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TITLE DECOMMISSIONING A NUCLEAR REACTOR

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Decommissioning a Nuclear Reactor

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Abstract

The process of decommissioning a facility such as a nuclear reactor or reprocessing plant presents many waste management options and concerns. Waste minimization is a primary consideration, along with protecting personnel and the environment. Waste management is complicated in that both radioactive and chemical hazardous wastes must be dealt with. This paper presents the general decommissioning approach of a recent project at Los Alamos. Included are the following technical objectives: site characterization work that provided a thorough physical, chemical, and radiological assessment of the contamination at the site; demonstration of the safe and cost-effective dismantlement of a highly contaminated and activated nuclear-fueled reactor; and techniques used in minimizing radioactive and hazardous waste.

BACKGROUND FOR THE WATER BOILER REACTOR PROJECT

Decommissioning a nuclear reactor is one of the largest and most complex tasks in waste management. A recent project at Los Alamos National Laboratory was the decommissioning of the Water Boiler Reactor.

Los Alamos National Laboratory was established in 1943 to build the world's first nuclear weapon. Today, the Laboratory is a multiprogram national laboratory of the US Department of Energy, still operated by the University of California. 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. For more than 30 years, the Water Boiler Reactor was part of that effort.

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.

History

Enrico Fermi advocated construction of what was to become the world's third reactor, 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. Fuel for the reactor consumed the country's total supply of enriched uranium. 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-ft-diameter stainless steel sphere shell surrounded by neutron-reflecting blocks of beryllium oxide on a graphite base (Fig. 1). The day in May 1944 that LOPO reached criticality, 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-ft-long stainless-steel cooling coils were installed in the 1-ft-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.

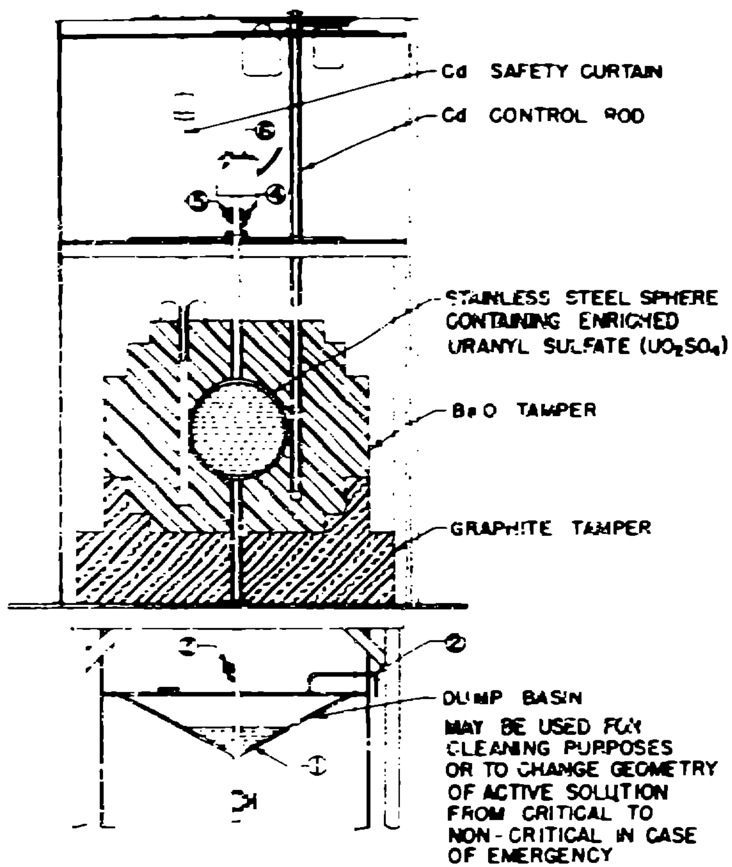


Figure 1. SUPO Reactor

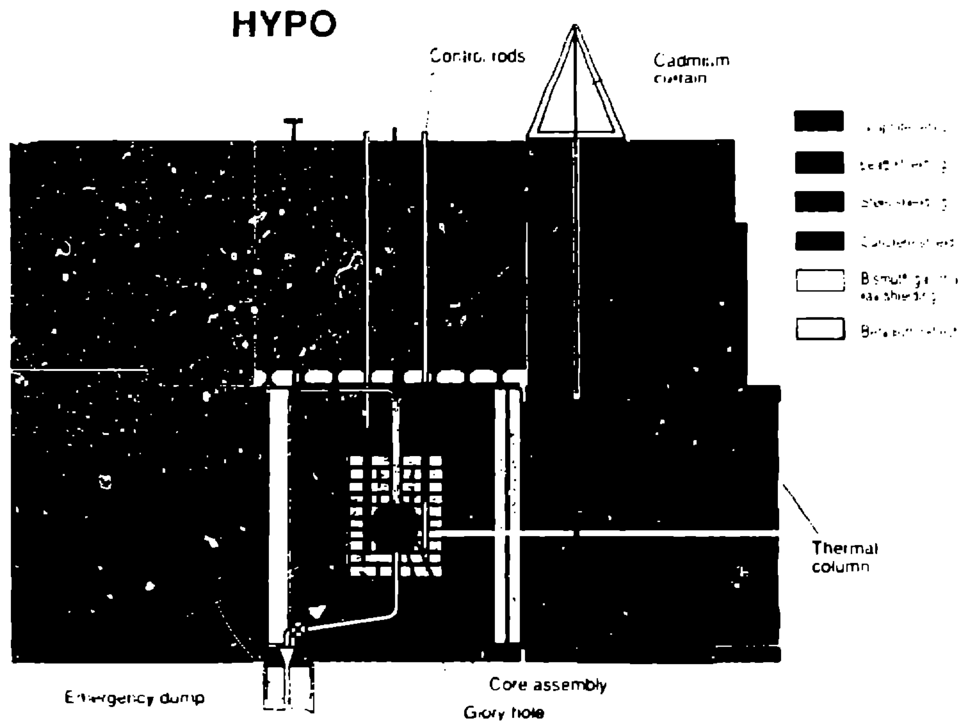


Figure 2. HYPO Reactor

- A gas recombination system was connected to the fuel vessel.

SUPO was operated almost daily until its deactivation in 1974.

Purpose

The Laboratory had to decontaminate and decommission the reactor inside Room 122, which housed the reactor, to provide reusable space at the site and to eliminate the hazard of accidental intrusion into a contaminated structure.

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 filled with a water solution of uranyl nitrate and surrounded by a graphite neutron reflector. Other major components included various shielding materials, a concrete biological shield 15 ft x 15 ft x 11 ft high, two thermal columns, various access ports, and a gas recombination system (Fig 3-6).

Technical Objectives

The project had the following technical objectives:

- demonstrate the safe and cost-effective dismantlement of a highly contaminated and activated nuclear-fueled reactor;

- optimize the use of a dedicated subcontractor labor crew to induce a transfer of decommissioning experience; and

- provide for technology transfer by generating project performance data and documenting the decommissioning experience for use in future decommissioning projects.

Laying the groundwork for the physical decommissioning for the project took almost a year. World Services is the on-site subcontractor to the Laboratory and was therefore the subcontractor for decommissioning operations. The Waste Management Group and the Radiation Protection Group 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

Figure 3. South Face of the Water Boiler Reactor

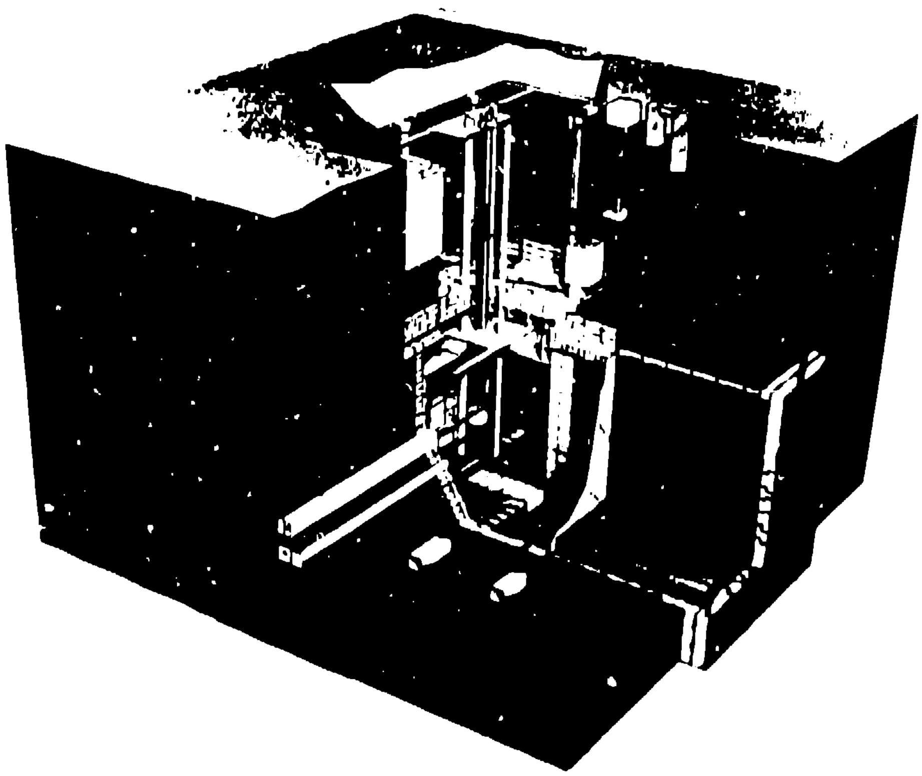


Figure 4. Cutaway View Looking Northeast

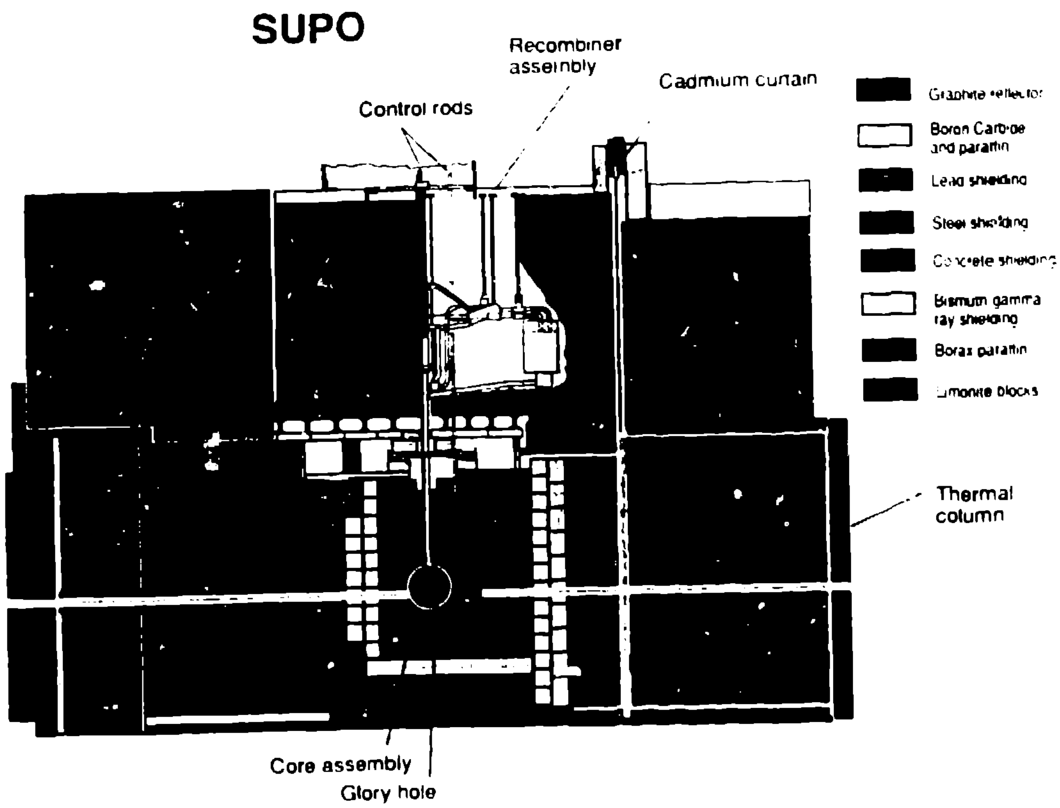


Figure 5. North-South Cross Section of the Reactor

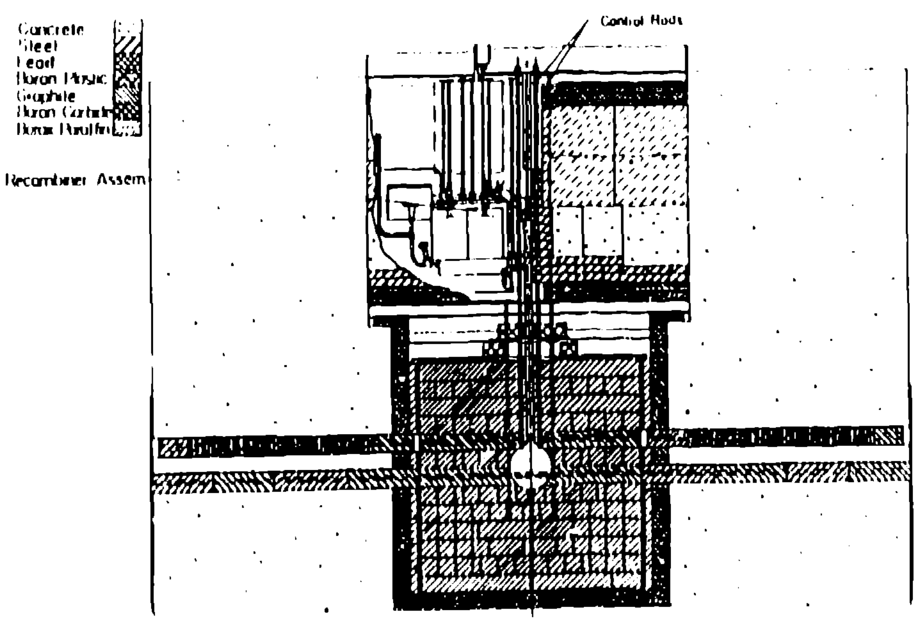


Figure 6. Eastwest Vertical Cross Section

contaminated filter plenum and unstacking the graphite thermal columns and the removable shielding, including an 8-1/2-in. bismuth pier in both the north and south thermal columns; 1/2-in. boron carbide (B_4C)+ concrete, and borax paraffin cans; paraffin; and 4-in. lead shielding. 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.

Description of the Site

The reactor was 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 was available except through the Los Alamos Canyon Road. Room 122 housed 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.

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, the lead was disposed of under regulations of the state and the Environmental Protection Agency.

Radiological Controls

Strict compliance with radiological control procedures were essential to minimize occupational radioactivity exposure to levels as low as reasonably achievable (ALARA) and to prevent spreading contamination to adjoining rooms, which remained occupied.

A trained health physics technician from the Radiation Protection Group provided continuous surveillance of all decommissioning activities associated with the reactor.

Special requirements for radiation protection of workers were specified under the Laboratory practice of issuing a Special Work Permit for radiation work.

Work was monitored to ensure that the procedures were followed. Health physics technicians 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 health physics technicians used portable survey instruments to measure loose surface contamination, the general area and contact radiation levels, and airborne contamination concentrations. They also ensured that personnel from World Services worked in a radiologically safe manner.

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 fitted each worker with respirators. Engineered systems, such as HEPA-filtered ventilators and/or enclosures, kept airborne concentrations below limits established by the Laboratory's health, safety, and environment policies.

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 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.

The project was completed without a release of radioactive material from the operations area or any worker overexposure.

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 radiation work permits,

- ongoing surveys,
- employee training,
- using dosimetric devices for exposure controls, and
- daily task planning.

The Project Management Plan 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.

Preplanning

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 health physics technicians 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.

DECOMMISSIONING THE REACTOR

Site Preparation

The first step in decommissioning the reactor was to prepare the site. The work included the following:

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

The room next to the reactor was modified to provide temporary office space and support facilities to World Services.

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.

Because the site was occupied and the Omega West Reactor was still operating, the Omega Site Emergency Plan was posted and in effect during all decommissioning activities. The objective of the plan was to minimize personnel injury and property damage in an accident or other emergency, such as fire, explosion, excursion by the Omega West Reactor, or radioactivity release. The evacuation route and assembly point were well marked.

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 determined the ventilation needs for the workers assigned to the project.

Steps in Decommissioning

The scope of the project was quite large. The decommissioning of the 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. The contaminated concrete and soil beneath the biological shield and related utility tunnels were also removed.

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 and disposed of at the Laboratory's solid waste disposal site.

These shielding materials were also removed and disposed of:

- limonite cans;
- the 8-1/2-in. bismuth pier in the north and south thermal columns;
- 1/2 in. of B_4C^+ paraffin; and
- 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.

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. 7). 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 in 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 then 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 where lead shielding was removed remotely before final disposition.

Also removed was the circulating blower, which kept static pressure negative to the stack to prevent radioactive gas leaks into the reactor room (Fig. 8). 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.

Next, the entrainment wool trap was removed. The wool trap was located ahead of the blower to stop any entrained liquid carried over (Fig. 9). 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, and, 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

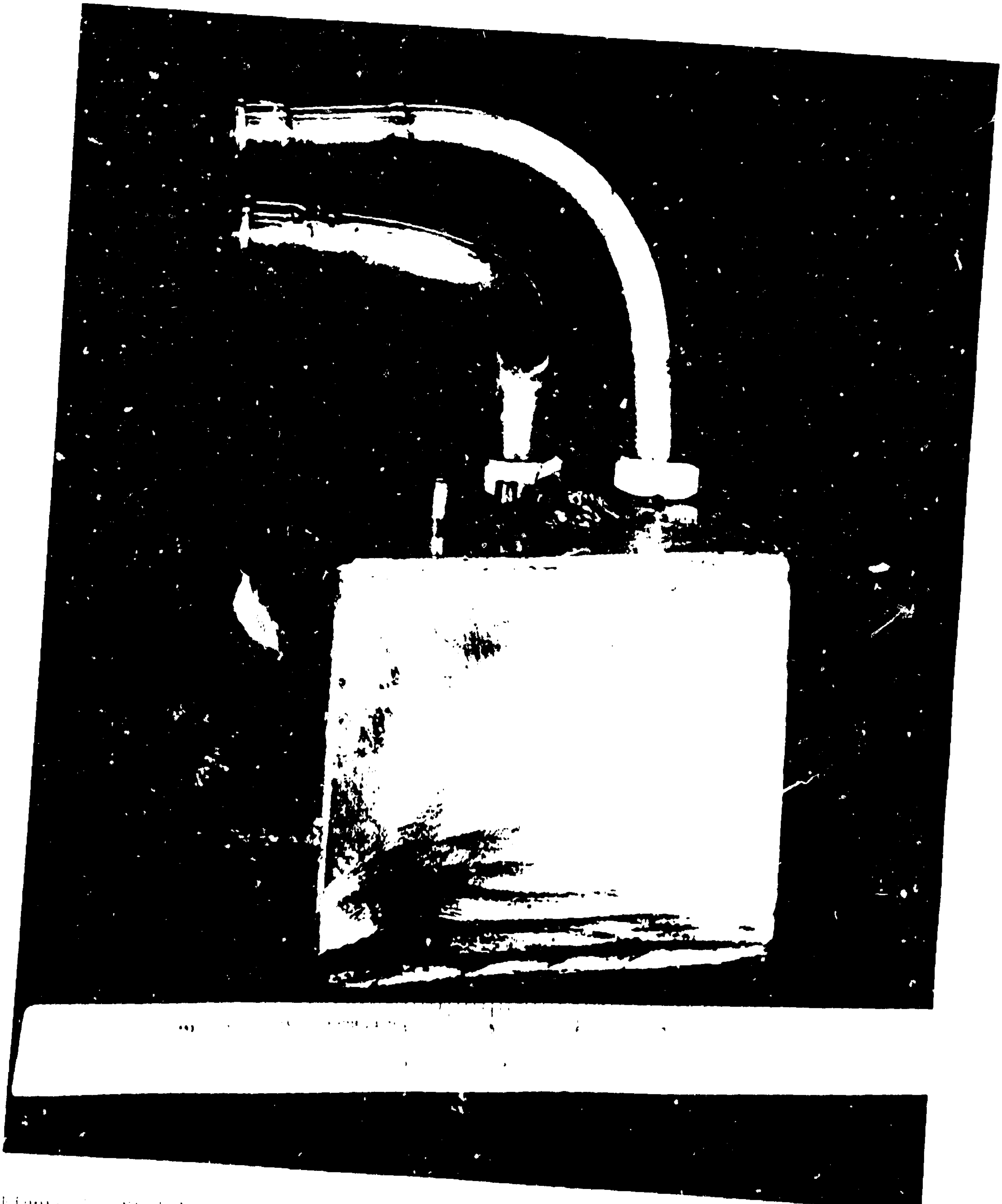


Figure [illegible]. Stainless Steel Recombiner

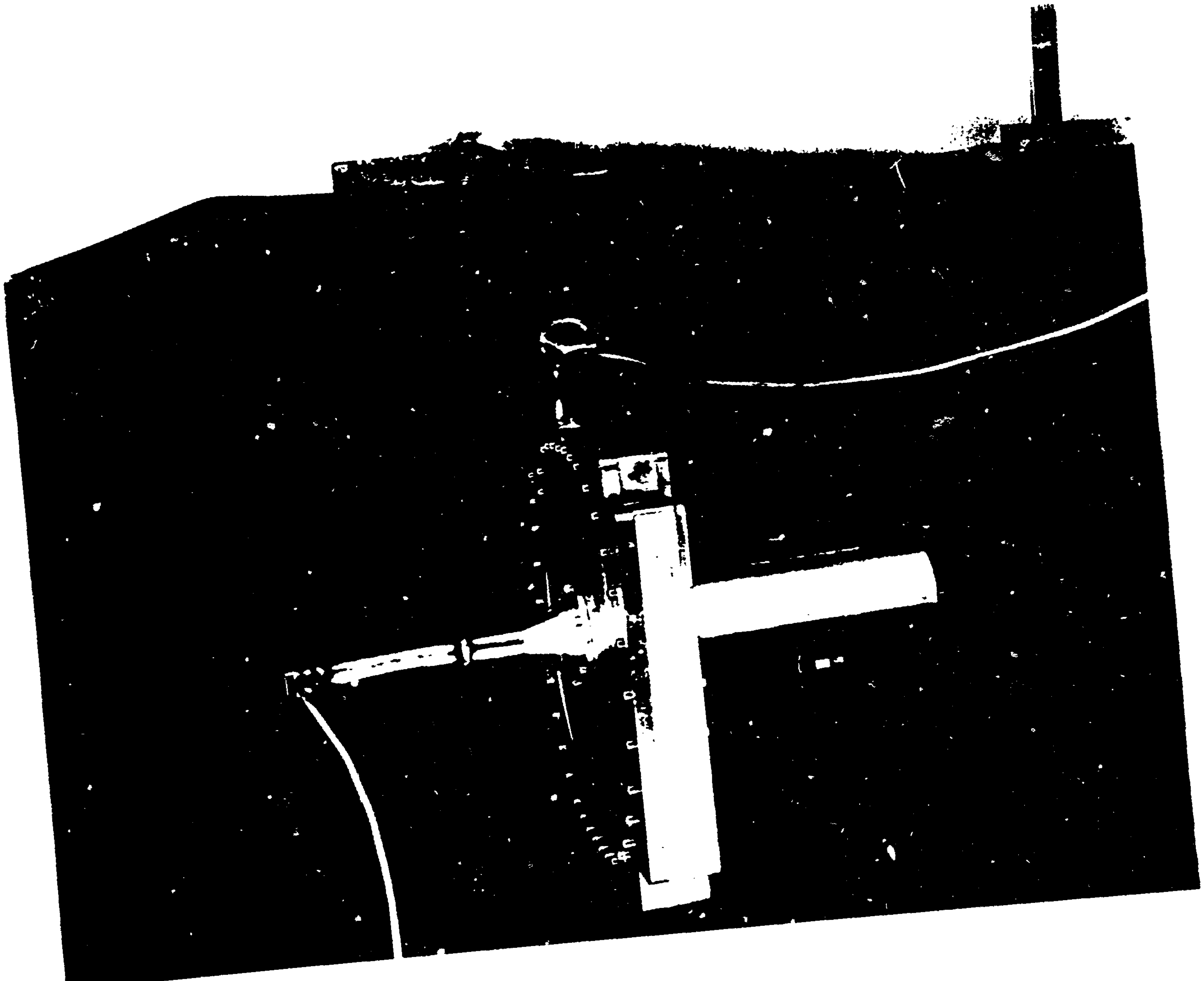
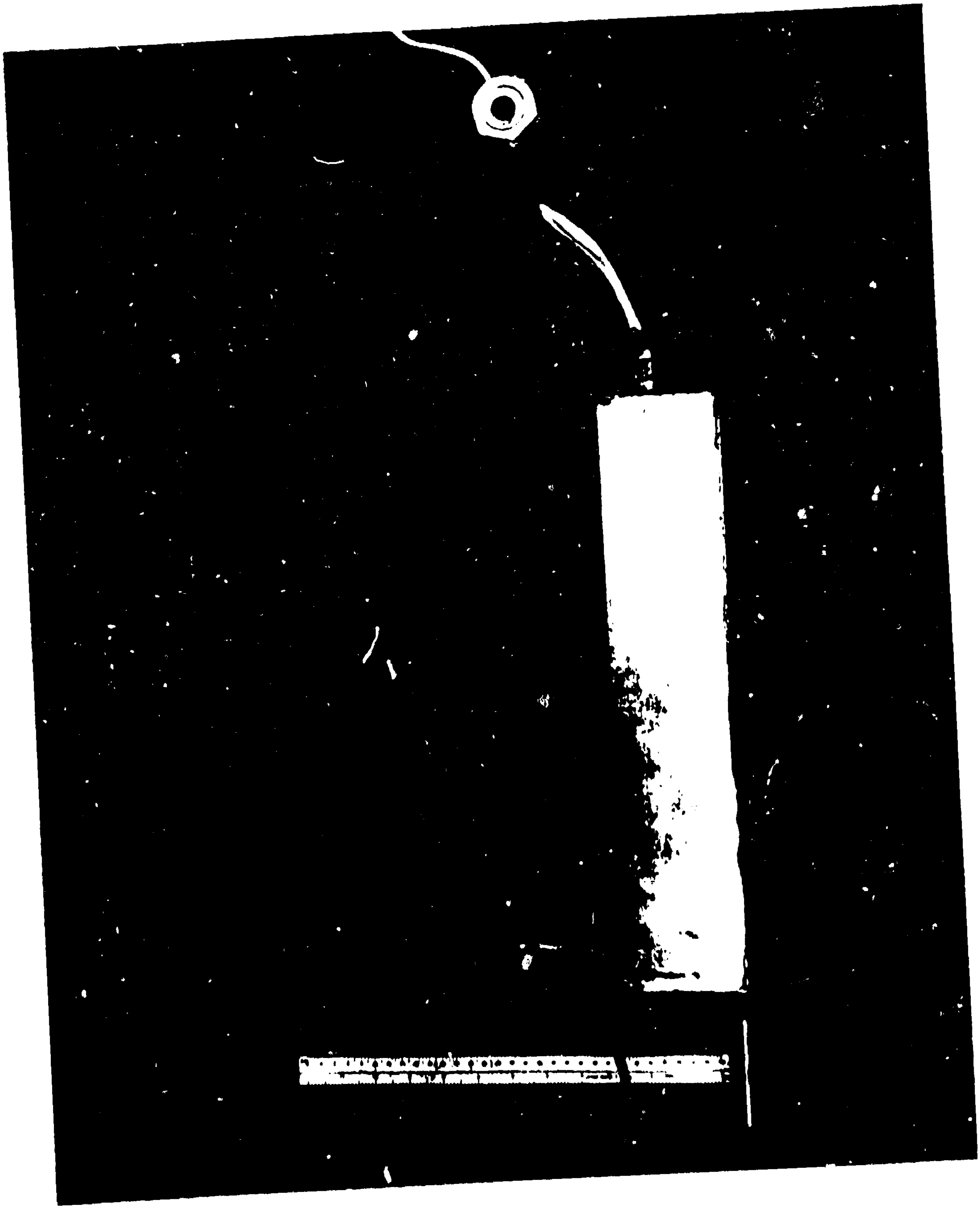


Figure 6. The Circulating Blower



plate, in box form, and lined with 4 in. of lead to reduce the exterior contact reading to approximately 15 mR/h.

Then the after-condenser was removed. The design requirements of the after-condenser were that it should simultaneously reduce the temperature of gas flowing through it and condense water (Fig. 10). The contact dose rate on the condenser was 20 R/h. The container for the condenser and related piping was constructed of a 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.

The next step was to remove 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 optimally 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 screw shank, which were welded to one end of each extension, were designed and 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.

The vessel was transported to the Laboratory's solid waste disposal site in a 6 ft x 6 ft x 8 ft 35-ton steel cask.

Next, the 15 ft x 15 ft x 11 ft concrete biological shield was removed. Workers tried to remove the 5-ft. thick steel-reinforced concrete biological shield without creating unnecessary dust. They used a star drill to bore holes at regular intervals; holes were filled with "s-mite," an expanding medium, so that the concrete would be broken. This attempt failed because of the amount of reinforced steel used in the concrete at the time of construction. The alternative was to use three jackhammers to break up the concrete shield (Fig. 11).

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

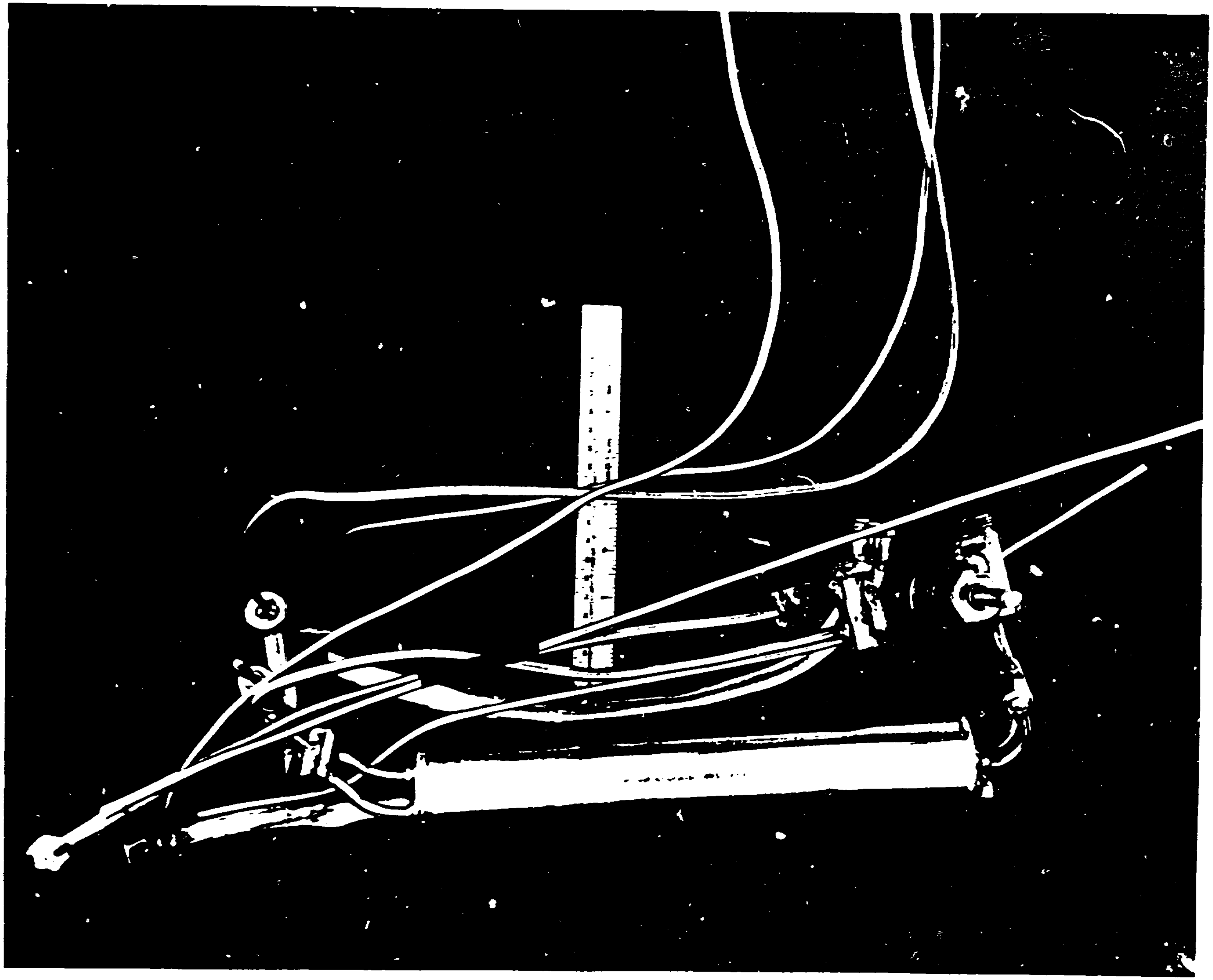


Figure 11. The After Condenser

[illegible] Shield [illegible] with Jackhammers alternative. A major cleanup of contaminated dust and debris followed.

Then the asbestos floor tile was removed; 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.

Special Tools and Techniques

Several specifically designed tools and techniques were used to safely and remotely remove highly activated components. The tools were fabricated on-site. Workers also used conventional tools with extensions 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 used when the recombiner assembly was removed.

Packaging and Transportation

All radioactive solid wastes were packaged and transported to comply with Laboratory requirements.

The project limited contact-handled waste packages to a maximum surface dose rate of 200 mR/h. The project got special approval from the Safety and Risk Assessment Group to package the highly activated components, up to 150 R/h. The radiation limits were raised to 1 R/h at contact with packaging.

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.

All waste loads were secured and covered for shipment to the waste disposal site, TA-54, Area G. The health physics surveyor from the Radiation Protection Group 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 escort vehicle from the Radiation Protection Group was used when transporting highly activated components to the waste disposal site.

Disposal of the Wastes

Low-level radioactive solid waste generated by the Water Boiler Reactor Decommissioning Project (WBRDP) was either buried in pits or placed in shafts at TA-54, Area G. Burial in pits consisted 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.

Site Release Program

To release a successfully decommissioned facility or site from the Surplus Facilities Management Program (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.

After the determination that the Water Boiler Reactor should be decommissioned and decontaminated, the reactor was designated for remedial action. Because the 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.

Three types of remedial action were done at the reactor site 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 filter or cleaned with a wet cloth.

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

The third type of remedial 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.

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

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 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.

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 (Fig. 12). The TA-2 Water Boiler Reactor was decommissioned with maximum attention to the safety of workers and the public and to protecting the environment. The skills employed, technology used, and lessons learned will assist others in planning and performing similar projects.

Figure 1[illegible]. Final Restoration of Room 122

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:

- o characterizing areas and equipment for radiological hazards;
- o detailed planning, including radiological controls, to preclude spreading contamination and to minimize radiation exposure;
- o preparation of contingency and emergency responses;
- o thorough training, supervision, and radiological monitoring; and
- o 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:

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

CONCLUSION

Through proactive efforts in safe decontamination and decommissioning and through a continuing commitment to protecting the public and the environment, the Waste

Management Group at Los Alamos ensures that facilities are safely decommissioned and that the wastes from such operations will pose no harm to the public or to the environment.