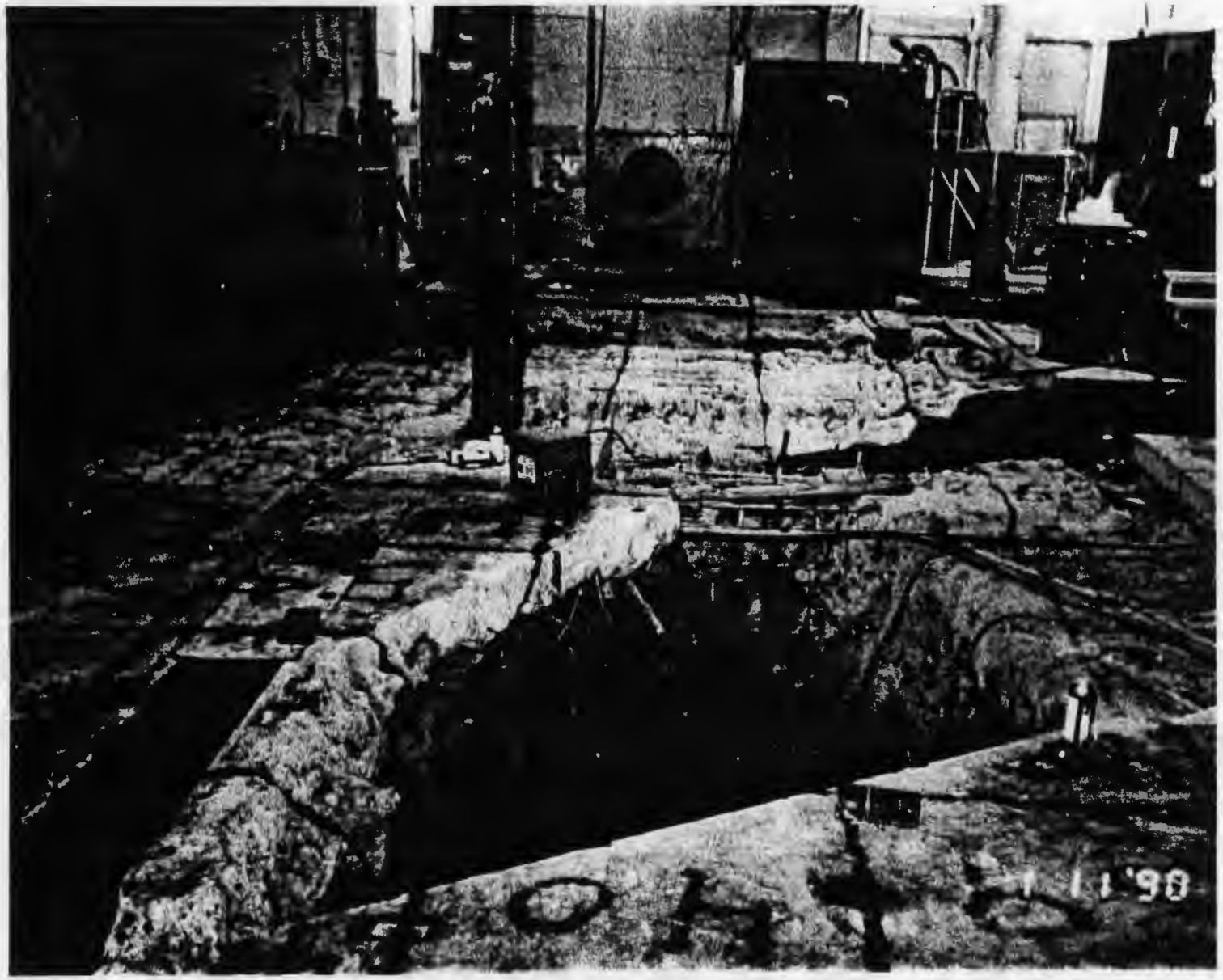

Figure 25. Floor-surface grid for monitoring.

After reviewing the data collected, the Laboratory determined that the Water Boiler Reactor Room conforms to applicable DOE radiological guidelines established for release of this site to Laboratory groups for light laboratory usage. TA-2 will remain as a restricted site under the control of the Isotope and Nuclear Chemistry Division, which currently occupies the site.

All remedial action was completed by April 1990. The action produced 73 30-gal. drums of low-level radioactive waste; and 18 55-gal. drums of mixed waste, contaminated lead (35 m^3), were stored in a secured area pending permanent disposal. The action generated 173 m^3 of low-level solid waste, which was treated as outlined in ARs 10-1 and 10-3 in the Laboratory's *Environment, Safety, and Health Manual.*[15]

6.0 LESSONS LEARNED

The TA-2 WBRDP management team experienced valuable lessons in decommissioning a highly contaminated and activated nuclear-fueled reactor.

Overall, the decontamination efforts at Los Alamos have demonstrated that nuclear cleanup and waste management can be done efficiently, safely, and cost effectively. The TA-2 Water Boiler Reactor was decommissioned with maximum attention to the safety of workers, the public, and protection of the environment. The skills employed, technology used, and lessons learned will assist others in planning and performing similar projects.

6.1 Summary of Lessons Learned

A brief synopsis of lessons learned during the WBRDP is as follows.

Implementation of radiological controls - The decontamination work was planned and executed with safety, waste minimization, and productivity priorities. To perform this work safely, each task required the following:

- characterizing areas and equipment for radiological hazards;
- detailed planning, including radiological controls, to preclude spreading contamination and to minimize radiation exposure;
- preparation of contingency and emergency responses;
- thorough training, supervision, and radiological monitoring; and
- proper selection and use of protective clothing.

Special tooling - A variety of commercially available tools and equipment was used. Some of the tools, including the following, were modified to meet project objectives:

- remote drilling and cutting;
- standard cutting tools such as drills and saws with abrasive and metal blades;
- special concrete cutting tools such as scabblers and concrete saws; and
- special ventilation and dust-removal techniques.

Surface fixatives - Before contaminated items (mainly concrete) were cut or broken, surface fixatives were used to contain loose contamination.

Radiological exposure - An aggressive ALARA campaign is employed at Los Alamos National Laboratory. Personnel exposures are routinely kept at less than 1 R/y. Detailed procedures, through training and extensive use of mock-ups, were aspects of the success of this program and the ultimate contributors to the success of this project.

ACKNOWLEDGMENTS

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APPENDIX A. Abbreviations and Units of Measure.

ACWP	actual cost of work performed
ALARA	as low as reasonably achievable
AR	Administrative Requirement in the Environment, Health, and Safety Manual
Ci	curie
cm	centimeter
CMP	corrugated metal pipe
D&D	decontamination and decommissioning
DOE	Department of Energy
DOE-HQ	Department of Energy - Headquarters
DOS	decommissioning operations subcontractor
dpm	disintegrations per minute
EPA	Environmental Protection Agency
ES&H	environment, safety, and health
FY	fiscal year
g	gram
GOCO	government-owned, contractor-operated
h	hour
HEPA	high-efficiency particulate air (filter)
HPAL	Health Physics Analysis Laboratory
HPS	health physics surveyor
HPT	health physics technician
HSE	Health, Safety, and Environment Division
HYPO	high-powered reactor
m	meter
mR	milliroentgen
mrad	millirad
mrem	millirem
nCi	nanocurie
NE	Office of Nuclear Energy
ORAU	Oak Ridge Associated Universities
OSHA	Occupational Safety and Health Administration
OWR	Omega West Reactor
pCi	picocurie
PMP	project management plan
QA	quality assurance
RCRA	Resources Conservation and Recovery Act
rem	radiation equivalent man
RESRAD	residual radioactive materials guidelines
RWP	Radiation Work Permit
SFMP	Surplus Facilities Management Program of the US Department of Energy
SOP	standard operating procedure
SUPO	super-powered reactor
SWP	Special Work Permit
WBRDP	Water Boiler Reactor Decommissioning Project
WBS	work breakdown structure
y	year

APPENDIX B. Table II of the Surface Contamination Guidelines (SFMP).

Radionuclides[b]	Allowable Total Residual Surface Contamination (dpm/100 cm^2)[a] Average[c,d]	Maximum[d,e]	Removable[d,f]
Transuranics, Ra-226, Ra-228, Th-230, Th-228, Pa-231, Ac-227, I-125, I-129	100	300	20
Th-Natural, Th-232, Sr-90, Ra-223, Ra-224, U-232, I-126, I-131, I-133	1,000	3,000	200
U-Natural, U-235, U-238, and associated decay products	5,000 alpha	15,000 alpha	1,000 alpha
Beta-gamma emitters (radionuclides with decay modes other than alpha emission or spontaneous fission except Sr-90 and others noted above)	5,000 beta-gamma	15,000 beta-gamma	1,000 beta-gamma

[a]As used in this table, dpm (disintegrations per minute) means the rate of emission by radioactive material as determined by correcting the counts per minute measured by an appropriate detector for background, efficiency, and geometric factors associated with the instrumentation.

[b]When surface contamination by both alpha- and beta-gamma- emitting radionuclides exists, the limits established for alpha- and beta-gamma-emitting radionuclides should apply independently.

[c]Measurements of average contamination should not be averaged over an area of more than 1 m^2. For objects of less surface area, the average should be derived for each such object.

[d]The average and maximum dose rates associated with surface contamination resulting from beta-gamma emitters should not exceed 0.2 mrad/h and 1.0 mrad/h, respectively, at 1 cm.

[e]The maximum contamination level applies to an area of not more than 100 cm^2.

[f]The amount of removable radioactive material per 100 cm^2 of surface area should be determined by wiping that area with a dry filter or soft absorbent paper, applying moderate pressure, and measuring the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination on objects of surface area less than 100 cm^2 is determined, the activity per unit area should be based on the actual area, and the entire surface should be wiped. The figures in this column are maximum amounts.