NUREG/CR-3293
Vol. 2 of 2

Technology, Safety and Costs of Decommissioning Reference Nuclear Fuel Cycle and Non-Fuel Cycle Facilities Following Postulated Accidents

Appendices

Prepared by H. K. Elder

Pacific Northwest Laboratory
Operated by
Battelle Memorial Institute

Prepared for
U.S. Nuclear Regulatory
Commission

NOTICE

Availability of Reference Materials Cited in NRC Publications

Most documents cited in NRC publications will be available from one of the following sources:

1. The NRC Public Document Room, 1717 H Street, N.W. Washington, DC 20555
2. The Superintendent of Documents, U.S. Government Printing Office, Post Office Box 37082, Washington, DC 20013 7982
3. The National Technical Information Service, Springfield, VA 22161

Although the listing that follows represents the majority of documents cited in NRC publications, it is not intended to be exhaustive.

Referenced documents available for inspection and copying for a fee from the NRC Public Document Room include NRC correspondence and internal NRC memoranda; NRC Office of Inspection and Enforcement bulletins, circulars, information notices, inspection and investigation notices; Licensee Event Reports; vendor reports and correspondence; Commission papers; and applicant and licensee documents and correspondence.

The following documents in the NUREG series are available for purchase from the NRC/GPO Sales Program: formal NRC staff and contractor reports, NRC-sponsored conference proceedings, and NRC booklets and brochures. Also available are Regulatory Guides, NRC regulations in the *Code of Federal Regulations*, and *Nuclear Regulatory Commission Issuances*.

Documents available from the National Technical Information Service include NUREG series reports and technical reports prepared by other federal agencies and reports prepared by the Atomic Energy Commission, forerunner agency to the Nuclear Regulatory Commission.

Documents available from public and special technical libraries include all open literature items, such as books, journal and periodical articles, and transactions. *Federal Register* notices, federal and state legislation, and congressional reports can usually be obtained from these libraries.

Documents such as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings are available for purchase from the organization sponsoring the publication cited.

Single copies of NRC draft reports are available free, to the extent of supply, upon written request to the Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

Copies of industry codes and standards used in a substantive manner in the NRC regulatory process are maintained at the NRC Library, 7920 Norfolk Avenue, Bethesda, Maryland, and are available there for reference use by the public. Codes and standards are usually copyrighted and may be purchased from the originating organization or, if they are American National Standards, from the American National Standards Institute, 1430 Broadway, New York, NY 10018.

NUREG/CR-3293
Vol. 2 of 2

Technology, Safety and Costs of Decommissioning Reference Nuclear Fuel Cycle and Non-Fuel Cycle Facilities Following Postulated Accidents

Appendices

Manuscript Completed: March 1985
Date Published: May 1985

Prepared by
H. K. Elder

Pacific Northwest Laboratory
Richland, WA 99352

Prepared for
Division of Engineering Technology
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
NRC FIN B2117

STUDY CONTRIBUTORS

STUDY LEADER

H. K. Elder

EDITOR

S. F. Liebetrau

REPORT CONTENTS OUTLINE

VOLUME II

CONTENTS

FIGURES

TABLES

APPENDIX A

REFERENCE FACILITY AND SITE DESCRIPTIONS

APPENDIX A

REFERENCE FACILITY AND SITE DESCRIPTIONS

This appendix contains descriptions of the reference facilities and the reference site used in this study as bases for analyzing post-accident decommissioning. The reference facilities and site of this study are the same as those used for previous studies of the decommissioning of nuclear fuel cycle and non-fuel cycle facilities following normal shutdown.[1-3] More complete descriptions can be found in the published reports of these studies.

The reference site assumed for all the facilities in this study is described first. This reference site is the same as that used in the previous fuel cycle decommissioning studies. Site information given is used to assess the public safety impacts of post-accident decommissioning activities. Only information directly relating to the radiation exposure pathway analysis, required for estimating radiation doses to the public, is included here. Although individual features of any actual nuclear facilities site may differ from those of the reference site, it is believed that the use of a reference site results in a more meaningful overall analysis of the potential impacts of decommissioning by allowing direct comparison of results between facilities and, for each facility, between shutdown conditions (i.e., normal-shutdown and post-accident). Site-specific assessments would be required prior to decommissioning particular facilities.

The descriptions of the reference facilities presented in this appendix are intended to provided the background for understanding the estimates of time and manpower requirements and waste volumes for post-accident decommissioning that are developed in other chapters and appendices of this report. The descriptions are based primarily on those included in the previous studies of normal-shutdown decommissioning of these facilities[1-3], with supplementary information added as needed.

The reference accident scenarios for this study, described in Appendix B, contain information about radioactive contamination, physical damage to structures and equipment, and radiation exposure rates that result from the postulated accidents at the reference facilities.

A.1 REFERENCE SITE DESCRIPTION

The reference site used in this study to assess the public safety impacts of post-accident decommissioning activities is the same as that used in previous fuel cycle facility decommissioning studies. The meteorological parameters and population distribution are based on information presented in

Reference 4. Other necessary site information is based on data reported in the site description of an operating nuclear power station.[5] Information in this appendix is believed to be representative of potential sites for nuclear fuel cycle facilities in the midwestern and middle-southeastern United States.

A.1.1 Site Location and Size

The reference site is located in a rural area with characteristics similar to those found in the midwesten or middle-southeastern United States. The site occupies about 4.7 km^2 in a rectangular shape of about 2 km by 2.35 km. A moderate-size river with an average follow rate of 1420 m^3/sec flows through one corner of the site.

A.1.2 Demography

The site is located in a rural area with a relatively low population density. The highest population densities occur at distances of 20 to 60 km from the site. Population distribution data are given in Table A.1-1. The total population residing within an 80-km radius of the reference site is about 3.52 million.

A.1.3 Land Use

Use of any part of the total site area for anything other than nuclear-related activities is assumed to be prohibited during the operational lifetime of the plant. The major plant facilities are located inside a smaller, fenced portion of the site. The minimum distance from the point of airborne release to the outer site boundary is 1 km. The outer site boundary is fenced and marked.

About 80% of the land within 20 km of the site is used for farming. The main crops are soybeans (60%); corn, oats, and other grains (30%); and hay (10%). It is expected that this area will remain largely agricultural, and that the population will not change significantly during the operational lifetime of the plant.

A wildlife refuge and a state forest and campground are located about 14 km from the site. A state park is located abut 10 km from the site in the opposite direction.

There are large truck gardens in the area. The nearest dwelling (the residence location of the maximum-exposed individual for the public safety analysis) is a farm located about 1.3 km from the site. A milk cow is kept at this farm and is maintained on fresh pasture 7 months of the year. A family garden with a growing season of 5 months is kept for fresh vegetables. River water is used to irrigate the crops on this farm.

TABLE A.1-1. Population Distribution Around the Reference Site for the Year 2000[4]

Distance from Site boundary (km)	Population Density (Persons/km^2)	Total Population In Annulus[a,b]	Cumulative Population
0 to 2	--[c]	10	10
2 to 3	136	2 130	2 140
3 to 5	104	5 230	7 370
5 to 6	230	7 940	15 300
6 to 8	133	11 700	27 000
8 to 20	85	89 300	116 000
20 to 30	239	375 000	491 000
30 to 50	175	878 000	1 370 000
50 to 60	298	1 030 000	2 400 000
60 to 80	127	1 120 000	3 520 000

(a) It is assumed that the population in each annulus is divided into 16 uniform 22.5-degree sectors.
(b) Totals are rounded to three significant figures.
(c) Indicates a population density less than 1.0/km^2.

A.1.4 Meteorology

The reference site has a typical continental climate. It is characterized by wide variations in temperature, modest winter precipitation, normally ample spring and summer rainfall, and a general tendency to extremes in all climatic features. January is the coldest month and July is the warmest. Table A.2-1 shows monthly meteorological statistics.

On the average, 12 days per year have maximum temperatures of 32°C and above. Annually, an average of 168 days has minimum temperatures of 0°C and below, and 40 of them at -18°C or below. The January average relative humidities at 7:00 a.m., 1:00 p.m., and 7:00 p.m. are 76, 68, and 70% respectively. The corresponding humidities for July are 86, 55, and 55%.

The average annual precipitation in the area is 610 mm. The months of May through September have the greatest amount of rainfall, with an average during this period of 432 to 457 mm (70% of the annual total). The maximum 24-hr total rainfall for the period 1894 through 1965 was 127 mm and occurred in

TABLE A.2-1. Monthly Meteorological Statistics at the Reference Site

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air Temperature (°C)												
Maximum	-6.1	-4.4	3.3	12.8	20	25	28.3	26.7	22.2	15	4.4	-3.3
Minimum	-16.1	-14.4	-6.7	1.7	7.8	13.3	16.1	15	10	3.9	-4.4	-12.2
Mean	-11.1	-9.4	-1.7	7.2	13.9	18.9	22.2	21.1	16.1	9.4	0.0	-7.8
Extreme Maximum	15	16.1	27.8	32.8	40.6	39.4	41.7	40	40.6	32.2	23.9	17.2
Extreme Minimum	-38.9	-36.7	-34.4	-15.6	-6.7	0.6	5.6	3.3	-5.6	-13.3	-27.8	-33.9
Mean Relative Humidity (%)												
	74	75	73	66	62	66	68	70	70	66	73	78

May. Thunderstorms, with an average annual frequency of 36, are the chief source of rain from May through September. Snowfall in the area averages 1070 mm annually, with occurrences recorded in all months except June, July, and August. Extremes of record in annual snowfall are 152 mm minimum and 2235 mm maximum.

The annual distribution of winds is predominantly bimodal. This bimodal distribution is characteristic of the seasonal wind distributions as well. The average wind speed for spring is 11 km/hr and for the other seasons is about 16 km/hr. The maximum reported wind speed of 148 km/hr was associated with a tornado. Tornadoes and other severe storms occur occasionally. The probability of a tornado striking a given point in this area is about 5×10^{-4} per year. For design purposes, a wind velocity of 480 km/hr is assumed to be associated with tornadoes.

Natural fog that restricts visibility to 0.4 km or less occurs about 30 hr/yr. Icing caused by freezing rain can occur between October and April, with an average of one to two storms per year.

Diffusion climatology comparisons with other locations indicate that the site is typical of the region, with relatively favorable atmospheric dilution conditions prevailing. Thermal inversions occur about 32% of the year, and the frequency of thermal stabilities is 19% slightly stable, 27% stable, 20% neutral, and 34% unstable.

Data from a number of river sites for nuclear power reactors[4] are used to calculate the "typical" annual atmospheric dispersion pattern in an average 22.5-degree sector around the site. This is done by calculating the dispersion factor, $\bar{\chi}/Q'$, for each sector at selected downwind distances and then calculating the average dispersion factor at each distance. In other words, the

dispersion factors in those sectors corresponding to overland trajectories are added without regard to direction and divided by the number of sectors involved. Thus, an average dispersion factor is obtained for each selected downwind distance for all 16 sectors.

Standards groups of meteorological data are interpolated from the specific site data. The groupings provide four stability classes based on vertical temperature gradient and five wind speed classes based on the Beaufort wind scale.(6) The stability classes are based on Reference 7 information, with Pasquill Classes A, B, and C classified as B (unstable); Pasquill Class D (neutral); Pasquill class E (slightly stable); and Pasquill Classes F and G as F (moderately stable).

Where wind-speed data are available for only one height, the measured values are extrapolated to the 10-m level for ground-level release calculations and to the 100-m level for releases from tall stacks. Where measurements at two heights are available, the highest is extrapolated to 100 m and the lowest to 10 m, using a standard power-law extrapolation procedure.(6)

The ratio of the maximum sector dispersion factor to the average sector dispersion factor is 2:5. This value is used for all release heights in this study. Investigation of the change in this ratio with increasing distance from the site shows that the ratio remains essentially constant. The dispersion factors for the average sector as a function of release height and downwind distance are shown in Figure A.1-1.

To assess the potential effect of increased stack height, atmospheric dispersion factors for stack heights of 150, 200, and 300 m are estimated from the original joint frequency distributions of the information from Reference 4. These values are graphically presented in Figure A.1-1.

No credit for plume rise from either momentum or buoyancy is taken in this study. Where large volumes of heated air are being ejected, the plume rise constant for momentum is estimated to be about 50 m^2/sec. Assuming an annual average wind speed of 2 to 3 m/sec, the increase in effective stack height because of momentum would be about 15 to 25 m. Plume rise from buoyancy (heat effect) would add at least another 25 to 100 m of effective stack height, depending on the temperature of the exhaust gases. Thus, $\bar{\chi}/Q'$ values illustrated in Figure A.1-1 are larger than they would be if credit had been taken for momentum and buoyancy.

A.2 REFERENCE SMALL MIXED-OXIDE FUEL FABRICATION PLANT DESCRIPTION

The reference small mixed-oxide (MOX) fuel fabrication plant is the Kerr-McGee Company plant, located in Cimarron, Oklahoma. The description of the

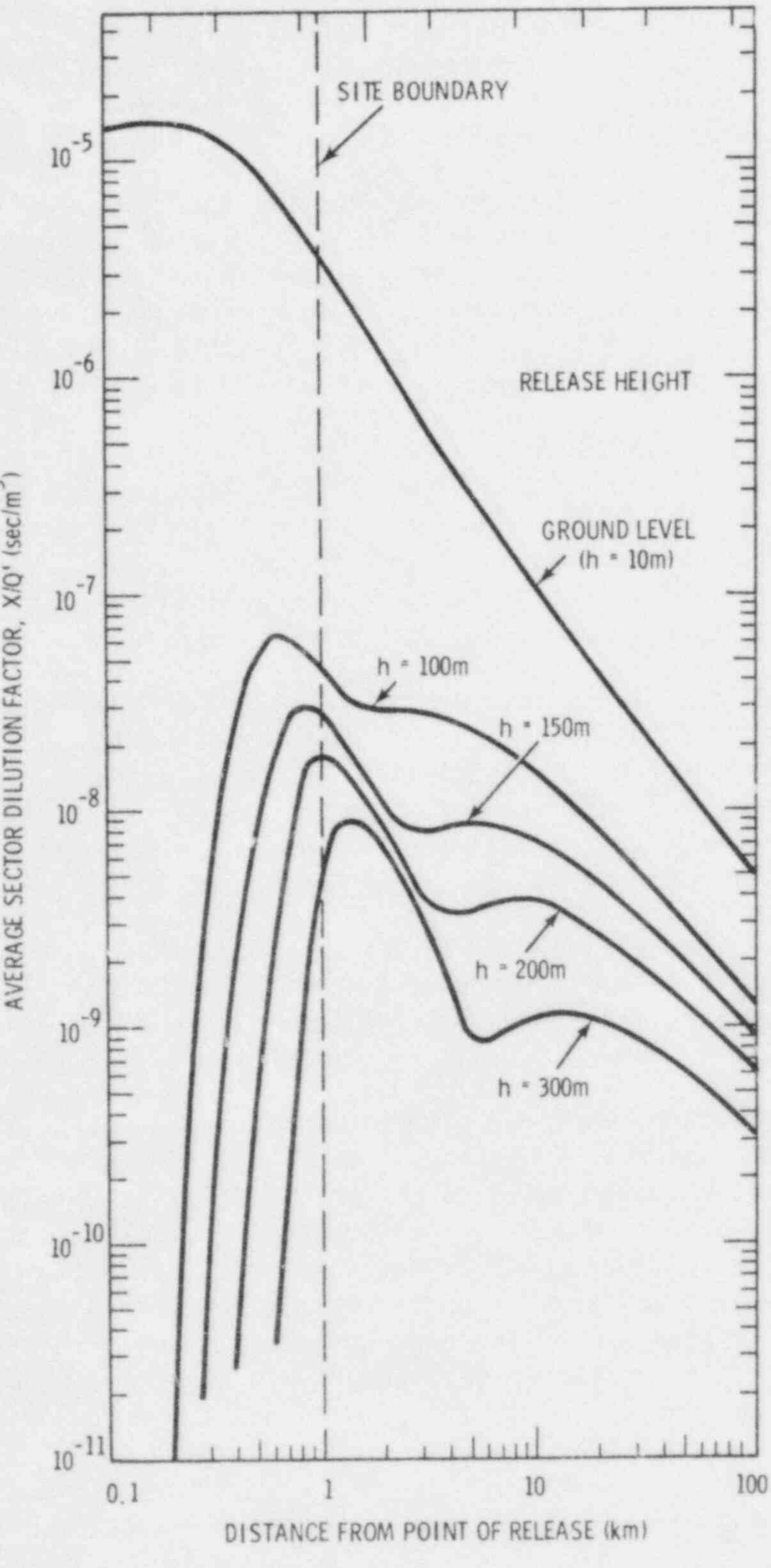


FIGURE A.1-1. Average ($\bar{\chi}/Q'$) Values Versus Distance in a Sector from the Reference Site

Cimarron MOX plant presented in this section is based primarily on the facility description in Appendix A of Reference 1. Additional details can be found in Reference 1. The use of the Cimarron plant as the reference MOX plant for this study should not be construed as implying anything about the reliability and/or safety of this plant relative to other MOX plants in operation or under construction. Its use facilitates comparisons with the earlier, non-accident, decommissioning study. The facility is assumed to be located on the reference site described previously in Section A.1 of this appendix.

The MOX plant description in Reference 1 is based largely on the Cimarron Plutonium Facility Safety Analysis Report[8] and Environmental Report,[9] with additional information supplied by the staff at the reference facility. For the normal-shutdown decommissioning study,[1] a conceptual head-end process design based on dry blending of preformed plutonium and uranium oxides was added to complement the existing wet-process head-end (based on blending of plutonium and uranium solutions, coprecipitation, and calcination to form a mixed oxide). A conceptual waste evaporator for concentrating liquid waste steams was also added. These conceptual additions to the facility design are also considered in this post-accident decommissioning study.

The description of the MOX facility is divided into two parts. The first part discusses the processes employed at the facility. The second part describes the plant structures and process equipment and their layout.

A.2.1 Mixed-Oxide Plant Processes

Process activities carried out during operation of the reference MOX plant include the following:

1. Conversion of plutonium and uranium nitrates or of plutonium and uranium oxides to $(U\text{-}Pu)O_2$ powder.
2. Production of $(U\text{-}Pu)O_2$ fuel pellets.
3. Manufacture of nuclear fuel rods containing $(U\text{-}Pu)O_2$ pellets.
4. Recovery of plutonium and/or uranium from unirradiated scrap materials.
5. Analytical and quality control functions in support of the activities listed above.

Glove box flow diagrams for the activities associated with mainline MOX fuel fabrication are given in Figure A.2-1. Summary descriptions of the major plant processes are presented in the following subsection; more detailed descriptions are given in Section A.1 of Reference 1.

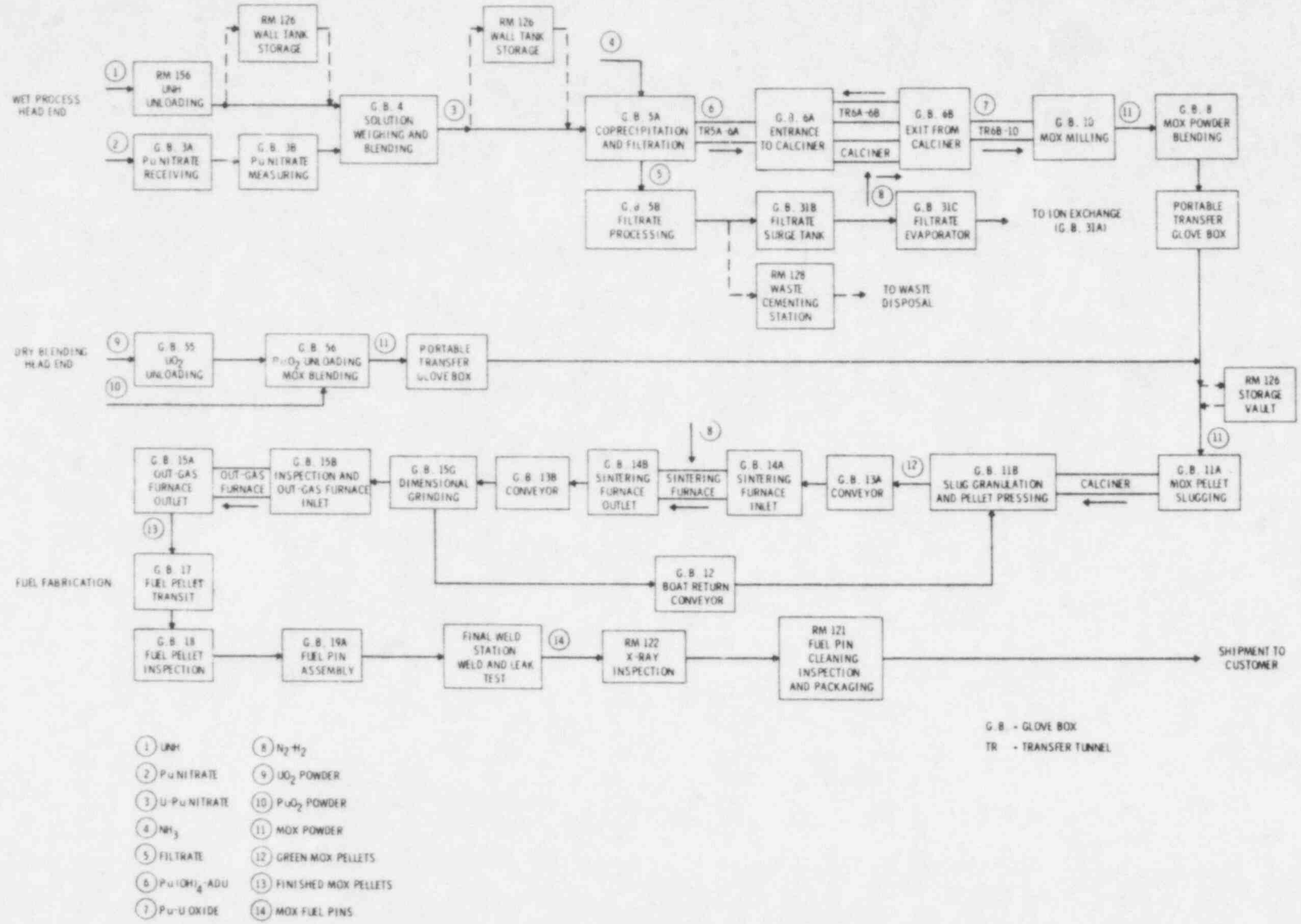


FIGURE A.2-1. MOX Plant Glove Box Flow Diagram, Mainline Fuel Fabrication Process

Coprecipitation Head-End Process

Coprecipitation of plutonium hydroxide and ammonium diuranate (ADU) from plutonium nitrate and uranium nitrate hexahydrate (UNH) feed solutions is carried out in glove boxes located in Room 128.

Plutonium nitrate feed solution is received in 10-ℓ polyethylene bottles that are transported in L-10 containers.[10] After checking an L-10 container for contamination due to leakage, a polyethylene bottle is removed from its container and transferred into the unloading glove box where it is weighed for receiving accountability. The plutonium nitrate solution is then vacuum transferred from the bottle to a 12 cm I.D., 14-ℓ transfer tank backed by a similar 14-ℓ vacuum trap tank. The empty bottle is washed with dilute nitric acid and the wash liquor is also vacuum transferred to the transfer tank. The plutonium nitrate feed solution is pumped from the transfer tank to one of two weighing stations for blending with UNH.

UNH feed solution is received in 0.21-m^3 steel drums with polyethylene liners. In the UNH receiving room (Room 156), the UNH is vacuum transferred from the drums to a designated 107-ℓ holding tank in the wall of the process building vault or directly to the weighing station for blending with plutonium nitrate. Transfer lines are equipped with thermostatically controlled electrical heating traces to prevent crystallization in the lines.

The weighed and blended solution of $PU(NO_3)_4$ and UNH can be pumped to one of the 107-ℓ wall tanks for storage until needed, or for further assay adjustment, or it can be pumped directly to a precipitation column.

In the coprecipitation step, mixed nitrate feed solution of known U/Pu ratio and acid concentration is transferred to a precipitation column together with a metered stream of ammonium hydroxide solution. The two preheated streams are blended and vigorously mixed to form a coprecipitate slurry that continuously overflows to a heated and agitated digestor tank, then to a pH adjustment tank, and to a second digestor tank. Following this, the slurry overflows to pan filter. The filter cake is washed with an ammonium hydroxide spray, manually removed with a knife, and loaded into metal trays.

Metal trays containing the wet filter cake are inserted manually, one at a time, into a retort furnace. The first section of the furnace provides a 200°C drying zone. The second section of the furnace provides an 850° to 950°C zone in a nitrogen atmosphere and is used for calcination and reduction of the coprecipitate to $(U\text{-}Pu)O_2$.

Trays of calcined filter cake are transferred to a hammer mill, where the mixed oxide is milled to ceramic-grade powder. The powder is then passed through a sieve, cross-blended in a V-type blender, and loaded into critically safe 2-ℓ stainless steel containers. These containers are loaded into a

portable glove box (on wheels) that is used for short-term in-vault storage of the powder or for transfer of the powder to the pellet processing area.

Conceptual Dry Blending Head-End Process

For the conceptual alternative dry process head-end, plutonium oxide and uranium oxide powder received at the plant are assumed to be of a quality that permits direct blending for fuel manufacture without the need for prior wet processing. Direct blending operations are carried out in glove boxes located in Room 155.

The PuO_2 is received in approved double containers. The inner container is removed, bagged into Glove Box 56, and opened. The PuO_2 is then transferred to the hammer mill (if necessary) and then to the PuO_2 feed hopper for storage until blending.

The UO_2 is received in 0.21-m^2 steel drums. A drum is positioned in Glove Box 55, which is floor-mounted for this purpose. The UO_2 is then unloaded into trays as needed for blending. The trays are passed into Glove Box 56, and the UO_2 is milled (if necessary) and loaded into the UO_2 feed hopper.

When a blend is to be made, the two oxides are metered from their respective feed hoppers into separate batch-weighing hoppers and then drained to a V-type blender. The two batch-weighing hoppers are interlocked to permit control of Pu:U ratio and blend size. Normally, several (three or four) sub-blends are made, and then reblended to make a batch.

After blending, the finished mixed oxide is packaged into critically safe 2-ℓ cylindrical stainless steel containers and manually loaded into a portable glove box as described previously.

Pellet Processing

The operations conducted in the pellet processing area include: preslugging, granulating, pellet pressing, sintering, centerless grinding, pellet washing and outgassing.

Dry ceramic oxide powder is batch transferred to the pellet process area in a small portable transfer glove box. In the pellet process area, the mixed oxide powder is transferred into the press glove box and loaded into the feed hopper of the slugging press, which is used for preliminary forming of pellets to increase the oxide density. The pellets formed by the slugging press are calcined and then ground up to provide feed for the final pellet forming press.

Two parallel presses are used for final pellet formation. The pellets formed are loaded into molybdenum sintering boats that are placed onto a belt conveyor and automatically inserted through a nitrogen flushed air-lock into a

sintering furnace with temperatures of 1600° to 1650°C. The sintered pellets are manually fed, one at a time, to a centerless grinder where they are ground to precise dimensional tolerances. The pellets then are passed through one of two parallel vacuum retort furnaces where they are first dried in flowing nitrogen and then outgassed at high vacuum at a temperature of 500° to 800°C. Outgassed pellets are removed from the furnace, allowed to cool, and transferred to the fuel rod fabrication area.

Fuel Rod Fabrication

The final operations for the manufacture of nuclear fuel rods containing MOX pellets are conducted in Rooms 123, 122 and 121. Fuel rod fabrication operations consist of pellet inspection, core loading, subassembly decontamination, fuel rod closure and weld decontamination. Final fuel rod inspection operations consist of leak detection, x-ray inspection, and dimensional and visual inspections.

Fuel pellets from the fabrication area are individually inspected for contamination or physical irregularities. They are then manually lined up in horizontal rows in a V-shaped trough in preparation for insertion in a cladding tube.

Zirconium cladding tubes received at the plant are inspected, cleaned ultrasonically, and one end cap is welded in place with an automatic welder inside a glove box with an inert atmosphere. The tubes are then loaded into a "Gatling Gun Fixture," a long tube 30 cm in diameter with inserts that permit up to 60 cladding tubes to be held in place. The fixture is attached to a glove box, and cladding tubes are manually removed, one at a time. The tubes are then loaded horizontally with the fuel pellets, the appropriate spacers and other hardware items previously placed in the loading troughs, and returned to the fixture.

When all of the 60 tubes have been assembled, the Gatling Gun Fixture is moved to the final weld station glove box where the tubes are evacuated and filled with helium or other inert gas, and the final end caps are welded in place.

Welds for completed fuel pins are checked at an inert gas leak test station. The rods are then removed from the Gatling Gun Fixture and transferred to the final rod inspection area. The fuel rods are x-rayed to check the end cap welds and the rod loadings, after which they are placed in a controlled process sink where the welds are scrubbed with cleanser and water to remove low-level surface contamination. The rods are then examined on a high-precision granite surface plate to detect bowing of as little as a few micrometers. Rods that meet inspection requirements are then packaged for shipment to the customer. Rods that do not meet inspection requirements are returned

to the rod fabrication area where the fuel pellets are removed, visually inspected, and inserted into new rods.

Scrap Recovery

The reference MOX plant contains two systems for the recovery of plutonium and/or uranium from scrap materials--a clean scrap recovery system and a dirty scrap recovery system. Glove Box diagrams for the two scrap recovery systems are shown in Figures A.2-2 and A.2-3. The clean scrap recovery system, located mainly in Room 127, is used to recover product from noncontaminated UO_2-PuO_2 reject pellets or grinding fines and from filtrate from the coprecipitation process. The dirty scrap recovery system, located mainly in Room B01, is used to recover product from chemically contaminated UO_2-PuO_2 reject pellets or powder, from combustible solids (paper, cloth, etc.), from organic "noncombustible" solids (gloves, plastics, etc.), and from contaminated aqueous and organic plutonium-bearing solutions. If necessary, both systems can utilize the solvent extraction equipment located in Glove Box 27A (Room B05). The waste storage tanks in Room B02 are used for storage of aqueous waste solutions generated by either of the scrap recovery systems. Details of the scrap recovery processes are presented in Section A.1.5 of Reference 1. Scrap recovery flow diagrams were presented previously in Figures A.2 and A.3.

Waste Treatment

Aqueous waste streams from the solvent extraction and anion exchange scrap recovery cycles are filtered and stored temporarily in 10-m^3 waste receiving tanks. The filtrate is then assumed to be concentrated by passing it through two conceptual waste evaporators in series. The evaporator bottoms (5% to 10% of the feed flow) are discharged into 0.21-m^3 steel drums and solidified for disposal. The evaporator vapors are exhausted to the stack via the ventilation system. Condenser cooling water and evaporator steam condensate are routed through an in-line monitoring system to the sanitary sewer.

Sanitary wastes originating from the nonradioactive laundry, showers, and sinks proceed batchwise to a 37.9-m^3 holding tank, where they are sampled for plutonium content and discharged to the sanitary lagoon. The alpha contamination discharged to the lagoon is approximately 1μCi per 3.8 m^3.(9) Sanitary wastes from the toilets pass through a septic tank system and are discharged into the sanitary lagoon. Waste from the hot laundry is collected batchwise in a 2.3-m^3 holding tank, sampled for plutonium content, and either discharged to the sanitary lagoon or evaporated and the residue solidified for offsite disposal.

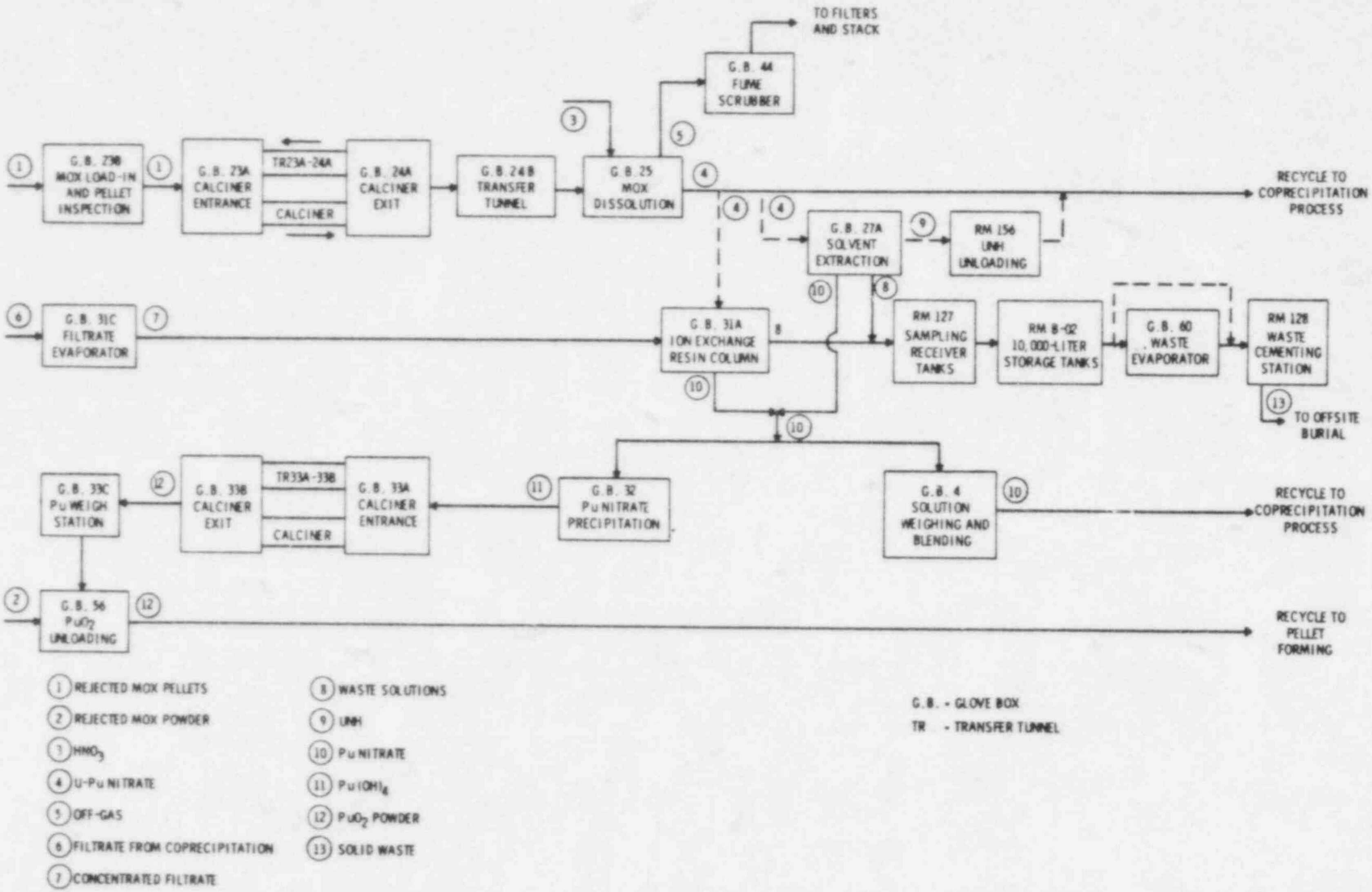


FIGURE A.2-2. MOX Plant Glove Box Flow Diagram, Clean Scrap Recovery

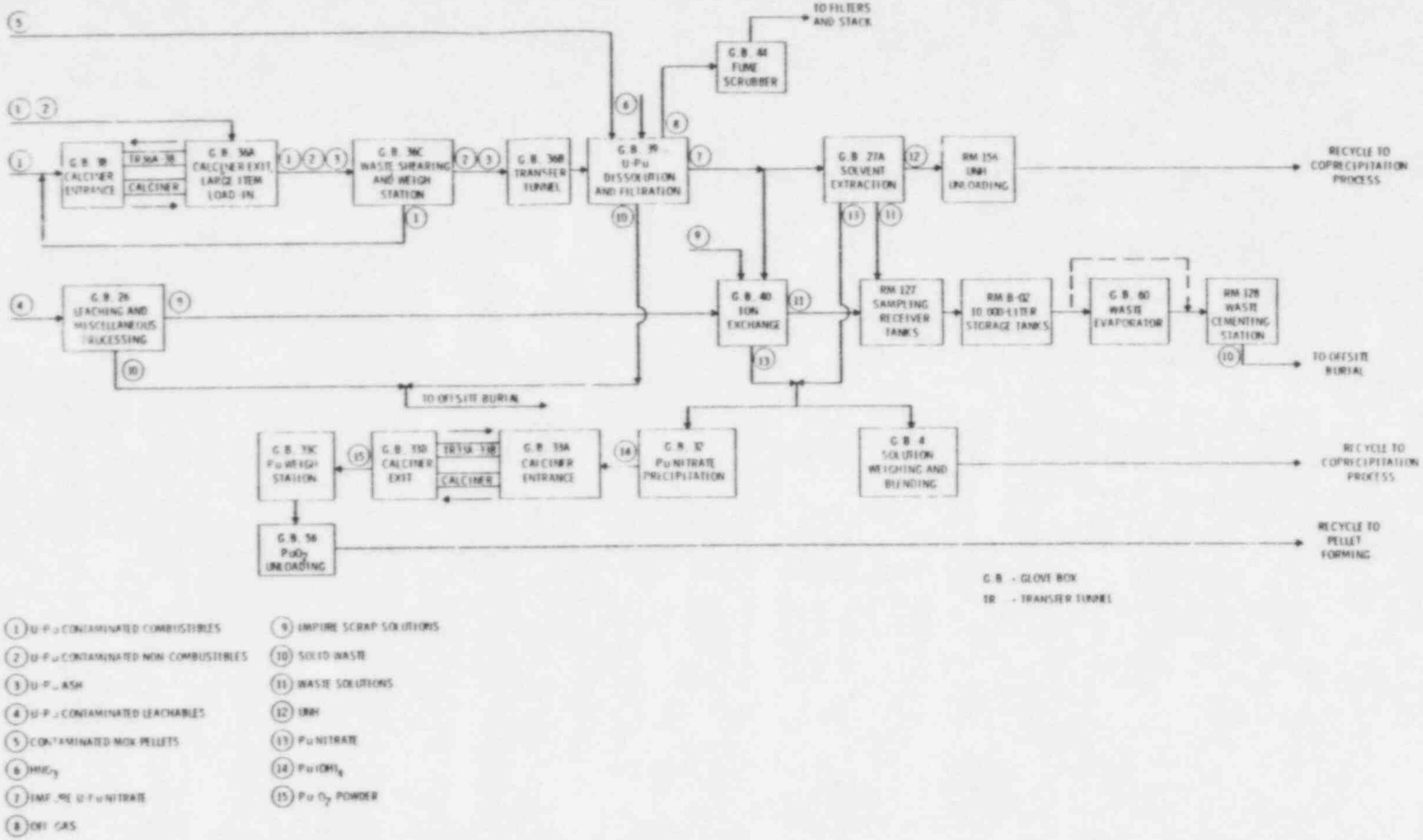


FIGURE A.2-3. MOX Plant Glove Box Flow Diagram, Dirty Scrap Recovery

A.2.2 Mixed Oxide Plant Structures, Equipment, and Layout

Summary descriptions of the major structures and equipment and their layout at the reference MOX plant are presented in this section. More detailed descriptions are given in Section A.2 of Reference 1.

The reference MOX plant is assumed to be located on the reference site described in Section A.1 of this appendix. The MOX plant and a cooling tower for the plant air conditioning system are located in a fenced exclusion area of about 1.2 hectares within the reference site; as shown in Figure A.2-4. Two sewage lagoons are located outside the exclusion area but within the reference site; these lagoons handle discharge from the nonradioactive laundry, showers, sinks and toilets in the plant. Because of very low alpha contamination present in the discharge from these systems, the lagoons are postulated to be drained and decontaminated as part of normal decommissioning activities.

Main Plant Building

All of the major activities at the reference MOX plant are carried out within the main plant building. The floor plan for this building is shown in

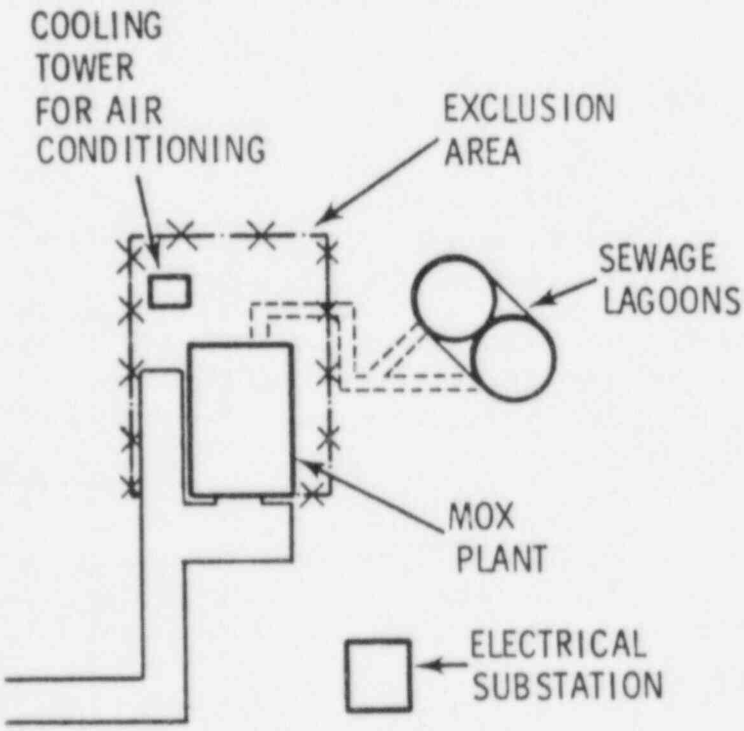


FIGURE A.2-4. Reference MOX Plant Site Plan

Figure A.2-5. The nearly rectangular building is 54.9 m long by 32.3 m wide at the north end, and 28.5 m wide at the south end. It has a partial second floor of approximately 28.5 m by 14.6 m that houses the supply air fan room and the exhaust air fan room. A partial basement in the northeast corner of the building houses the dirty scrap recovery and waste treatment areas.

The outside building walls are approximately 7.3 m high at the north end and 5.5 m high at the south end. The second floor is about 5.3 m above the first floor and has walls that extend 4.3 m above the second floor level.

The roofs and the second floor are constructed of precast concrete double-tee slabs about 2.4 m wide by 0.5 m thick. The roof is supported by the exterior walls and by precast beams and columns in the building interior. The exterior walls are composed of precast concrete panels about 3.7 m wide that run the full height of the building. These panels are a minimum of 0.15 m thick, with inner and outer layers of concrete over a central styrofoam insulation core. Interior building partitions are concrete block 0.15 m to 0.2 m thick.

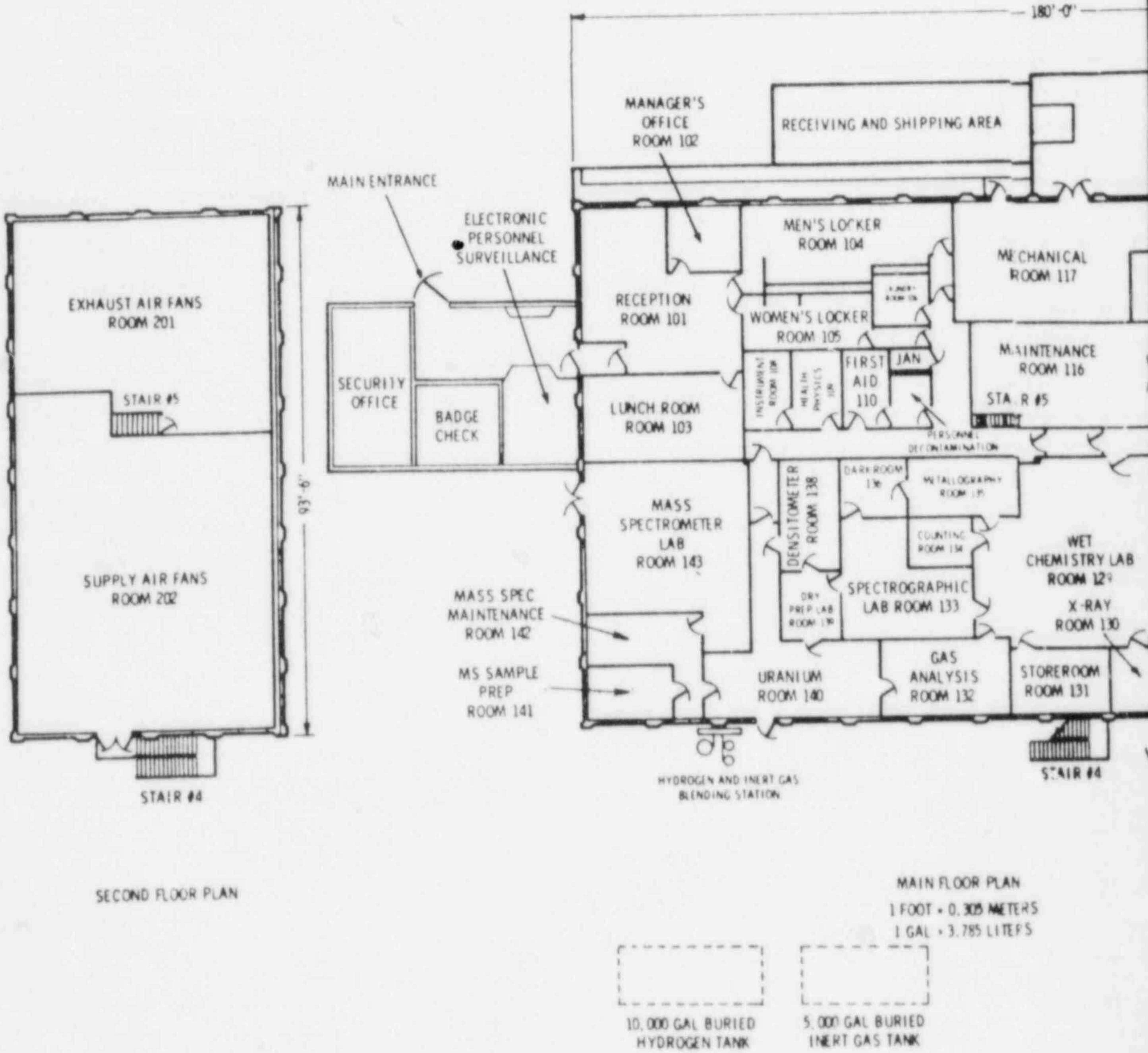
Administrative and support facilities (e.g., offices, locker rooms, lunch room and laundry) are located in the southwest corner of the building. The majority of the remaining area in the building is taken up by process equipment and laboratories.

The process and laboratory areas of the MOX plant typically consist of rooms with custom-made, stainless steel and plexiglass glove boxes housing the necessary equipment. Various support equipment (e.g., electrical controls and conduit, piping, tanks, and sealed passages between gloves boxes) is also located where needed. The rooms are laid out to facilitate efficient operation of the plant, with a minimum of extra space.

Detailed descriptions of the plant process and laboratory areas are provided in Section A.2 of Reference 1. Included in these descriptions are tabulations of the glove boxes and major equipment items located in each room, with estimates of shipping volumes for the various items. Assumptions used to estimate shipping volumes are given on pp. A-19 and A-20 of Reference 1.

There are several additional plant areas that provide specialized functions and that may be of particular significance to post-accident decommissioning of the MOX plant. These areas, described in the following subsections, are as follows:

- the storage vault and associated wall tanks (Room 126)
- the equipment maintenance room (Room 116)
- the supply air fan room (Room 202)
- the exhaust air fan room (Room 201).


180'-0"
MANAGER'S OFFICE ROOM 102
RECEIVING AND SHIPPING AREA
MAIN ENTRANCE
ELECTRONIC PERSONNEL SURVEILLANCE
MEN'S LOCKER ROOM 104
MECHANICAL ROOM 117
EXHAUST AIR FANS ROOM 201
RECEPTION ROOM 101
WOMEN'S LOCKER ROOM 105
MAINTENANCE ROOM 116
SECURITY OFFICE
BADGE CHECK
LUNCH ROOM ROOM 103
FIRST AID 110
JAN
STAIR #5
STA. R #5
PERSONNEL DECONTAMINATION
93'-6"
MASS SPECTROMETER LAB ROOM 143
DENSITOMETER ROOM 138
DARK ROOM 136
METALLOGRAPHY ROOM 135
COUNTING ROOM 134
WET CHEMISTRY LAB ROOM 129
SUPPLY AIR FANS ROOM 202
MASS SPEC MAINTENANCE ROOM 142
SPECTROGRAPHIC LAB ROOM 133
X-RAY ROOM 130
MS SAMPLE PREP ROOM 141
URANIUM ROOM 140
GAS ANALYSIS ROOM 132
STOREROOM ROOM 131
STAIR #4
HYDROGEN AND INERT GAS BLENDING STATION
STAIR #4
SECOND FLOOR PLAN
MAIN FLOOR PLAN
1 FOOT = 0.305 METERS
1 GAL = 3.785 LITERS
10,000 GAL BURIED HYDROGEN TANK
5,000 GAL BURIED INERT GAS TANK

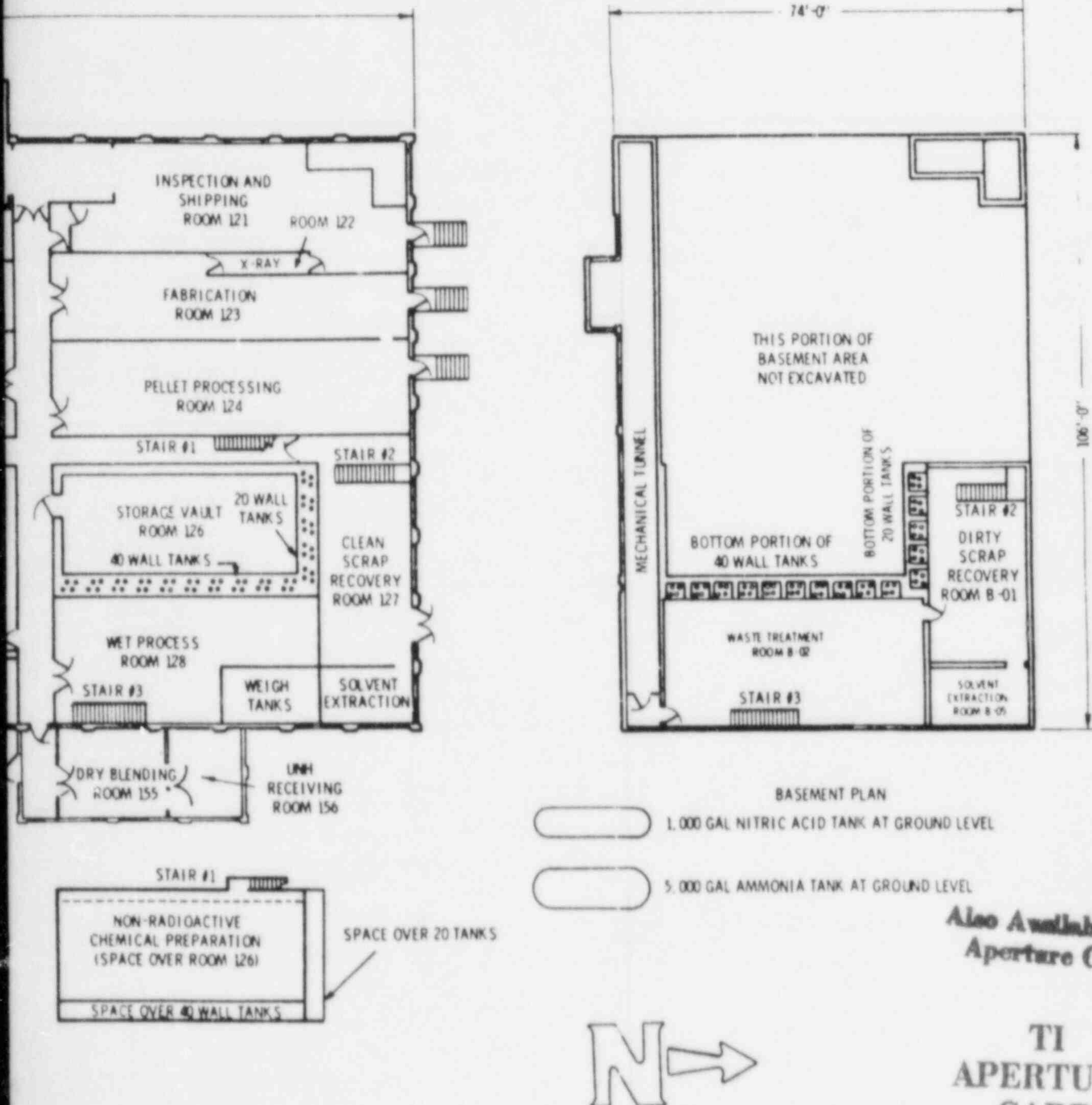


FIGURE A.2-5. Floor Plan of the Reference MOX Plant

Storage Vault and Wall Tanks. The storage vault has approximate interior dimensions of 13.7 m by 6.0 m by 4.3 m high, and provides space for temporary storage of plutonium and uranium solutions, and plutonium oxide and mixed oxide powder. It is designed to provide protection against tornadoes, and is capable of withstanding wind loads of 480 km/hr and a pressure change of 0.34 atm. The north and east walls of the vault are constructed of reinforced concrete about 1.2 m thick and contain 20 and 40 tanks, respectively, that are used for storage of U-Pu nitrate, UNH, and scrap solutions.

The wall storage tanks are about 9.1 m long and 0.14 m O.D. and are constructed from schedule 80 stainless steel pipe. To prevent absorption of storage tank leakage by the concrete wall, each tank is mounted inside a sleeve of 0.15-m-I.D. schedule 40 wrought iron pipe. Pumps, valves, and piping connections for the wall storage tanks are heated in Rooms B01 and B02. A plan view of the storage vault and wall tanks is shown in Figure A.2-6.

Equipment Maintenance Room. The equipment maintenance room is about 10.7 m by 6.1 m by 4.3 m high, and is located adjacent to the main processing area corridor. A stainless steel glove box is provided for maintenance and repair of contaminated equipment. Other major features of the room are a fence hood, work benches, and various maintenance tools.

Supply Air Fan Room. The supply air fan room contains the building ventilation intake system, and is located on the second floor directly above the laboratory and maintenance areas (see Figure A.2-5). Access to this room is by an external stairway on the east side of the building. The supply air fan room contains the louvers, supply air fans, motor-driven dampers, dust filters, and heating and cooling coils needed to condition building intake air. A mixing plenum and volume controller are also located in this room, as are the main electrical distribution panel and distilled water treatment system for the plant.

Exhaust Air Fan Room. The exhaust air fan room is also located on the second floor of the building, adjacent to the exhaust air stack located on the roof of the building. Access to the exhaust air fan room is through the supply air fan room or by an interior stairway that terminates in the equipment maintenance room. The exhaust air fan room contains the high efficiency particulate air (HEPA)-filtered exhaust air systems (i.e., the process exhaust air system and the room air exhaust system). The plant ventilation system is described below.

Piping and Ductwork

Substantial amounts of piping and ductwork are present in the process, laboratory, and maintenance areas of the reference MOX plant. Estimates of the

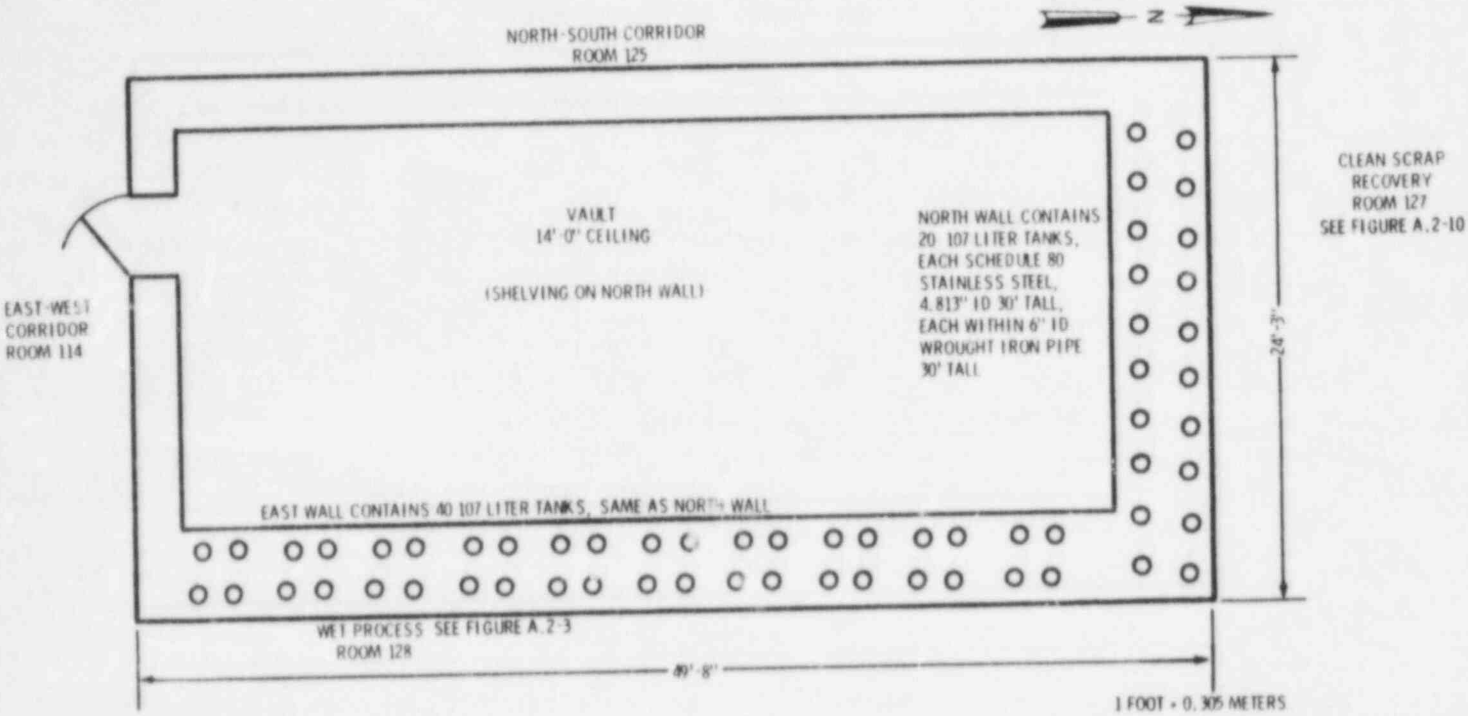


FIGURE A.2-6. Plan View of Storage Vault and Wall Tanks (Room 126)

lengths and volumes of this piping and ductwork are given by room in Table A.2-2. Piping includes process piping, service piping, electrical conduit and instrumentation lines. Piping estimates are based on engineering judgment, accounting for room size and the type of operation carried out in a room. Ductwork estimates are based on room size and on the number of glove boxes and hoods in a room.

Plant Ventilation System

Air inside the reference MOX plant is maintained at a pressure below atmospheric (-6 mm water gage) to ensure ambient air flow into the building. The flow of air within the building is controlled so that air moves from clean areas to areas with successively higher contamination potential, and finally into the glove box enclosures containing process equipment where the ventilation system becomes effectively a gaseous radioactive effluent treatment system. A simplified air flow diagram for the plant ventilation system is shown in Figure A.2-7.

Air is supplied to the building through an intake system that provides for dust filtration, heating or chilling as appropriate to the season, and distribution to the various rooms of the building. All air is supplied to the rooms

TABLE A.2-2. Piping, Conduit, and Ductwork in Process, Laboratory, and Maintenance Areas of the Reference MOX Plant

Room Number	Piping, Conduit, etc.(a,b) Length (m)	Piping, Conduit, etc.(a,b) Shipping Volume (m^3)	Ductwork(c) Length (m)	Ductwork(c) Shipping Volume (m^3)
116	320	1.8	15	0.7
121	460	2.6	18	0.8
123	600	3.4	36	1.6
124	600	3.4	52	2.3
126	140	0.8	14	0.6
127	720	4.2	46	2.1
128	650	3.8	39	1.8
129	370	2.2	35	1.6
130	90	0.5	4	0.2
131	140	0.8	6	0.3
132	230	1.3	13	0.6
133	240	1.4	12	0.5
134	90	0.5	4	0.2
135	170	1.0	10	0.5
136	90	0.5	4	0.2
138	160	0.9	6	0.3
139	120	0.7	4	0.2
140	320	1.8	16	0.7
141	130	0.8	9	0.4
142	180	1.0	7	0.3
143	270	1.6	14	0.6
155	190	1.1	15	0.7
156	210	1.2	5	0.2
B01	490	2.8	21	0.9
B02	740	4.3	18	0.8
B05			7	0.3
201	230	1.3	61	2.8
202	290	1.7	30	1.4

(a) Includes process piping, electrical conduit and instrument lines.
(b) Assume average O.D. of 38 mm.
(c) Assume average dimensions of 0.3 m x 0.3 m.

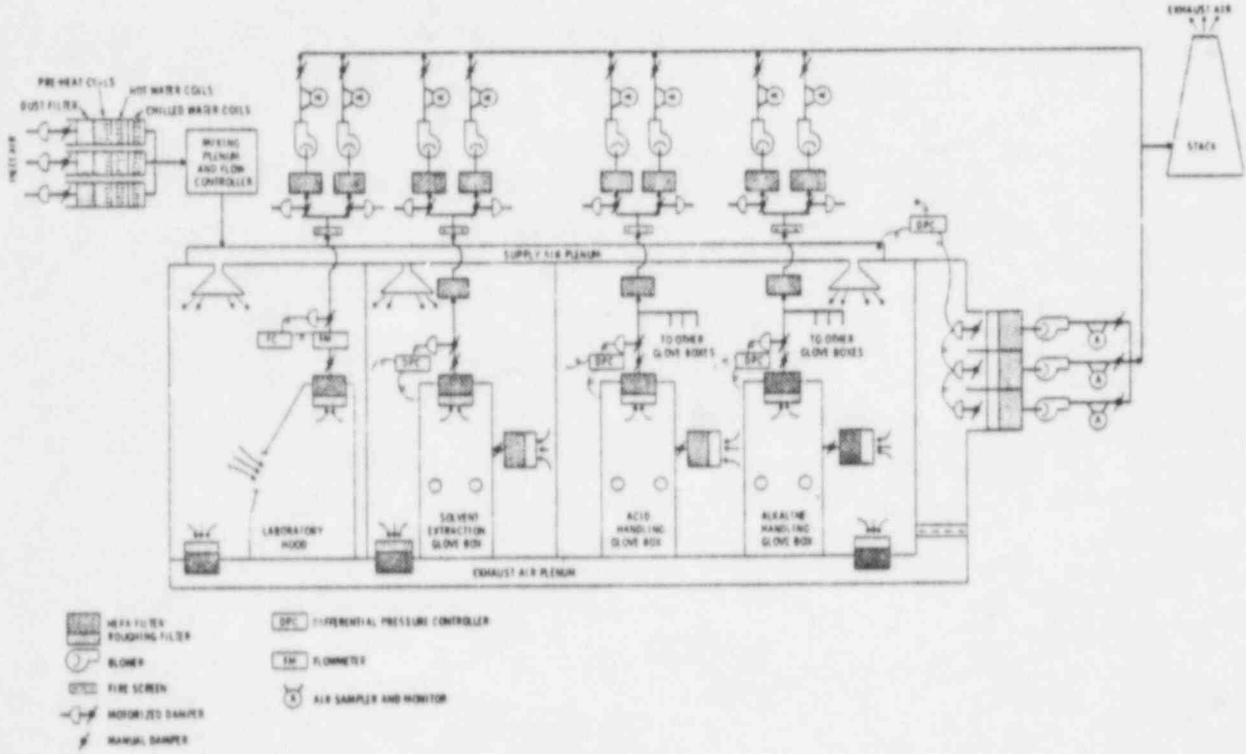


FIGURE A.2-7. Simplified Flow Diagram for the Reference MOX Plant Ventilation System

of the plant through ducts and diffusers located in the ceilings. The flow of air in a room is from ceiling to floor, and all room air is exhausted through the floor into underground exhaust ducts. A roughing filter followed by a HEPA filter is installed in the floor of each room at the entrance to the underground ducts. The room air exhaust ductwork leads to a final bank of HEPA filters installed in the exhaust air fan room ahead of the exhaust air fans.

Supply air and room exhaust air fan systems consist of three fans each, any two of which can supply and exhaust the required air though the interior of the building. The third fan serves as a standby fan in each system and also as an emergency fan to increase the airflow in any given area when required. Supply and exhaust air fans are interlocked so that a failure of a fan in either system will shut down the corresponding fan in the other system. All supply and exhaust fans are equipped with back-flow preventers.

All operations involving handling of plutonium are performed in glove boxes maintained at a negative pressure compared to the room atmosphere (-12 mm water gage). Room air entering a glove box is filtered by roughing and HEPA filters. Air leaving a glove box is filtered first by roughing and HEPA filters at the glove box and then by a second HEPA filter located in each room for

all glove boxes in the room. The air then enters a central ductwork system and is filtered by a final bank of HEPA filters before being exhausted from the plant.

Air for hoods in the laboratory area is drawn in from the room without filtration. Exhaust air is filtered once at the hood and once more before discharge into the central stack.

The process exhaust fan system for glove boxes and laboratory hoods is divided into four separate subsystems that exhaust the air from the following glove boxes and laboratory hoods:

- acid handling glove boxes
- solvent extraction glove boxes
- glove boxes containing alkaline solutions
- all laboratory hoods.

The normal exhaust volume from the plant (both room air exhaust and process exhaust) is 1400 m^3/min $\pm$ 140 m^3/min, depending on filter conditions and atmospheric conditions.

An air monitoring system in the MOX plant provides continuous sampling and measurement of general room air and stack effluent concentrations. Room air samples are collected continuously at approximately 95 fixed locations throughout the plant using a central vacuum system to pull room air through filter paper media. Plutonium radioactivity is determined by counting 20 to 30 of these filters each day in a calibrated alpha counter. Additional room air samples are collected with portable air samplers during nonroutine operations and/or in work areas not serviced by the central vacuum system. Stack monitoring is accomplished by continuously sampling air from the stack and filtering it through a fixed filter. This filter is monitored continuously by a system capable of detecting 0.001 of MPC within one hour. The stack filter is changed weekly and counted in a calibrated alpha counter to determine the plutonium activity released in the stack effluent.

Liquid Waste Handling

Contaminated liquid waste streams are assumed to be filtered and concentrated by evaporation prior to solidification. Sanitary waste from nonradioactive portions of the plant are routed to the sanitary lagoon. Facilities for handling contaminated and sanitary liquid wastes are described in the following paragraphs.

Contaminated Wastes. Contaminated aqueous waste streams are filtered and stored temporarily in 10-m^3 waste receiving tanks located in the waste treatment room (Room B02). The filtrate is then assumed to be concentrated by evaporation in a conceptual two-stage evaporator system.

The waste evaporator system is contained in a floor-mounted, stainless steel and plexiglass glove box. The system is composed of matched pairs of evaporators, de-entrainers, and mist eliminators, coupled in a series arrangement via an interstage vapor condenser. The system is critically safe by geometry and is constructed of stainless steel. The capacity of the system is 125 ℓ/hr of feed solution. Emissions are designed to be one-tenth of EPA's allowable <0.5 μCiα/GW-yr for the total fuel cycle.[11] The evaporator vapors are exhausted to the plant stack via the plant ventilation system. The concentrated wastes produced by the evaporator are routed to the waste solidification station in the wet process room (Room 128) to be solidified and packaged for disposal. The conceptual waste evaporator system is described in more detail in Section A.2.10 of Reference 1.

Sanitary Wastes. The MOX plant site includes two sanitary lagoons that receive the discharge from the cold laundry, showers, sinks, and toilets, as well as the condenser cooling water and evaporator steam condensate from the conceptual contaminated liquid waste evaporator system. Each lagoon covers an area of about 1850 m^2 and has a depth of 1.2 m. The sanitary lagoons have a very low alpha contamination (about 1 μCi of plutonium alpha radioactivity per 3800 ℓ of liquid discharged[9]. Based on a mean annual evaporation rate of 2.14 m per year, the annual input of plutonium radioactivity to the two lagoons from normal operations is estimated to be 2.2×10^{-3} Ci/yr. The total amount of plutonium in the lagoons after 10 years of normal operation is estimated to be about 0.25 g.

A.3 REFERENCE URANIUM FUEL FABRICATION PLANT DESCRIPTION

The reference uranium fuel fabrication (U-Fab) plant is the Wilmington, North Carolina, plant of the General Electric Company. The description of the Wilmington U-Fab plant presented in this section is based primarily on the facility description in Appendix A of Reference 2; additional details can be found in Reference 2. The use of the Wilmington plant as the reference U-Fab plant for this study should not be construed as implying anything about the reliability and/or safety of this plant relative to other U-Fab plants in operation or under construction. Its use facilitates comparisons with the earlier, non-accident, decommissioning study. The facility is assumed to be located on the reference site described previously in Section A.1 of this appendix.

The U-Fab plant description in Reference 2 is based largely on the Special Nuclear Materials Application for Wilmington Plant[12] and the Environmental Report.[13] Additional information was supplied by the staff at the reference facility.

The Wilmington plant currently employs two head-end processes to convert gaseous UF_6 to UO_2. The primary method is a chemical process involving hydrolysis of vaporized UF_6 to ammonium diuranate (ADU) precipitate using ammonia, followed by reduction and calcining of the ADU to dry UO_2 powder. The secondary method involves direct conversion of UF_6 vapor to U_3O_8 in a flame conversion reactor and subsequent reduction of the U_3O_8 to UO_2 powder in a reduction-calciner. Both head-end processes are conceptually decommissioned in this study.

The UO_2 powder from either head-end process is milled and pressed into pellets which are sintered and ground to size. The pellets are loaded into rods and sealed. The rods are assembled into bundles for use in light water reactors.

The description of the U-Fab plant is divided into two parts. The first part discusses the processes employed at the plant. The second part describes the plant structures and process equipment and their layout.

A.3.1 U-Fab Plant Processes

Process activities carried out during operation of the reference U-Fab plant include the following:

1. Conversion of uranium hexafluoride (UF_6) to uranium dioxide (UO_2) powder.

2. Fabrication of UO_2 pellets.

3. Assembly of UO_2 fuel rods and UO_2-Gd_2O_3 shim rods.

4. Assembly, storage and packaging of UO_2 fuel bundles for light water reactors.

5. Recovery and purification of uranium from scrap materials.

6. Treatment of fluoride, nitrate and radioactive liquid wastes.

7. Analytical, quality control, maintenance, and process development functions in support of the activities listed above.

A process flow diagram for the reference U-Fab plant is shown in Figure A.3-1. Summary descriptions of the major plant processes are presented in the following subsections; more detailed descriptions are given in Section A.1 of Reference 2.

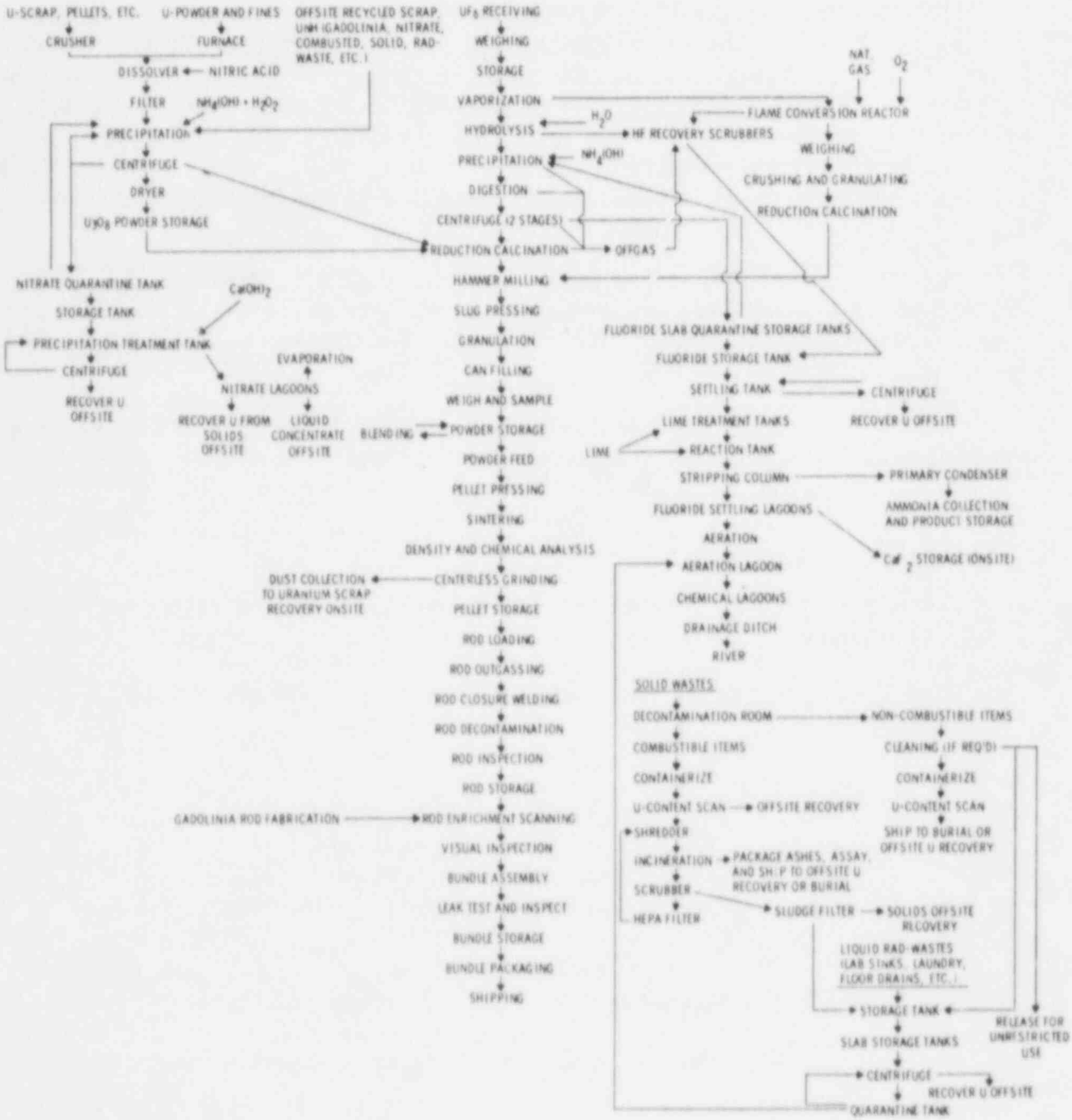


FIGURE A.3-1. Reference U-Fab Plant Process Flow Diagram

Primary Head End UF_6 Chemical Conversion

Uranium hexafluoride (UF_6) enriched from 2 to 4 wt% in ^{235}U arrives by truck at the plant site in 2300-kg, 0.76-m-diameter cylinders (Model OR-30B). UF_6 enriched slightly about 4 wt% in ^{235}U arrives in 25-kg, 0.13-m-diameter cylinders (Model OR-5A). The UF_6 cylinders are protected by outer containers during shipment.

Upon receipt, the UF_6 cylinders are removed from the shipping containers and weighed for accountability purposes. The cylinders are then stored or transferred to the vaporization room to provide process feed.

For vaporization, each cylinder is transferred by overhead bridge crane to one of 11 vaporization chambers. After the cylinder is connected to a flexible discharge line, it is heated by electrically heated air to volatilize the UF_6.

The UF_6 vapors are routed to one of four vessels filled with water, where the vapors are hydrolized to form UO_2F_2 and HF. The HF in the off-gas is scrubbed and may be recovered as a by-product. The uranyl fluoride solution is recirculated through one of two identical hydrolysis storage tanks until the proper UO_2F_2 concentration is achieved, after which it is transferred to the chemical precipitation tank.

In the precipitation tank, ammonium hydroxide is added to the solution to precipitate uranium as ADU. The resulting ADU slurry is transferred to a digester tank for a specified time and is then dewatered and concentrated (by two stages of centrifuging) to a paste. The aqueous effluent stream is pumped to quarantine tanks in the fluoride waste treatment system.

The ADU paste is continuously fed to the horizontal chamber of a gas-fired reduction calciner, where the ADU is defluorinated, reduced, and dried to produce ceramic-grade uranium dioxide powder. Off-gas from the calciner passes through a scrubber to remove entrained powder, ammonia, and fluorides prior to filtration. The UO_2 powder discharged from the calciner is placed in 19-ℓ cans for transport to the second-floor UO_2 powder preparation area.

Secondary Head-End UF_6 Direct Conversion

Four flame conversion reactors are connected to three vaporization chambers and can be used to directly convert UF_6 to U_3O_8. In each reactor, UF_6, natural gas, and oxygen are mixed at a carefully controlled temperature to optimally convert UF_6 to U_3O_8 and HF. The HF contained in the reactor off-gas is scrubbed and recovered as a by-product, while the U_3O_8 is retained in filter tubes and collected in one of two identical powder collection pots. U_3O_8 is then pneumatically transferred to a hopper, collected in 19-ℓ cans, and weighed.

The U_3O_8 is crushed and granulated, and the resulting powder is led to a horizontal gas-fired reduction calciner to produce ceramic-grade UO_2 powder.

Pellet Fabrication

The UO_2 powder is processed through a hammer mill, a predensifier press, and a granulator that crushes the compacted powder into material of uniform particle size. The sized particles are placed in 19-ℓ buckets and transferred to the mezzanine storage area, where the buckets are weighed and samples are obtained and analyzed for particle size, enrichment, uranium content and moisture content. If found acceptable, the material is placed in storage and/or blended with other UO_2 to attain the desired enrichment.

When needed, the powder is placed in a hood and dumped into a hopper that gravity-feeds one of the 14 pellet presses located below on the main floor. Right-cylindrical pellets approximately 13 mm in diameter are formed in the pellet press. The green pellets are loaded into molybdenum boats and transferred to the sintering area.

The boats of pellets are charged into one of five continuous sintering furnaces and processed at up to 1650°C in a reducing atmosphere. The pellets are sintered to about 95% of theoretical UO_2 density, after which they are transferred to the grinding area.

In the grinding area, the pellets are dumped into a pellet feeder bowl that orients and feeds them to one of five centerless grinders. After dimensional gauging, the finished pellets are placed in trays and transported to storage cabinets. Reject pellets are packaged and stored for recovery in the uranium purification system.

Rod Assembly

Pellets are removed from storage as needed and carted to one of four rod loading stations where they are loaded into fuel rod mock-up channels and checked against required specifications. An acceptable string of pellets is pushed into an empty zircaloy tube seal-welded at one end. The loaded tubes, now called rods, are placed in rod trays.

The rod trays are transferred to one of three horizontal outgas ovens, which maintain an inert atmosphere below atmospheric pressure at about 260°C. After rods are cooled, they are analyzed for moisture. If acceptable, the rods are moved to one of three final rod closure welding stations. At the station, individual rods are inserted into a controlled-atmosphere weld box, evacuated by vacuum, and then filled with inert gas. An end plug is inserted into the rod and automatically welded in place using the tungsten inert gas process.

The completed rod is removed from the welder and transferred to a table where the weld and rod are inspected. The rods are decontaminated and placed in contamination-free trays in special rod-storage compartments in the bundle assembly area until required at bundle assembly.

Gadolinia Rod Assembly

Gadolinia rods are fabricated in a special facility adjacent to the uranium fuels production area. Dry UO_2 and Gd_2O_3 powders are blended in the proper proportions for fuel-bundle-assembly shim rods. The powders are processed and assembled into rods in essentially the same manner as the UO_2, as described previously.

Fuel Bundle Assembly and Final Inspection

Each fuel rod is scanned for ^{235}U content to confirm the enrichment. Based on rod enrichment requirements for a bundle matrix form, the required number of rods of each enrichment is laid out on an assembly table. The rods are visually inspected for cleanliness and defects and replaced as necessary.

The spacer hardware is positioned within the fixtures on a horizontal bundle-loading table. The fuel rods are inserted into the spacer hardware according to a predetermined sequence. When all rods are in place, the end pieces or tie plates are bolted into position and the assembly is raised vertically, unlocked from the fixture, and removed by an overhead crane to the leak-test and inspection station.

The assembled bundle is leak-tested in a vacuum chamber. The bundle is next placed in a lighted inspection fixture, when the rods are examined for various design requirements. Upon passing the leak test and inspection, the bundle is wrapped in a plastic dust cover and removed by overhead crane to the bundle storage racks to await shipment.

Uranium Scrap Recovery and Purification

Internally generated, "clean" uranium scrap in various physical forms that does not meet quality standards or that is mixed with combustible foreign material is reprocessed through scrap recovery equipment known collectively as the Uranium Purification System (UPS). Material to be reprocessed through the UPS is accumulated in safe batches (normally 19-ℓ buckets) and stored until processed.

Uranium pellets and other compacts are crushed prior to purification. Uranium powder, grinder fines, etc., are processed through a furnace to remove impurities and combustible materials.

Next, the scrap uranium (~21-kg lots) is slowly charged into one of nine dissolver tanks (arranged in sets of three) filled with hot nitric acid (88°C). After dissolution, the uranyl nitrate is filtered, cooled, and sent to one of three precipitation tanks. Ammonium hydroxide and hydrogen peroxide are used to precipitate uranium tetroxide (UO_4 - H_2O) from the solution. The UO_4 slurry is dewatered in a centrifuge, and the UO_4 cake is pumped from the UO_4 receiver tank to a gas-fired reduction calciner. The effluent from the centrifuge is pumped to the nitrate quarantine tank or back to a precipitation tank. In the calciner, the UO_4 is converted to UO_2 powder, collected in 19-ℓ buckets, and returned to the powder storage area in the main process area.

Uranium scrap that is mixed with foreign materials (e.g., gadolinia process wastes, nitrate wastes) and does not meet UPS quality standards for reprocessing is shipped to an offsite contractor for rework and recovery of uranium. The recovered uranium is returned to the facility as UNH and is used as feed for the main process.

Liquid Waste Processing

Uranium-bearing liquid waste streams are segregated as fluoride wastes, nitrate wastes, and radwastes, allowing individual treatment of each waste stream in a manner compatible with the recycle of valuable materials. Each waste stream has its own quarantine tank system within the main building to permit temporary storage of the liquid wastes. Based on uranium content, the liquid wastes are either released for final waste treatment or are recycled to recover the uranium residuals. Liquid waste processing at the reference U-Fab plant is shown schematically in Figure A.3-2.

Fluoride Wastes. Chemical wastes generated from the UF_6 to UO_2 conversion process are pumped from the fluoride waste quarantine tank system to a 246-m^3 storage tank, where the wastes are continuously recirculated to keep solids suspended until transfer to a 379-m^3 settling tank. In the settling tank, the solid material settles and is centrifuged out and stored in 19-ℓ buckets until recycled or discarded. The supernate is decanted into two 45-m^3 tanks where it is treated with lime slurry [Ca $(OH)_2$] to precipitate uranium residuals in a calcium fluoride matrix.

Final adjustment of the chemistry occurs by adding lime in a reaction tank in the ammonia recovery system. The liquid waste is pumped into the top of a packed stripping column. In the column, steam is intimately contacted with the liquid waste to strip ammonia from the waste solution. The ammonia vapors emerging from the top of the column flow into a condenser where the ammonia is condensed into an aqueous solution and subsequently pumped to an ammonia collection and storage system. The stripped fluoride solution emerging from the bottom of the column is pumped to the fluoride storage lagoons where the CaF_2 solids are allowed to settle. The clarified liquid in the storage lagoons

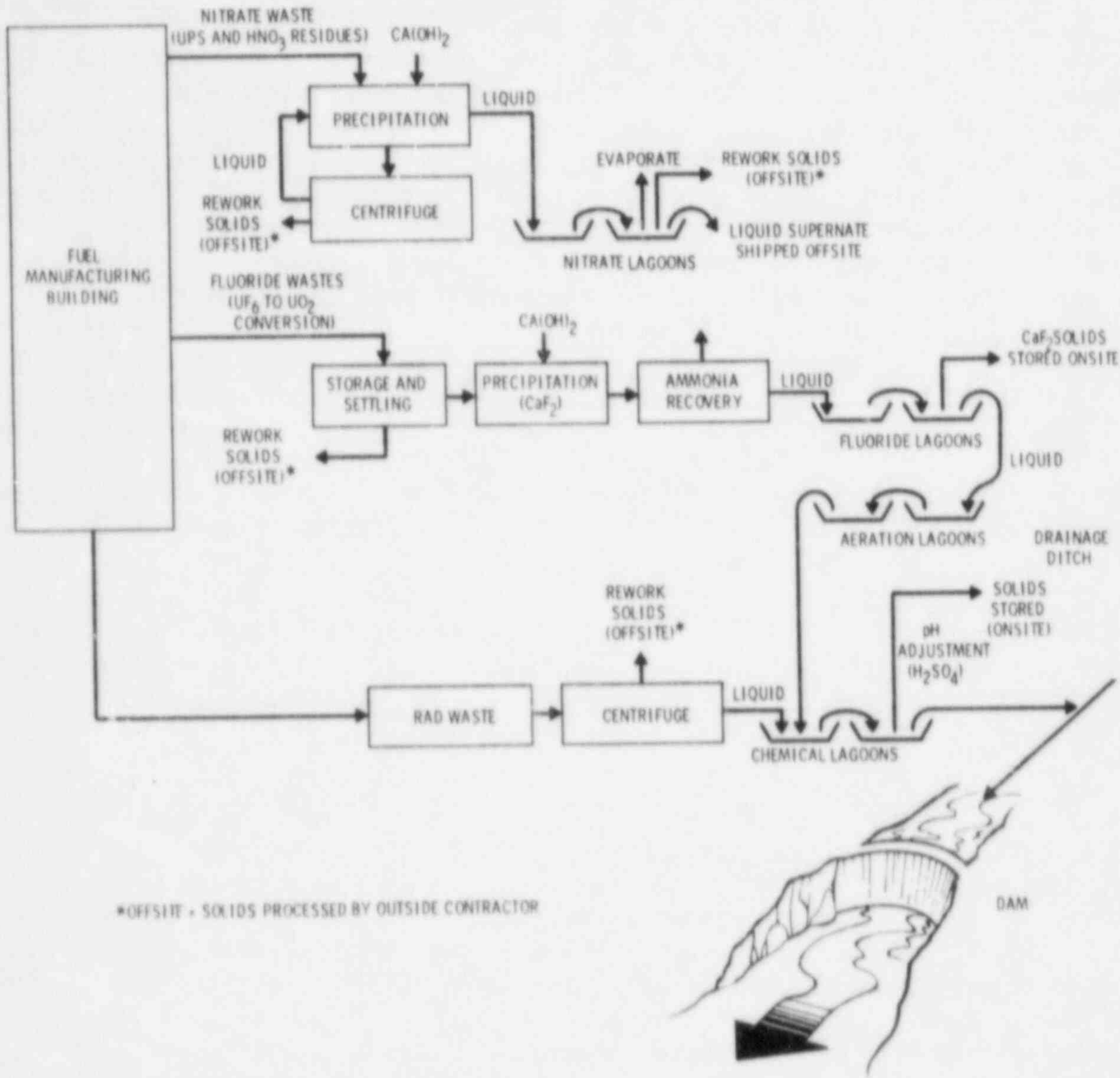


FIGURE A.3-2. Liquid Waste Processing Schematic

is pumped to the aeration lagoons for removal of residual ammonia, if necessary. Finally, the fluoride waste solution is sent to the chemical lagoon to be mixed with other chemical waste liquids from the plant and released to a drainage ditch that flows offsite to the river.

CaF_2 solids in the fluoride storage lagoons are periodically removed and stored onsite for eventual reprocessing to recover the uranium residuals.

Nitrate Wastes. Nitrate wastes generated during uranium scrap recovery operations are collected in the UPS quarantine tank system and treated on a

batch basis. Nitrate waste treatment consists of a lime [$CA(OH)_2$] addition to precipitate and settle any uranium compounds present in the wastes. The uranium-bearing sludge collected in the precipitation tank is centrifuged to remove the residual liquid, placed in 19-ℓ buckets, and, if the uranium content of the sludge warrants reprocessing, sent to an offsite contractor for rework. The residual liquid from the centrifuge is recycled back into the precipitation tank. The clarified liquid (clear supernate) is pumped from the 76-m^3 precipitation tank to the nitrate storage lagoons (hypalon-lined evaporation ponds) where the treated nitrate liquid wastes are impounded. Clarified nitrate solution from the nitrate lagoons is pumped back into the waste treatment facility for further concentration before offsite shipment to a paper manufacturing firm. Periodically, sludge that accumulates in the bottom of the nitrate lagoons is removed and sent to an offsite contractor for recovery of the uranium. The remainder of the effluent is removed by natural evaporation.

Radwastes. Waste solutions from sources such as laboratory sinks, laundering machines, and floor drains are initially collected in a tank located in the Radwaste Room. This tank feeds a slab accumulator tank where liquid radwastes are held for processing through a centrifuge. The centrifuge removes suspended uranium compounds and other solids that are put into 19-ℓ pails for eventual rework. The clarified liquid (mostly water) flows into a quarantine tank where it is sampled and either pumped to the waste lagoons or returned to the process for rework.

Solid Waste Processing

Solid wastes such as paper, rags, mops, plastic, wood, protective clothing, damaged tools, and equipment are constantly generated during plant operations. To prevent loss, these waste materials are collected in designated containers at the point of origin. Filled containers are sealed, tagged, stored, and eventually transferred to the waste handling facility in the Fuel Manufacturing Building. In the waste handling facility, uranium-bearing categories and treated or disposed of as described below. A schematic of the solid waste processing at the reference U-Fab plant is shown in Figure A.3-3.

Noncombustible Materials. Containers of noncombustible waste are emptied onto a hooded cleaning and sorting table. High-velocity water spray and/or steam cleaning equipment is used to decontaminate the wastes, which are then either packaged directly for final disposition or sent to a local dump after release for unrestricted use. Contaminated wastes are generally reduced to a smaller volume, packaged and shipped to a government-licensed shallow-land burial site for disposal.

Noncombustible wastes not meeting the established release limit for uranium are recycled (reworked) in the facility. Liquids generated from the decontamination processes are discharged to the radwaste system described above.

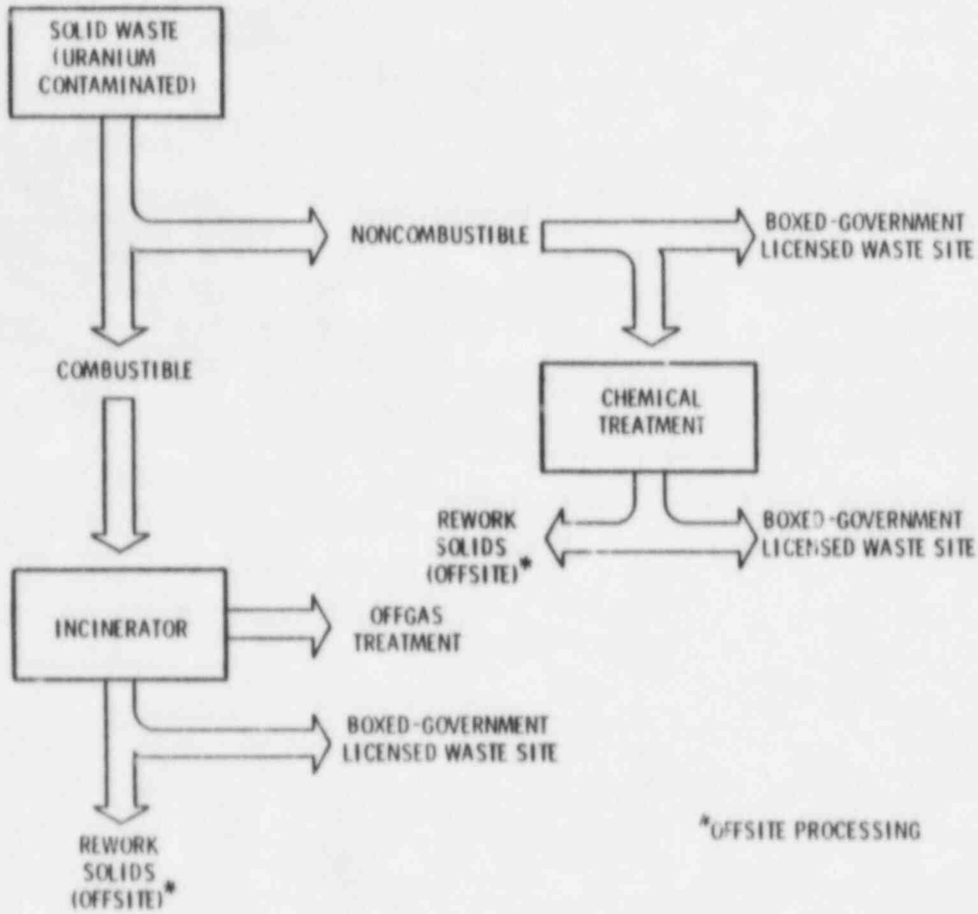


FIGURE A.3-3. Solid Waste Processing Schematic

Combustible Wastes. Combustible wastes are generally incinerated, but may be compacted, packaged, and shipped to a shallow-land burial site if incineration is not desirable.

The incineration system consists of a shredder, a blow-tube unit, a vortex incineration chamber, an off-gas scrubber, and a filter unit, all housed in a building next to the Fuel Manufacturing Building. Materials to be incinerated are shredded and blown into the vortex incineration chamber. The incinerator operates at about 1100°C to produce ash and off-gases.

The solid ash is removed regularly on a batch-control basis, using known uranium input measurements, and placed in buckets for sampling and eventual shipment offsite for processing to recover uranium. Combustion gases are scrubbed in a liquid blanket-type spray scrubber, demisted, and filtered through a HEPA filter prior to discharge from the stack. Liquids from the incineration process are discharged to the radwaste system.

A.3.2 U-Fab Plant Structures, Equipment, and Layout

Summary descriptions of the major structures and equipment and their layout at the reference U-Fab plant are presented in this section. More detailed descriptions are given in Section A.2 of Reference 2.

The reference U-Fab plant is assumed to be located in the reference site described previously in Section A.1 of this appendix. The immediate plant area includes about 285 hectares that contain the fuel fabrication plant, waste treatment facilities, equipment and materials storage pads, and other supporting facilities, as shown in Figure A.3-4. The sanitary lagoon to the north is used to handle discharge from the plant nonradioactive laundry, showers, sinks, and toilets. The sewage treatment plant and sanitary lagoons contain very

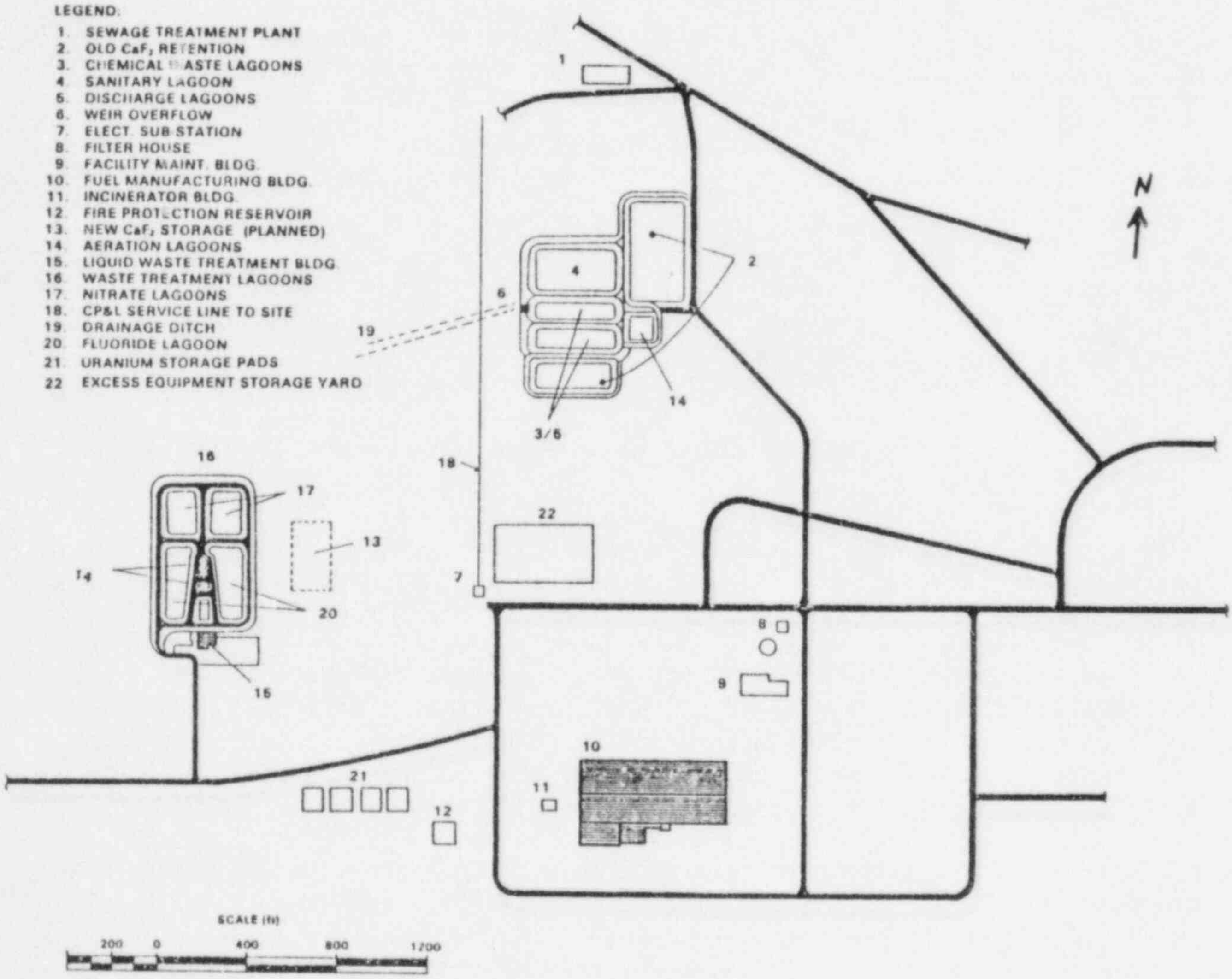


FIGURE A.3-4. Reference U-Fab Plant Site Plan

little if any contamination from normal plant operations and, thus, are not postulated to require decommissioning following normal plant shutdown.

The main plant building (the fuel manufacturing building) encompasses 19,300 m^2 of manufacturing, laboratory, maintenance, decontamination, storage, and office space. Adjacent and connected to the south side of the main building are two separate but interconnected single-story structures. The structures house the chemical-metallurgical laboratory, the uranium scrap recovery room, and the UO_2 powder warehouse, with 770 m^2, 340 m^2, and 810 m^2 of floor space, respectively. Contaminated waste incineration operations occupy another 220 m^2 of floor space in a separate building located 30 m to the west of the main building. Other auxiliary facilities include a fluoride and nitrate waste treatment plant and associated lagoons, ammonia recovery facilities, a liquid radwaste treatment system, liquid chemical waste treatment lagoons, a sanitary waste treatment plant, a propane station, a tank and pump station, equipment storage yards, uranium storage yards, an electrical substation and warehouse, and CaF_2 storage grounds.

Major Plant Buildings

The majority of the activities that take place during normal operations at the reference U-Fab plant are carried out in the fuel manufacturing building and adjacent structures and additions. The floor plans for the ground floor and mezzanine floor of these buildings are shown in Figures A.3-5 and A.3-6 respectively.

The fuel manufacturing building is an 80-m by 211-m structure that is built to allow for future expansion to double the current production capacity. It is fabricated of 38-mm insulated metal siding attached to a steel framework. The interior walls are constructed of concrete block and gypsum wallboard. The ground floor and the first meter of the outside walls are reinforced concrete 100 to 150 mm thick. The mezzanine area floors are steel grating or reinforced concrete. The steel beams supporting the building steel framework are anchored in the outside 1-m-high walls. The roof consists of a 35-mm insulated corrugated metal deck that is capped with asphalt and gravel.

The processing areas or rooms within the fuel manufacturing building are generally partitioned with painted cinderblock walls, or in some instances, with painted wall board. The floors of the production areas are generally covered with 0.3-m-square tiles, most of which are removed and replaced yearly. The chemical area has a sealed concrete floor. Nonproduction and noncontaminated areas in the facility generally have a concrete floor. Offices and change rooms have either tiled or painted floors.

The chemical-metallurgical (chem-met) laboratory is a single-story structure 21 m wide by 37 m long that is separated from the main building by a 3-m

enclosed corridor. The laboratory building is constructed of concrete slab siding and concrete floors and has the same type of roof as the main building. The laboratory is divided equally into a controlled and an uncontrolled section. The controlled section has hoods, enclosures, and glove boxes for testing, handling, and containment of uranium in various physical and chemical forms.

The uranium scrap recovery and powder storage addition is a single-story structure attached to both the main building and the chem-met laboratory, and is 27 m wide by 47 m long. The building is constructed of insulated metal siding attached to a metal framework that is anchored to a concrete foundation and floor. The roof is sloped and constructed of insulated corrugated metal decking.

The waste incineration building is a 12.2-m by 18.3-m structure approximately two stories high that is located approximately 30 m to the west of the main building. It is constructed of insulated corrugated metal siding attached to a metal frame. The frame and metal siding rest on a concrete floor-foundation. The roof construction is similar to that of the main building.

The fluoride and nitrate waste treatment building is a multistoried, roofed structure that is open on four sides. It covers an area of about 12 m by 19 m. It is constructed of large steel framework members that serve as supports for the numerous tanks, columns, pumps, and piping associated with the facility. A small enclosed area on the ground floor of the building houses a control room for the facility and a uranium recovery (centrifuge) room. A separate 7-m by 14-m building next to the waste treatment facility houses a boiler for supplying steam to the ammonia stripping column.

Detailed descriptions of rooms in the plant process and laboratory areas are provided in Section A.2 of Reference 2. These descriptions include tabulations of the major equipment items located in each room, with estimates of shipping volume and mass for each item.

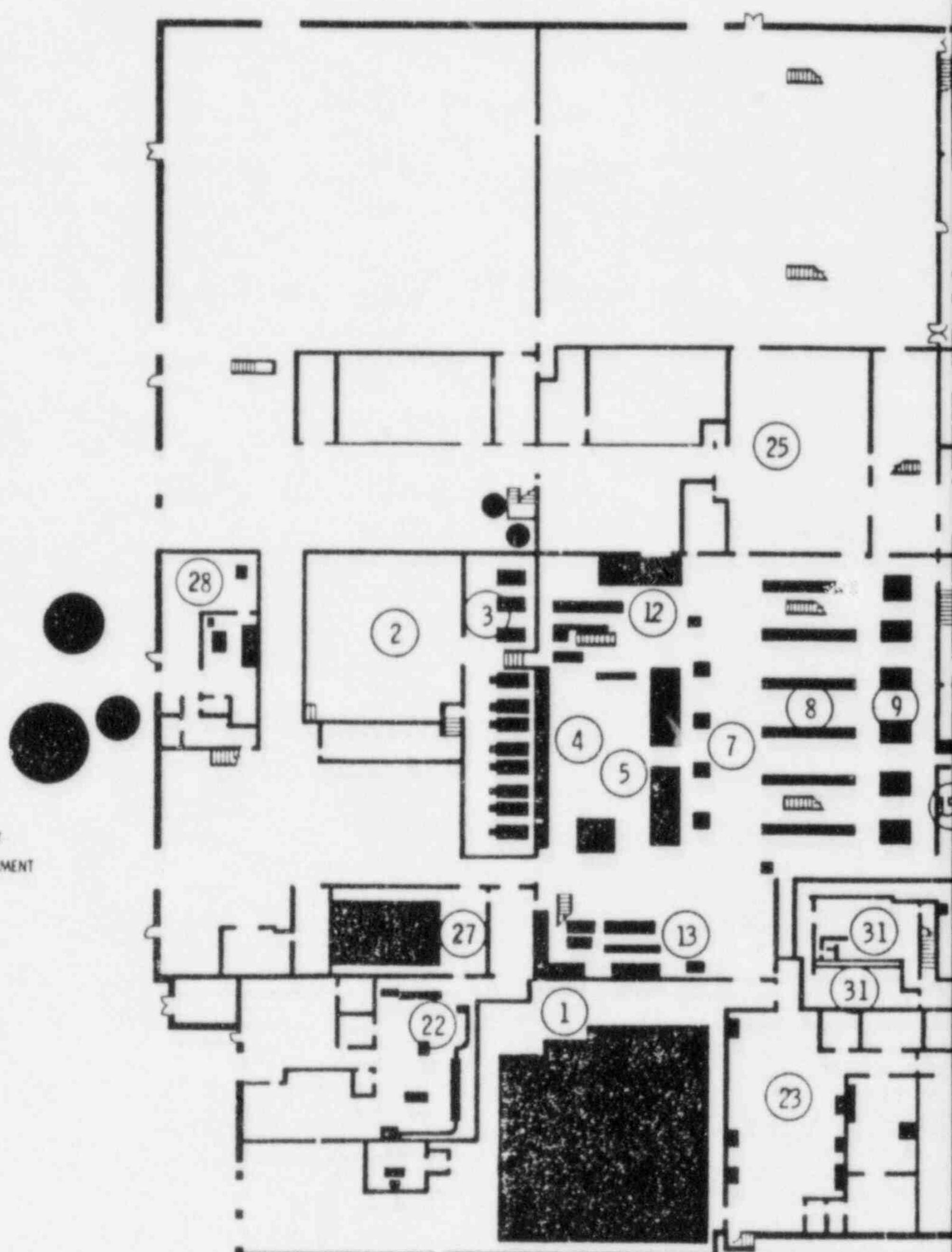
Several plant areas provide specialized functions and may be of particular significance to post-accident decommissioning of the U-Fab plant. These areas, described in the following subsections, are as follows:

- the hot maintenance shop
- the hot instrument shop
- the decontamination facility
- the ventilation HEPA filter rooms.

Hot Maintenance Shop. The hot maintenance shop is located on the ground floor of the fuel manufacturing building. The shop has a floor area of about

GROUND FLOOR LEGEND

NUMBER	AREA DESCRIPTION
1	POWDER WAREHOUSE
2	UF_6 CYLINDER STORAGE
3	UF_6 VAPORIZATION ROOM
4	HYDROLYSIS
5	PRECIPITATION AND DIGESTION
7	2ND STAGE CENTRIFUGE
8	REDUCTION CALCINATION
9	SLUG PRESSING
12	FLAME CONVERSION REACTION
13	URANIUM PURIFICATION SYSTEM
15	PELLETIZING ROOM
15a	BLENDING
15b	POWDER TREATMENT
15c	PELLET PRESSING
16	SINTERING
17	PELLET GRINDING
18	ROD LOADING
19	ROD OFFGASSING
20	ROD CLOSURE WELDING, INSPECTION AND DECONTAMINATION
21	GADOLINIA ROD FABRICATION
22	URANIUM SCRAP RECOVERY
23	CHEMICAL AND METALLURGICAL ANALYTICAL LABORATORY
24	PROCESS DEVELOPMENT LABORATORY
24a	BLENDING DEVELOPMENT
24b	SINTERING AND CERAMIC DEVELOPMENT
24c	FLAME CONVERSION REACTION DEVELOPMENT
24d	ROD AND METALS DEVELOPMENT
25	HOT MAINTENANCE SHOP
26	HOT INSTRUMENT SHOP
27	RAD-WASTE ROOM
28	DECONTAMINATION FACILITY
31	CHANGE ROOMS
	ROD STORAGE
	ROD ENRICHMENT SCAN
	BUNDLE ASSEMBLY
	BUNDLE LEAK TEST AND INSPECTION
	BUNDLE STORAGE
	BUNDLE PACKAGING AND SHIPPING



GROUND FLOOR

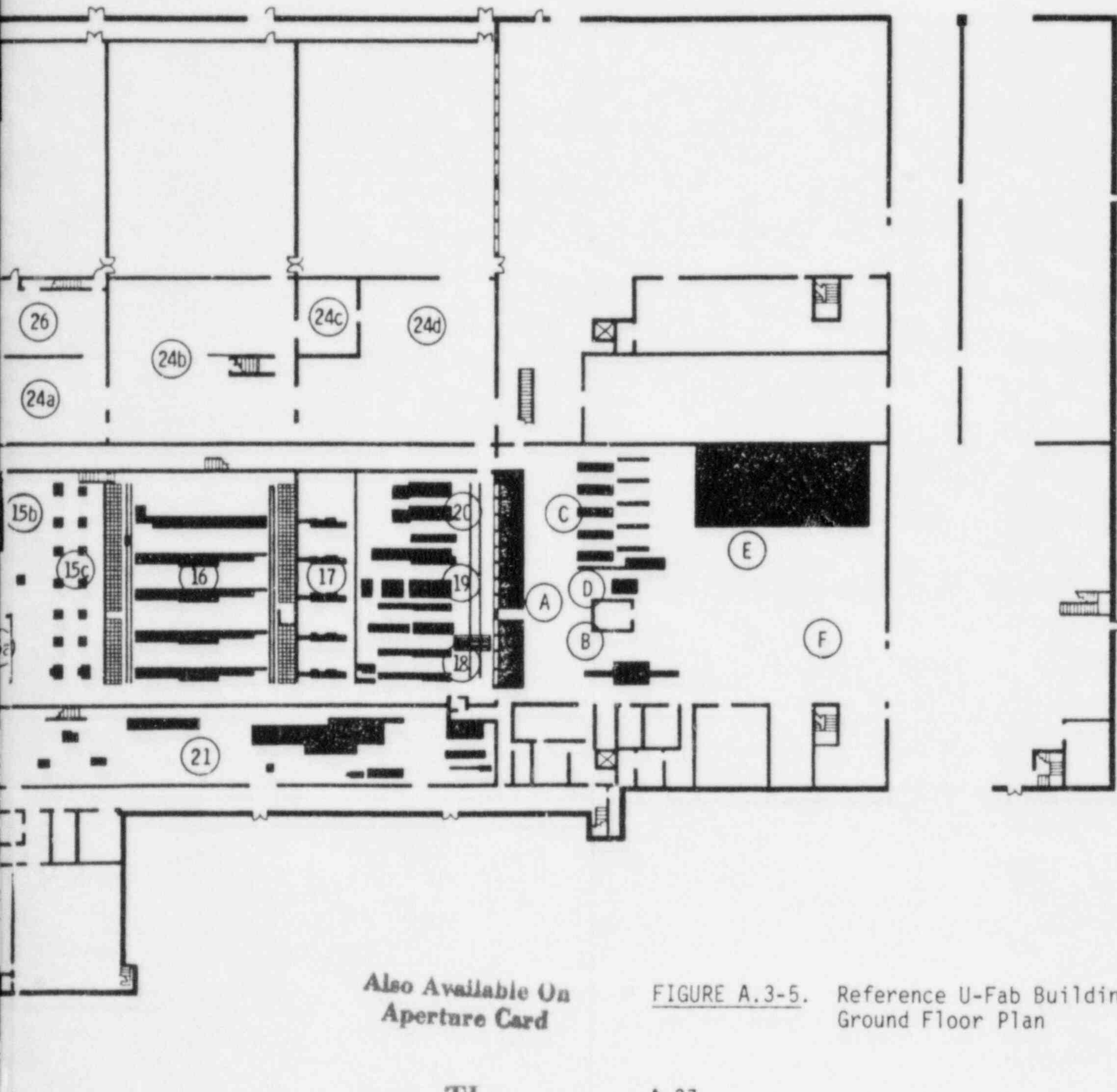
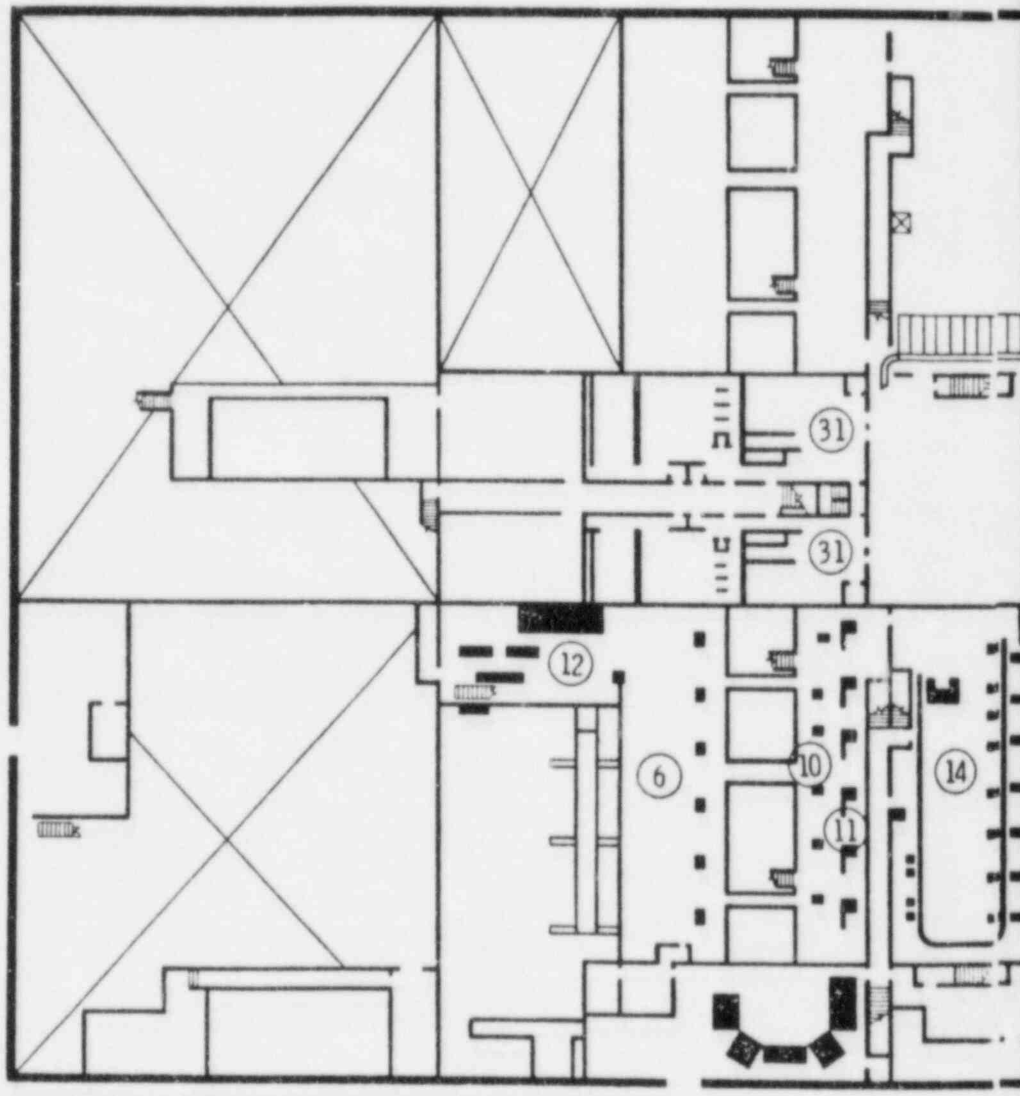


FIGURE A.3-5. Reference U-Fab Building Ground Floor Plan

8506170550-02

MEZZANINE LEGEND

NUMBER	AREA DESCRIPTION
6	1st STAGE CENTRIFUGE
10	HAMMER MILLING
11	GRANULATING AND BUCKET FILLING
12	FLAME CONVERSION REACTION
14	POWDER STORAGE AND FEED
29	VENTILATION HEPA FILTER ROOMS
30	LAUNDRY ROOM
31	CHANGE ROOMS



MEZZANINE

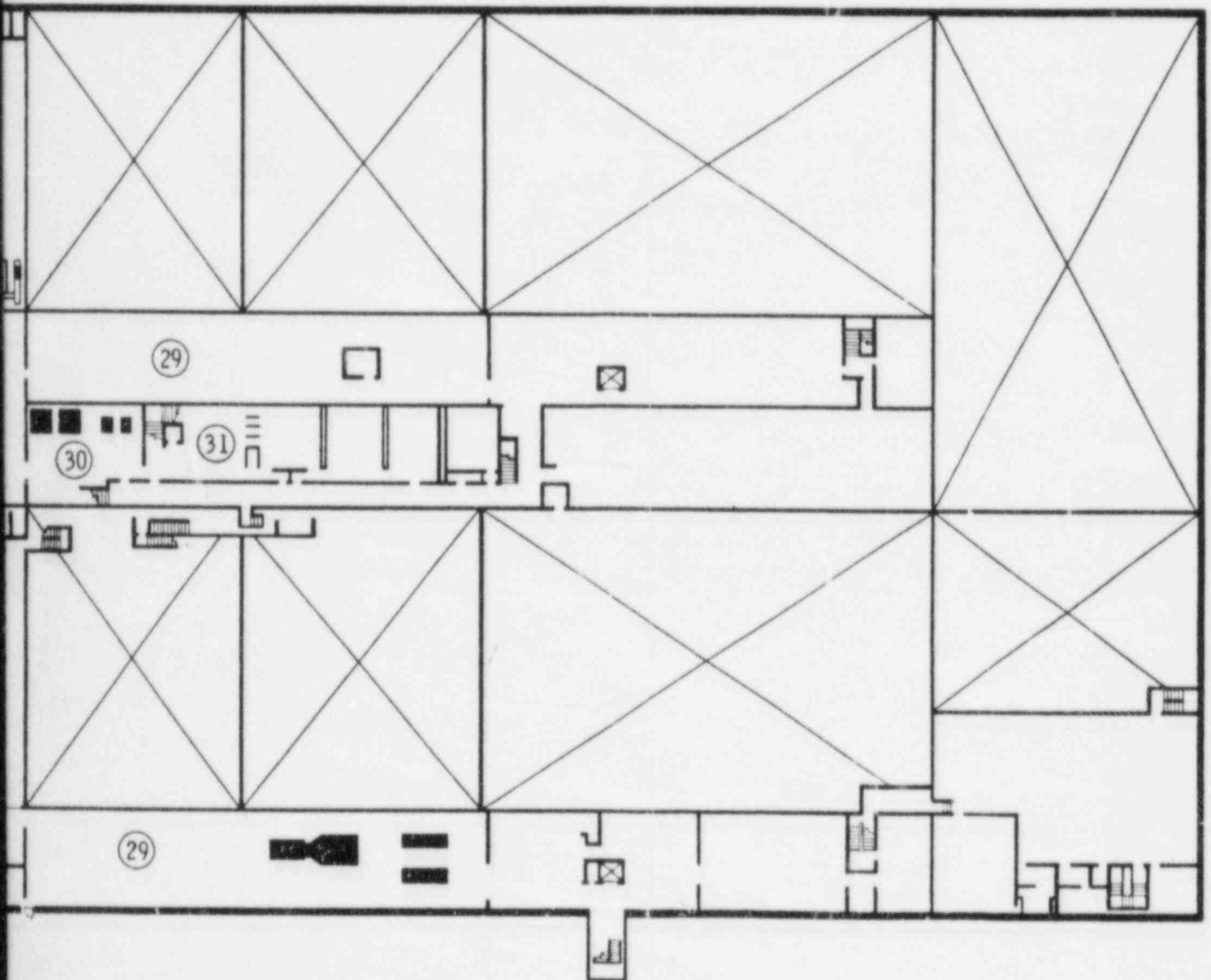


FIGURE A.3-6. Reference U-Fab Building Mezzanine Floor Plan

400 m^2 and a room volume of over 1900 m^3. The shop is equipped with various machine tools (e.g., lathes, drill presses, mills), work benches and tool cabinets, welding equipment, pipefitting equipment, and cleaning equipment. Two HEPA filter units are provided to purify exhaust air from the hot maintenance shop.

Hot Instrument Shop. The hot instrument shop is located in the fuel manufacturing building adjacent to the hot maintenance shop. The hot instrument shop has a floor area of about 125 m^2 and a volume of over 600 m^3. The shop contains a variety of equipment for doing maintenance on electrical and electronic equipment. A HEPA filter unit is used to treat exhaust air from the shop.

Decontamination Facility. The decontamination facility is located on the ground floor at one end of the fuel manufacturing building. The facility has a floor area of about 170 m^2 and a volume of over 1600 m^3. The facility includes equipment for cleaning (i.e., a spray booth and cleaning sinks), sorting, cutting, compacting, uranium scanning, and packaging of contaminated materials. Air treatment is provided by two HEPA filter units.

Ventilation HEPA Filter Rooms. Two rooms contain HEPA filters for the plant ventilation system. These rooms are located on the mezzanine level of the plant, as previously shown in Figure A.3-6. The two rooms contain about 830 m^2 of floor space and about 4000 m^3 of room volume. A total of about 250 HEPA filters are located in these rooms, paired with an equal number of roughing filters. (The plant ventilation system is described below.

Piping and Ductwork

Substantial amounts of piping and ductwork are present in the areas of the reference U-Fab plant to be decommissioned. Estimates of the volumes and masses of piping and ductwork are given by room in Table A.3-1. Piping includes process piping, service piping, electrical conduit, and instrument lines. Ventilation ducts and hood ducts are included in the ductwork estimates. The trays include hangers with piping and conduit, which are batched and supported by the trays. Light fixtures include all main overhead lighting, most of which is fluorescent.

Plant Ventilation System

A simplified air flow diagram for the reference U-Fab plant ventilation system is shown in Figure A.3-7. Only the ventilation flows for the main production rooms are shown. The gadolinia facility, uranium scrap recovery, chem-met laboratory, process development laboratory, and other supporting areas are

TABLE A.3-1. Piping, Ductwork, Trays, and Lighting Fixtures in the Reference U-Fab Plant

Location	Piping and Conduit		Ductwork and Supports		Trays and Light Fixtures	
	Compacted Volume (m^3)	Mass (Mg)	Non-Compacted Volume (m^3)	Mass (Mg)	Compacted Volume (m^3)	Mass (Mg)
Powder Warehouse	0.7	0.7	20.6	1.0	6.3	7.2
UF_6 Cylinder Storage	0.3	0.4	18.2	0.9	4.5	5.2
UF_6 Vaporization Room	3.1	3.5	54.6	2.5	4.5	5.2
Chemical Area	64.4	74.6	359.8	18.3	79.9	92.5
Powder Storage and Feed Room	1.0	1.2	27.0	1.2	7.5	8.7
Pelletizing Room	1.6	1.8	57.7	2.7	6.2	7.2
Sintering Room	9.3	10.7	212.4	9.8	13.3	15.4
Grinding Room	2.8	3.3	26.7	1.2	3.9	4.3
Rodding Room	5.1	5.9	50.8	2.3	11.8	13.6
Gadolinia Shim Rod Fabrication Facility	7.8	9.0	119.0	5.5	20.0	23.1
Uranium Scrap Recovery Room	1.7	2.0	24.1	1.1	6.2	7.2
Chem./Met. Analytical Laboratory	1.4	1.6	27.5	1.3	5.0	5.8
Process Development Laboratory	4.1	4.8	66.6	3.1	17.5	20.3
Hot Maintenance Shop	1.4	1.6	33.2	6.4	4.0	4.6
Hot Instrument Shop	0.5	0.5	3.7	0.2	1.5	1.7
Radwaste Room	1.7	2.0	5.5	0.3	3.0	3.5
Decontamination Facility	1.4	1.6	19.4	0.9	2.5	2.9
Laundry Room	0.3	0.3	12.9	0.6	2.0	2.3
Change Rooms	0.4	0.4	32.4	1.5	2.5	2.9
Ventilation Filter Room	0.9	1.1	849.6	67.4	6.2	7.2
Incinerator Facility	2.2	2.6	48.5	2.2	4.5	5.2
Fluoride Waste Treatment System	81.7	94.5	--	--	--	--
Nitrate Waste Treatment System	17.2	19.8	--	--	--	--
Waste Treatment Building	3.1	3.6	--	--	3.9	4.3
Radwaste Treatment System	14.5	16.7	--	--	--	--
Totals	228.6	264.2	2 070.2	130.4	216.7	250.3

not included because they have similar, smaller-scale systems. Ventilation system capacities and capabilities in the main production areas are summarized in Table A.3-2.

Each room in the main building has a separate handling system that is designed to provide clean, thermally conditioned air to the operating area and to exhaust filtered or scrubbed and filtered air to the environs. The flow of air within the building is controlled so that the recirculating air moves from clean areas to areas with successively higher contamination potential.

The UF_6 vaporization room receives all of its make-up air from the outside air stream. The chemical room receives about 80% of its make-up air from outside and the remaining 20% from other areas in the building. The grinding and

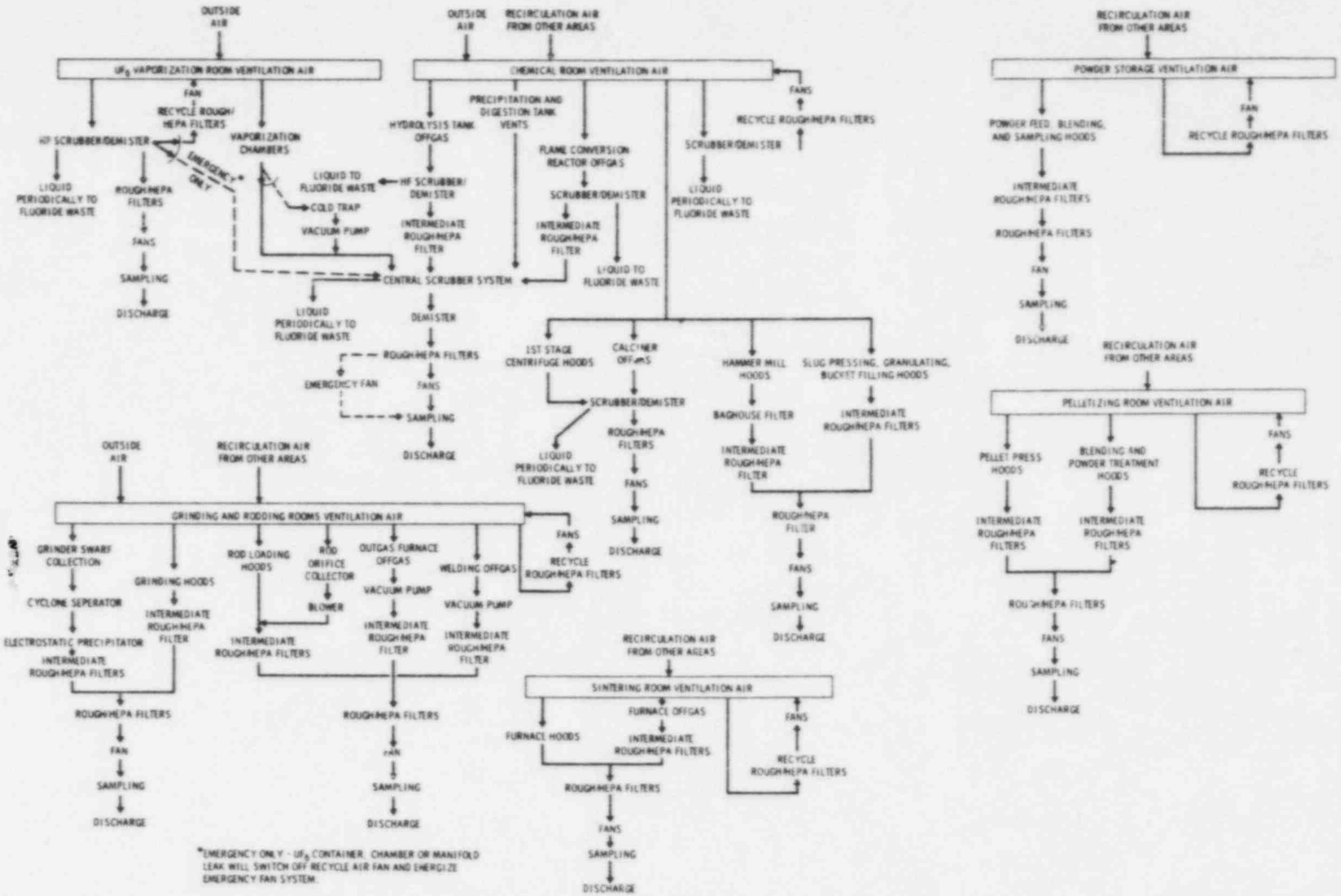


FIGURE A.3-7. Simplified Flow Diagram for the Reference U-Fab Plant Ventilation System

TABLE A.3-2. Ventilation System Capabilities in Main Fuel Fabrication Areas of the Reference U-Fab Plant

Area	Room Volume (m^3)	Exhaust Rate (scmm)	Recirculation Rate (scmm)	Total Rate (scmm)	No. of Air Changes/hr	Scrubber/ Demister System	Roughing/ HEPA Filter System
Vaporization	1 890	170	255	425	13.5	Yes	Yes
Chemical	13 325	973	2 549	3 522	15.9	Partial	Yes
Powder Storage	2 375	142	198	340	8.6	No	Yes
Pelletizing	1 905	238	312	550	17.3	No	Yes
Sintering	5 845	340	1 700	2 040	20.9	No	Yes
Grinding and Rodding	6 250	210	453	663	6.4	No	Yes

rodding rooms receive about 40% of the make-up air from outside air and 60% from other areas. The powder storage, pelletizing, and sintering rooms receive all their make-up air from other areas within the building (e.g., offices, change rooms, etc.).

Make-up air from other plant areas comes from the plant recirculating air ventilation system. Recirculation air is drawn from building areas having little or no contamination. The recirculating air is blended with fresh outside air, filtered through dust and HEPA filters, heated or cooled as required, and then distributed within the plant.

There are 32 stacks associated with the exhaust air systems for fuel manufacturing operations; 28 of these are located on the roof of the main building and the other four are located on the roof of the incinerator building. These separate air exhaust systems remove air from the building through hoods containing highly contaminated process equipment or through room exhaust systems in potentially contaminated rooms.

Exhaust air from vaporization, hydrolysis, precipitation, digestion, flame conversion, centrifuging, and calcining process steps is scrubbed and dried before passing through HEPA filter assemblies. The scrubbing action removes the fluoride, uranium and other compounds from the air for subsequent recovery and waste treatment operations. Exhaust air from other process areas generally is filtered through at least two HEPA filters in series. One intermediate HEPA is generally located at the work station or area for quick routine changeout. In front of each HEPA filter is a roughing filter that removes the larger particulates.

REFERENCES

1. C. E. Jenkins, E. S. Murphy, and K. J. Schneider, Technology, Safety and Costs of Decommissioning a Reference Small Mixed Oxide Fuel Fabrication Plant, NUREG/CR-0129, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, February 1979.

2. H. K. Elder and D. E. Blahnik, Technology, Safety and Costs of Decommissioning a Reference Uranium Fuel Fabrication Plant, NUREG/CR-1266, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, October 1980.

3. E. S. Murphy, Technology, Safety and Costs of Decommissioning Reference Non-Fuel-Cycle Nuclear Facilities, NUREG/CR-1754, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, February 1981.

4. Final Environmental Statement Concerning Proposed Rule-Making Action: Numerical Guides for Design Objectives and Limiting Conditions for Operation to Meet the Criteria "As Low as Practicable" for Radioactive Material in Light-Water-Cooled Nuclear Power Reactor Effluents, WASH-1258, Volume 1, of 3, Figure 6B-1, p. 6B-43, Figure 6C-8, p. 6C-12, and Table 6B-6, p. 6B-36, U.S. Atomic Energy Commission, Washington, D.C., July 1973.

5. Final Environmental Statement Related to Operation of Monticello Nuclear Generating Plant, Docket No. 50-263, pp. II-15 to II-26, U.S. Atomic Energy Commission, Washington, D.C., November 1972.

6. D. H. Slade, ed., Meteorology and Atomic Energy 1968, TID-24190, p. 73, U.S. Atomic Energy Commission, Washington, D.C., July 1968.

7. Regulatory Guide 1.23, Onsite Meteorological Programs (Safety Guide 23), U.S. Atomic Energy Commission, Washington, D.C., February 1972.

8. Application for Special Nuclear Material License, Kerr-McGee Corporation, Safety Analysis Report for its Cimarron Plutonium Fuel Plant, March 1969.

9. Applicants Environmental Report, USAEC Docket No. 70-1193, Supplement No. 1, Kerr-McGee Corporation, December 1973.

10. Directory of Packagings for Transportation of Radioactive Materials, WASH-1279, U.S. Atomic Energy Commission Division of Waste Management and Transportation, Washington, D.C., October 1973.

11. Federal Register, Volume 42, No. 9, January 1977. (See also 40 CFR 190.)

12. Special Nuclear Materials License Application for Wilmington Plant. Docket 70-1113, General Electric Co., December 19, 1975.

13. Environmental Report General Electric Nuclear Facility, Wilmington, North Carolina, NEDO-20197 Class 1, General Electric Co., January 1974.

APPENDIX B

DETAILS OF REFERENCE ACCIDENT SCENARIOS AND RESULTANT CONTAMINATION LEVELS

APPENDIX B

DETAILS OF REFERENCE ACCIDENT SCENARIOS AND RESULTANT CONTAMINATION LEVELS

Details to support the descriptions of reference accident scenarios and resultant contamination levels presented in Chapter 6 are given in this appendix. The details include an explanation of the methods used to estimate radiation exposure rates from radioactive contamination of the plant buildings.

B.1 DETAILS OF EXPOSURE RATE CALCULATIONS

This section provides details of the methods used to estimate average radiation exposure rates from contamination of the MOX and U-Fab plant buildings for the reference accident scenarios described in Chapter 6. Average exposure rates are estimated for gamma radiation from plateout on building surfaces and equipment. The methodology uses equations for calculating photon fluxes from uniformly contaminated regular geometric sources given in the Reactor Shielding Design Manual.(1)

This section describes the equations used to estimate average exposure rates from gamma radiation plated out on building and equipment surfaces as a result of the reference accidents. An evaluation of the effect on exposure rate calculations of changes in room size and changes in the distribution of radioactive contamination between the floor, walls, and ceiling of a room is described in Section B.2. The results of this analysis show that, for a room in which the contamination levels on walls and ceilings are smaller than the average contamination level on the floor, the calculated average exposure rate is approximately equal to the exposure rate from a uniformly contaminated infinite plane. Therefore, the infinite plane equation is used to estimate exposure rates from plateout on building surfaces.

The equation for the photon flux at a point P located on the axis at a distance d from a plane disk source with uniform surface contamination (see Figure B.1-1) is

$$\phi = \frac{BS_A}{2} E_1(b_1) - E_1(b_1 \sec \theta) \qquad (B.1)$$

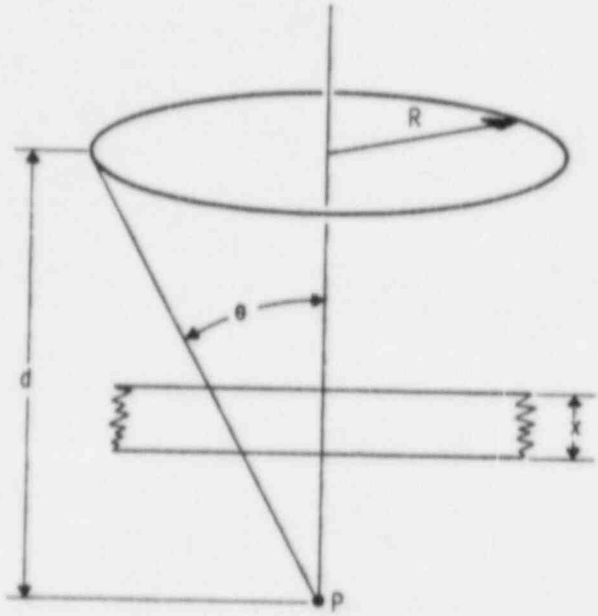


FIGURE B.1-1. Plane Disk Source

where

ϕ = flux (photons/cm^2-sec)
B = dose buildup factor (dimensionless)
S_A = source strength (photons/cm^2-sec)
$b_1 = \Sigma\, u_i\, x_i$ (dimensionless)
u_i = total macroscopic attenuation coefficient for the i^{th} shield material (cm^{-1}).
x_i = thickness of the i^{th} shield material (cm)

$$E_n(b) = b^{n-1} \int_b^\infty \frac{e^{-t}}{t^n}\, dt \text{ for } n>0.$$

B is assumed to be equal to 1 for air. Graphs for evaluating the logarithmic integral, $E_n(b)$, are given in Reference 1.

For a uniformly contaminated infinite place, the photon flux in air at a distance d becomes

$$\phi = \frac{S_A}{2} [E_1 (u_a d)] \qquad (B.2)$$

where u is the macroscopic attenuation coefficient for air. For 0.662-MeV gamma rays, u_a is approximately equal to 0.0001 cm-1. Thus, at a distance of 1 m from an infinite plane that is uniformly contaminated with ^{137}Cs, the photon flux is

$$\phi = \frac{S_A}{2} [E_1 \ (0.01)] \qquad (B.3)$$

Conversion factors for converting from photon flux (in units of photons/cm^2-sec) to exposure rate (in units of R/hr) are given in Reference 1. For 0.662-MeV gamma radiation, the conversion factor is 1 photon/cm^2-sec = 1.4 x 10-6 R/hr. Average exposure rates from surface contamination, calculated using Equation B.3 and this conversion factor, are given in Chapter 6.

B.2 ROOM MODEL FOR ESTIMATING RADIATION EXPOSURE RATES

The BWR decommissioning study[2] included an investigation of the relationship between room size, surface radionuclide contamination levels, and calculated gamma radiation exposure rates. The analysis evaluated the effect on the calculated exposure rate of changes in room size and changes in the distribution of radioactive contamination between the floor, the walls, and the ceiling of the room. Radiation exposure rates were calculated at a point in air 1 m above the floors of rooms of various sizes, with 1 Ci/m^2 of ^{60}Co uniformly distributed on the room surfaces. Exposure rate calculations were also made for rooms in which the walls and ceilings contained 50% and 10%, respectively, of the floor contamination level. For comparison purposes, the gamma exposure rate at a point in air 1 m from a uniformly contaminated infinite plane was also calculated.

The floor of the reference room was assumed to be square and the walls of the room to be 3 m high. Room surfaces were modeled as uniformly contaminated disk sources, and exposure rates were calculated using the applicable equations from the Reactor Shielding Design Manual, as described in Section B.1.

The results of this analysis are shown in Figure B.2-1. For very large, uniformly contaminated rooms, the exposure rate approaches a value equal to twice the exposure rate from a uniformly contaminated infinite plane. For rooms in which the contamination levels on the walls and ceiling are much smaller than the contamination level on the floor, the calculated average exposure rate is closely approximated by the exposure rate from a uniformly contaminated infinite plane.

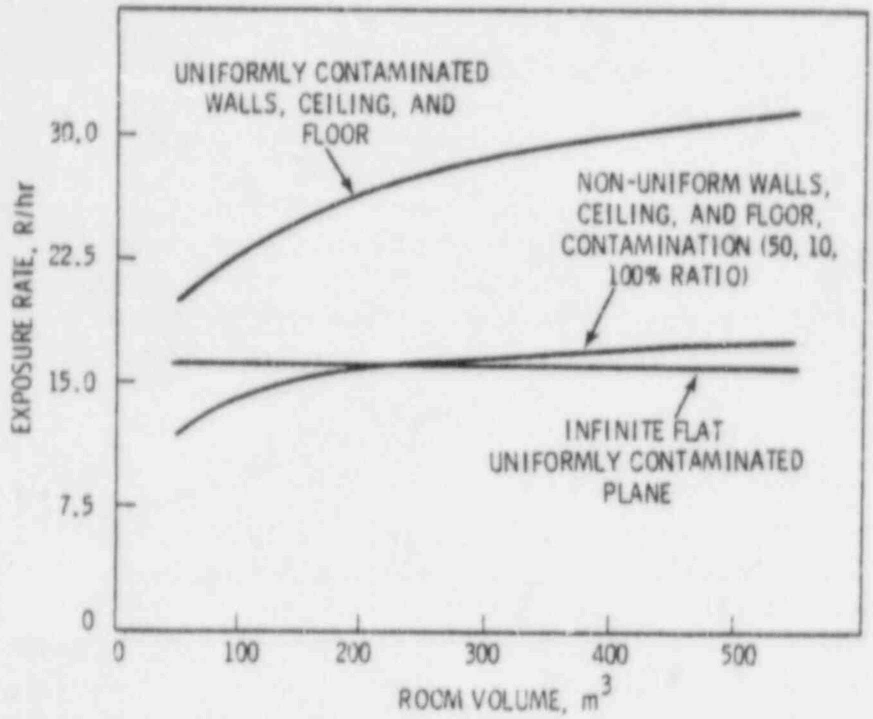


FIGURE B.2-1. Exposure as a Function of Room Volume for a ^{60}Co Deposition of 1 Ci/m^2 (from Reference 2)

REFERENCES

1. T. Rockwell, Reactor Shielding Design Manual, TID-7004, U.S. Atomic Energy Commission, Washington, D.C., March 1956.

2. H.D. Oak, et al, Technology, Safety, and Costs of Decommissioning a Reference Boiling Water Reactor Power Station, NUREG/CR-0672, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, June 1980.

APPENDIX C

GENERIC CLEANUP AND DECOMMISSIONING INFORMATION

APPENDIX C

GENERIC CLEANUP AND DECOMMISSIONING INFORMATION

Although each cleanup and decommissioning of an accident-damaged facility is a unique operation with requirements that depend on the specific facility and the nature of the accident, all post-accident cleanup and decommissioning operations include some common activities and requirements. This appendix provides information on some of these common elements, including:

- decontamination of structures and equipment
- contamination control
- special tool and equipment requirements
- packaging, transportation, and disposal of wastes
- essential systems and services
- quality assurance
- environmental surveillance.

C.1 DECONTAMINATION OF STRUCTURES AND EQUIPMENT

Three basic methods can be used to remove radioactive materials from contaminated surfaces. These are 1) dissolution of the surface film containing the radionuclides, 2) physical cleaning of the surface, and 3) physical removal of the contaminated structural material. Various techniques used for each of these methods are discussed in this section.

C.1.1 Chemical Decontamination

The major use of surface film dissolution during cleanup and decommissioning is for internal decontamination of components than might be used for the MOX and U-Fab plants. Several chemical decontamination methods are available for the removal of radioactive contamination from inside surfaces of piping, tanks, and other equipment of the MOX and U-Fab plants. Some methods are designed for piping systems where the chemicals can be recirculated until the desired degree of decontamination is obtained. Others are designed to complete the decontamination in one pass, so that they can be used where recirculation is impractical. Additional information on chemical decontamination is available in References 1 through 5.

In the reference plants, the principal systems to be chemically decontaminated are the pipelines and tanks in the chemical processing, uranium purification, and the fluoride, nitrate, and radwaste treatment systems.

During the decommissioning planning and preparation stage, procedures and results from routine chemical decontamination efforts carried out during plant

operation are reviewed to obtain maximum benefit from previous experience. Current as-built drawings are reviewed to identify system deadlegs and to facilitate the planning of any system modifications required to achieve decontamination. Existing procedures are reviewed for applicability to the present effort and modified as necessary. A detailed step-by-step procedure is developed for the decommissioning decontamination campaign, with checklists for valve settings, etc., to assure proper operation of the systems. Chemical decontamination procedures can usually provide the necessary decontamination to meet current shallow-land burial limits[6] of 10 nCi of transuranics per gram of waste for the process equipment located in the wet processing and scrap recovery areas. In some cases, additional treatments such as electropolishing are required.

Some typical chemical solutions that might be used for chemical decontamination of the reference plants are given below:

1. A solution of 0.025 $\underline{M}$ KF - 0.1 M $AlNO_3$ may be used to remove plutonium and uranium silicate deposits.

2. Many sludge deposits may be removed by using a solution of 20% HNO_3 - 6% AlF_3.

3. A solution of 10 $\underline{M}$ HNO_3 - 0.1 wt% CaF may be used to remove plutonium contamination from stainless steel surfaces with only modest surface corrosion.

4. A tri-sodium phosphate (TSP) solution may also be used; the chemical solution chosen must be compatible with the materials used in the system.

Plutonium and uranium are recovered from decontamination flush solutions using existing methods and process equipment. Therefore, a process-compatible solution of 10 $\underline{M}$ HNO_3 and 0.064 $\underline{M}$ (0.1 wt%) HF is used, which dissolves plutonium oxides, sludges, etc., and does not interfere with the process recovery of plutonium or cause excessive damage to process equipment.

Chemical decontamination is postulated to be accomplished with batches of acid flush solution. Up to five flushes may be required with recirculation times Averaging three to four days per flush. Recovery of the plutonium and uranium from the spent acid is achieved by passing the decontamination flush solutions (chemically adjusted if necessary) through an existing, freshly changed ion exchange resin bed. Final treatment for disposal of the decontamination solution is accomplished by conventional evaporation and solidification methods.

C.1.2 Physical Cleanup of Surfaces and Equipment

This section describes some physical methods for the removal of smearable radioactive contamination from surfaces such as walls, floors, and tank exteriors, and from equipment surfaces. Appropriate combinations of these methods can be used for the decontamination of an accident-damaged reactor facility. Physical methods considered include:

- hose wash
- high-pressure water jet or steam jet
- vacuuming
- janitorial techniques
- strippable coatings
- electropolishing
- vibratory finishing
- ultrasonic cleaning.

While these methods can be used for the decontamination of a variety of surfaces, they may not be effective or even applicable to the decontamination of untreated concrete because of the adsorption of contamination liquids into the body of the material. Concrete decontamination can require the complete removal of a surface layer.

Hose Wash

Hose wash is a decontamination technique that allows workers to stay some distance from the radiation source. It offers the advantages of flow rate control, flow pattern, and directional properties and can be effective in the decontamination of hard-to-reach areas that cannot be adequately cleaned by remote operation of the building spray system.

Because of low impact forces, hose wash is less effective than high pressure water jet or steam jet techniques. If the surface to be cleaned is covered with oil or grease, hose wash is ineffective. Depending on conditions, hose wash decontamination factors range from 2 to 100. Flow rates for hose wash are typically about 0.003 m^3/sec.

High-Pressure Water Jet or Steam Jet

High-pressure water or steam jets are quite effective for some types of surface decontamination work. They are particularly effective in decontaminating surfaces covered with oil or grease. High-pressure water jets utilize a high-pressure, positive-displacement pump with a hand-held lance or gun for delivery. The selective use of nozzles can improve decontamination efficiency by matching nozzle flow patterns to specific work tasks. High-pressure water jet systems can produce pressures as high as 100 MPa. The high impact force of these units makes them effective tools for the removal of hard-to-remove contamination, and decontamination factors as high as 1000 may be obtained. Water

jets can be turret-mounted to reduce operator fatigue during long hours of use and can be used in conjunction with the holdback-carrier technique discussed previously. Disadvantages of these units are the large volumes of contaminated water produced and the difficulty in controlling the scattering of contaminants released from surfaces by this method.

Steam-jet decontamination is similar to water-jet decontamination. Water or reagents are introduced into an injector system and mixed with steam. The water-steam mixture is expelled through a nozzle at pressures that are typically less than 7 MPa. The delivery rate is about 0.0015 m^3/sec at 5 MPa.

Vacuuming

Dry vacuuming is an effective method for the removal of contamination in areas where dust has accumulated. The vacuuming involves the use of a specially equipped machine with roughing and HEPA filters in the exhaust stream for the retention of radioactive particles. Worker exposure from airborne radioactivity may be increased by the vacuuming activity and protective respiratory equipment must be worn. Dry vacuuming does not work well on crusted deposits; therefore, it is used primarily in areas where dust has not been wetted or crusted.

Wet vacuuming can be used to decontaminate areas where contaminants adhere tightly to surfaces. The method involves scrubbing with water and industrial detergents and then vacuuming the resulting solution. The wash solution is filtered and stored in barrels until it can be solidified for disposal.

Janitorial Techniques

Janitorial techniques are hands-on decontamination procedures that include sweeping, wiping, wet-mopping, and scrubbing. Remote and semi-remote decontamination methods should be used first to the maximum extent possible to minimize the radiation dose to workers.

For small quantities of loose contamination on floors or other surfaces, brushing, sweeping, or dry vacuuming is often effective. For more tenacious contaminants, various cleansing compounds are used in combination with hand-wiping and scrubbing techniques. Several proprietary decontamination solutions are available.[a] Ordinary household detergents are quite effective but produce sizable quantities of waste water that may require special processing. Aerosol-type foaming cleansers are effective and eliminate the wastewater problem, but their use produces sizable quantities of contaminated wiping material. Trichlorethylene, Freon-113, and other solvents are effective degreasing agents that can be used to decontaminate equipment surfaces covered

(a) Reference 4 contains a list of proprietary decontamination solutions.

with a layer of oil or grease. The use of these solvents generates contaminated organic solutions that must be processed.

Contaminated floors require scrubbing either by industrial floor scrubbers or by hand, followed by wet vacuuming, and possible detergent-cloth wiping. A final reagent/rinse mopping then completes the effort.

Overhead areas may require damp scouring with reagents followed by rinses and cloth wipes. High-elevation work above floors involves the use of bosun chairs, scaffolding, and telescoping platforms to reach all surfaces. The area above the polar crane may be reached by using the crane beams as a staging platform.

Strippable Coatings

This method involves the application and subsequent removal of a strippable coating. As the coating is removed, it adheres to and takes with it the surface contamination. Strippable coatings are commonly applied to decontaminated areas to facilitate subsequent decontamination if recontamination should occur.

Electropolishing

Electropolishing is an electrochemical process used on metal objects to remove a thin layer of the exterior surface and attached contamination.[7] The process is illustrated schematically in Figure C.1-1. The method commonly employs a tank containing an acid solution as an electrolyte and a low-voltage, high-current electrical source. The phosphoric acid in the decontamination tanks is recirculated through a filter that accumulates much of the contaminated solids removed from the surface. Small tools and parts can be cleaned in a very short time to nondetectable levels and the process is effective on all surfaces exposed to the electrolyte.

Electropolishing can also be used for in-situ decontamination of the internal surfaces of cylindrical tanks. The electrolyte is sprayed onto the tank wall from nozzles mounted on rotating arms. A power supply provides current to these arms and, via the electrolyte stream, to the tank wall. Contaminated electrolyte is collected at the tank bottom and returned to an electrolyte handling system for cooling, filtration, and radiation monitoring.

Vibratory Finishing

Vibratory finishing is a surface-finishing technique that employs a vibrating tub of loose media through which a liquid chemical compound flows.[8]

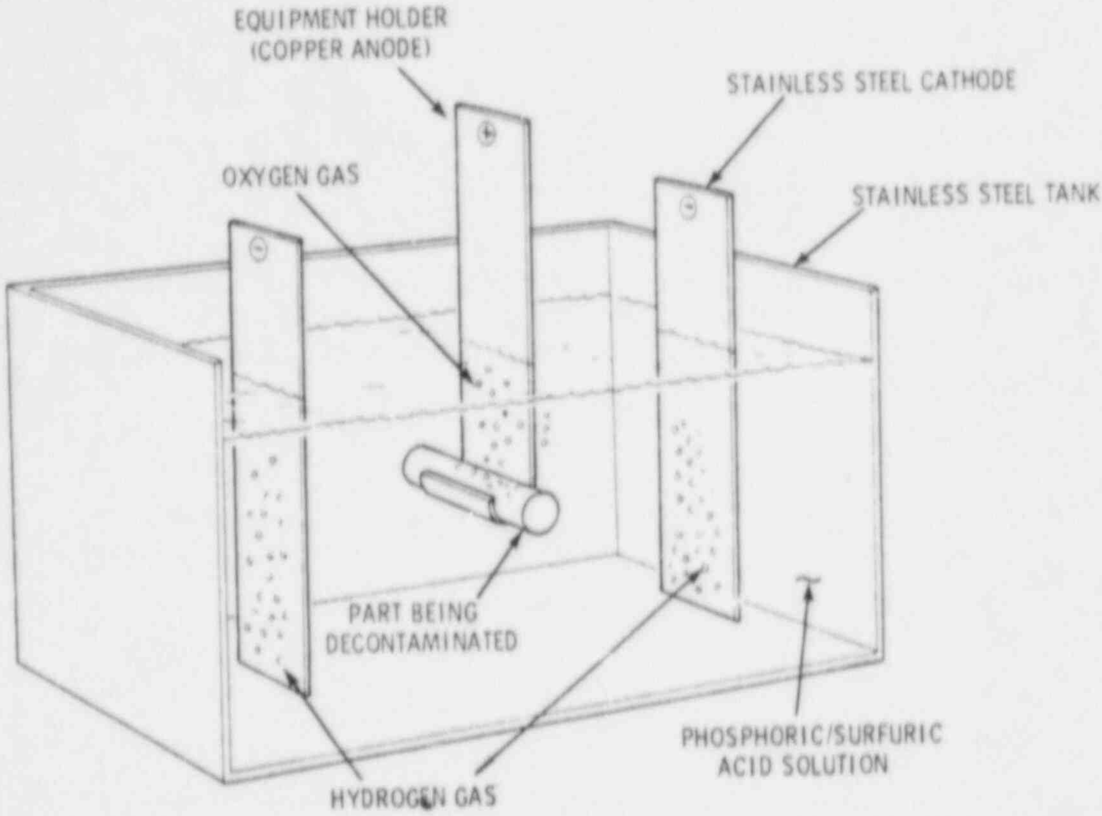


FIGURE C.1-1. Schematic Diagram of Electropolishing Cell

The technique is illustrated schematically in Figure C.1-2. The energy from the tub causes the media to scrub the surfaces of the objects being finished, while the liquid compound flushes away the material removed by the scrubbing action. The process is effective on external and internal surfaces, in threads, and in holes. It is being developed as decontamination technique for processing surface-contaminated metallic and nonmetallic (e.g, plastic) waste. Vibratory finishing will not usually decontaminate objects to the nondetectable levels obtainable with electropolishing. However, it removes essentially all of the smearable contamination as well as contaminated surface scale and corrosion.

Ultrasonic Cleaning

For cleaning applications in which small objects are immersed in a chemical or detergent bath, ultrasonics provide an effective method for agitation of the cleaning solution. Ultrasonic cleaning therefore combines the advantages of chemical cleaning and mechanical action. It is particularly suitable for irregularly shaped objects that contain crevices and inaccessible areas.

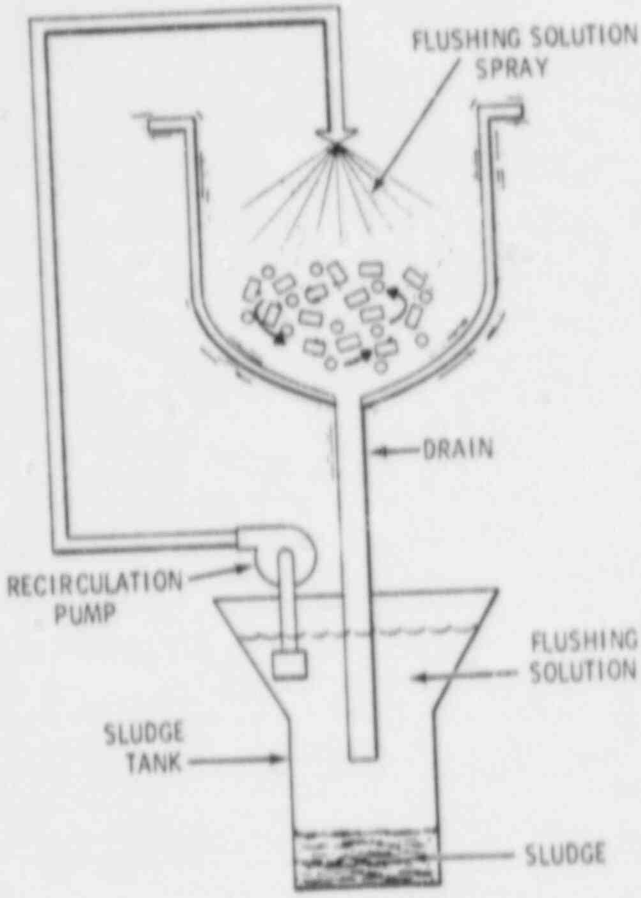


FIGURE C.1-2. Vibratory Finishing System

A typical ultrasonic cleaning system is shown schematically in Figure C.1-3. The system consists of three basic components: a generator, a transducer, and a cleaning tank. The generator converts utility line power at a relatively low frequency of 60 Hz to a more usable form of electrical energy at relatively high frequencies in the range from 18 to 90 kHz. The transducer converts these relatively high-frequency electrical impulses to low-amplitude mechanical energy of the same frequency--18 to 90 kHz. The cleaning tank contains the liquid cleaning medium through which the mechanical energy is propagated in the form of supersonic waves to the object being cleaned.

C.1.3 Removal of Structural Material

Some concrete in nuclear facilities is contaminated below the surface and cannot be decontaminated to release levels by physical surface cleaning alone. The structural materials must be physically removed and disposed of during decommissioning.

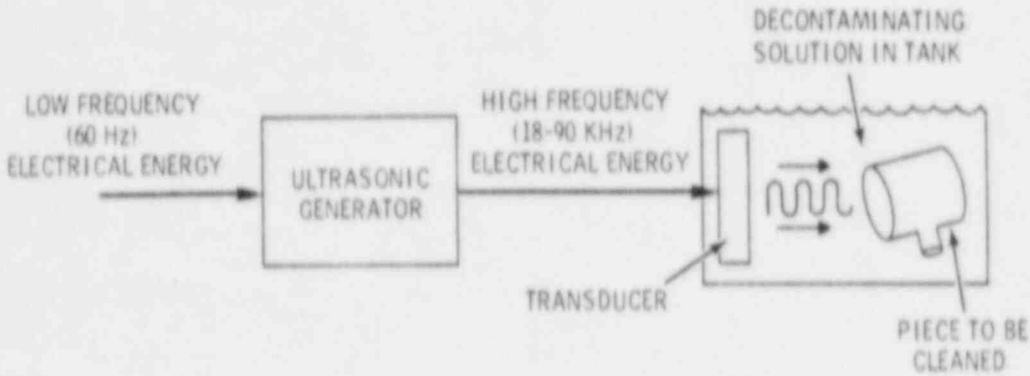


FIGURE C.1-3. Ultrasonic Cleaning System

Several criteria should be considered when selecting a material removal method for a particular location in the plant. The method chosen should minimize personnel radiation exposure and airborne contamination dispersion. In addition, the size and weight of removed materials should facilitate packaging and shipping for offsite disposal.

The major methods available for concrete surface removal include:

- sandblasting
- vacuum blasting
- jackhammer
- pneumatic or hydraulic impactor
- concrete spaller
- flame cutting
- thermic lance cutting.

A comparison of these surface removal techniques is presented in Table C.1-1.[9] The techniques are discussed in the following paragraphs. The use of controlled blasting with explosives for bulk concrete removal is also described.

Sandblasting

Sandblasting, where the surface is mechanically eroded away, removes only a minimal surface thickness and produces large quantities of small, contaminated particles. Sandblasting primarily removes paint and a little of the concrete surface. It does not effectively remove contamination from the pores in the concrete or from expansion joints. A large exhaust and air filtration system is needed with this method to control contaminated dust. This technique is relatively slow if the contamination penetrates beyond a thin surface layer.

TABLE C.1-1. Comparison of Major Concrete Surface Removal Techniques

Technique	Advantages	Disadvantages	Type of Rubble Produced	Size of Air Filtration System Required
Sandblasting	Useful for removing thin layers and paint	Contamination embedded in pores not effectively removed generates large quantities of dust and airborne particulates	Small particles	Large
Vacuum blasting	Useful for limiting the spread of dust and abrasive	Vacuum pickup not efficient on irregular surfaces	Small particles	Medium
Jack hammer	Proven technique	Awkward to use on walls. Generates quantities of dust.	Medium-size pieces and small particles	Medium
Pneumatic or hydraulic impactor	Proven technique	Limited to large accessible facilities. Generates moderate quantities of dust.	Medium-size pieces and small particles	Medium
Concrete spaller	Proven technique. Controlled rate of material removal	Awkward to use on irregular surfaces or in cramped quarters. Cutting through steel rebar slows cutting speed and damages drill.	Medium-size pieces and small particles	Small
Flame cutting	Cuts both concrete and steel without difficulty. Adaptable for remote operation.	Generates large quantities of toxic gases and smoke. Hot gases can damage HEPA filters, making contamination control difficult.	Small particles	Large
Thermic lance cutting	Cuts both concrete and steel without difficulty. Adaptable for remote operation.	Generates moderate quantities of toxic gases and smoke. Hot gases can damage HEPA filters, making contamination control difficult.	Small particles	Large

Vacuum Blasting

Vacuum blasting is an abrasive blasting technique in which the nozzle is surrounded by a concentric exhaust air cone to remove the blast dust and abrasive (see Figure C.1-4). The cone through which the debris and spent abrasive is exhausted is connected by a hose to a vacuum system.

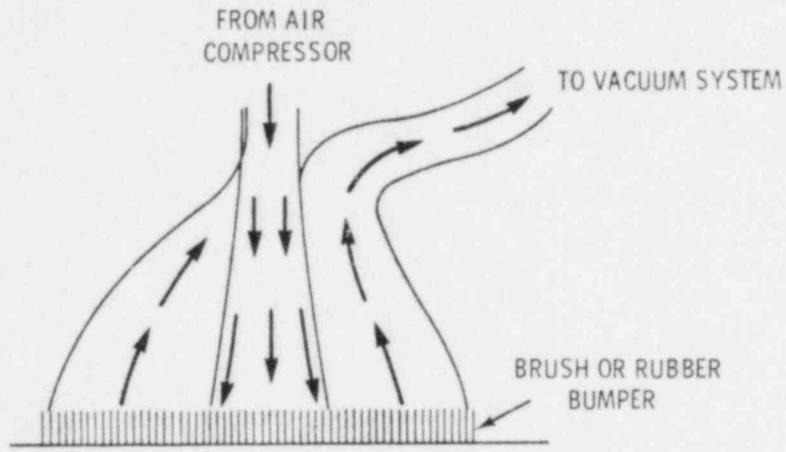


FIGURE C.1-4. Cross Section of a Vacuum Blaster Nozzle

Commercial vacuum blasting units are available that use a cyclone separator to remove the abrasive from the exhaust air stream and that filter the air for collection of the radioactive dust. The abrasive material is reused. Units can be floor-mounted or hand-held, thus allowing either semi-remote or hands-on operation. Vacuum blasting is most useful when the unit can be held perpendicular to the surface being cleaned. On irregular surfaces, reflection of abrasives can be a problem and vacuum pickup is less efficient. Decontamination factors of 1000 can be achieved with this technique.

Jackhammer

Jackhammers, powered by compressed air, are readily available and are easily operated by one man. They are used to chip off the surface material deep enough to remove the contamination. Because they are difficult to position on walls and ceilings, jackhammers are used primarily on floors. A medium-size air filtration system is necessary to control the dust produced by the use of this equipment.

Impactor

Impactors (or hoe rams), similar in operation to jackhammers but much larger, have been used successfully in several decontamination projects.(9,10) An impactor, powered either pneumatically or hydraulically, uses a pick chisel

point that is driven into the concrete surface with high-energy impacts several times per second. The use of impactors also requires an air filtration system for dust control.

Concrete Spaller

The concrete spaller, shown schematically in Figure C.1-5, is a lightweight, fully portable rock-splitting tool consisting of a split collar with a sharp triangular ridge around the circumference, mounted on a traveling shaft which has a tapered end. The spaller is operated by inserting the expanding bit into a predrilled hole and activating the device hydraulically, causing the concrete surrounding the bit to be spalled off. Use of the spaller permits localized concrete removal to depths of 50 to 75mm with no explosions and relatively little dust. (The principal source of the dust is the drilling of the hole into which the splitting tool is inserted.) The hole pattern and the spacing between holes are important parameters in the effectiveness of this technique.

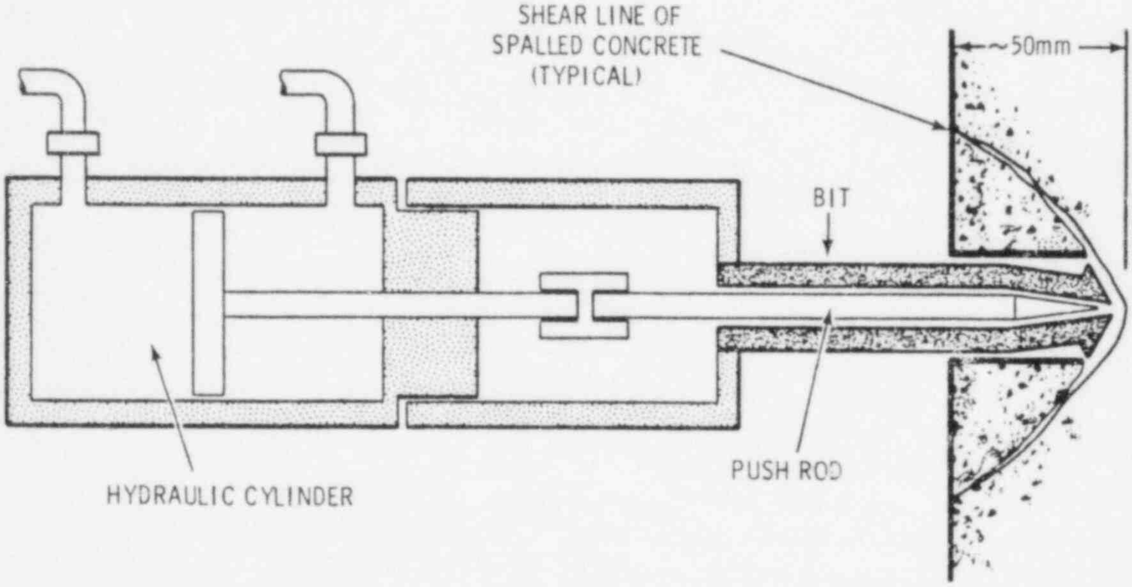


FIGURE C.1-5. Schematic of Concrete Spaller

The concrete spaller is selected as the reference device used in this study for removal of contaminated concrete surfaces.

Flame Cutting

Flame cutting of concrete consists of a thermite reaction process whereby a powdered mixture of iron and aluminum is ignited in an oxygen jet at a

temperature of approximately 9000°C, resulting in rapid decomposition of the concrete in contact with the jet. The mass flow through the flame-cutting nozzle clears away the decomposed concrete, leaving a clean kerf. Reinforcing rods in the concrete add iron to the reaction to sustain the flame and assist the reaction.

Flame cutting results in the production of copious quantities of toxic gases and smoke. The gases and smoke may be removed by a squirrel cage blower, and directed through a flexible duct that houses a water fogger to hold down smoke particulate. The high gas temperatures preclude the use of HEPA filters for contamination control, making the flame-cutting technique unsuitable for use on radioactive concrete unless the effluent gas is precooled.

Thermic-Lance Cutting

The thermic lance consists of an iron pipe packed with a combination of steel, aluminum, and magnesium wires through which a flow of oxygen gas is maintained. The thermic lance utilizes a thermite reaction at the tip of the iron pipe, in which the constituents are completely consumed and temperatures in the range of 2500°C to 6000°C are generated. Thermic-lance cutting, like flame cutting, results in the production of large quantities of smoke and hot gases.

Controlled Blasting with Explosives

Controlled blasting is ideally suited for demolition of massive or heavily reinforced, thick concrete sections. The process consists of drilling holes at preselected locations in the concrete, loading the holes with explosives, and detonating using a delayed firing technique. Placement of blasting mats over the affected region prevents flying debris from penetrating the confinement envelope. Fog sprays of water, typically used from one minute before to about 15 minutes after blasting, help settle the dust from the explosion. Although blasting sequences are designed to minimize air pressure surges, the ventilation enclosures must be designed to withstand those pressure surges that do occur. Similarly, attention must be given to the ventilation system to close dampers during blasting to prevent surge damage to filters.

Various types of explosives are available for use in demolition applications. The selection of the best type of explosive and of the appropriate blasthole design for a given demolition application should be made by a qualified blasting expert. In this study, the services of a certified blasting technician are assumed to be retained for the duration of bulk concrete removal activities.

C.2 CONTAMINATION CONTROL

Decontamination following an accident requires large-scale transfers of personnel and equipment between highly contaminated areas and less contaminated areas. Many decommissioning operations, particularly cutting operations required for equipment disassembly and concrete removal operations, have the potential to generate significant amounts of airborne radioactive contamination. Effective methods of contamination control are required to minimize the spread of contamination during these activities and to reduce the hazard to decommissioning workers.

Requirements for contamination control during decommissioning can be categorized as follows:

- isolation of contaminated areas
- local mitigation of contamination sources
- collection of contamination

Contamination control measures in each of these categories are described in the following subsections.

C.2.1 Isolation of Contaminated Areas

Barriers are used to isolate contaminated areas and to minimize the spread of radioactivity from highly contaminated areas to less contaminated areas.

One type of barrier commonly used in the nuclear industry to isolate contaminated areas is a "greenhouse." A greenhouse is constructed by covering a framework, usually steel scaffolding or wood frame, with plastic sheeting and sealing all joints. Overlapping flaps of plastic are generally used for the door. The greenhouse is connected either to the plant ventilation system or to a portable system, which prevents outward leakage of contamination by drawing a slight vacuum on the greenhouse. Greenhouses can be semipermanent, portable structures that can be moved from one location to another as needed, but are more often temporary confinement structures that are dismantled and discarded after each job.

In many cases, construction of a complete greenhouse is unnecessary. A simple plastic curtain partitioning off one section of a room may be all that is required to isolate a contaminated area. The type and degree of isolation required depends on the equipment or structures involved, the associated level and mixture of radioactive contamination, the ventilation balance (direction of airflow), and the cleanup or decommissioning operation being performed.

C.2.2 Local Mitigation of Contamination Sources

Mechanical or physical measures can be used to limit the spread of radioactive contamination. Two methods that have been successfully used are

1) water sprays to reduce airborne dust dispersion, and 2) painting of contaminated surfaces to prevent smearing.

The wetting of dust with water or other liquids is one of the oldest methods of contamination control and can be very effective if properly used. Water sprays are widely used to control fugitive dust emissions from construction sites. The spraying of water containing detergent (as a wetting agent) has been used in the nuclear industry to reduce dust concentrations in air during waste exhumation operations.(11) To be effective, the liquid application must be designed to blanket the dust source completely and to wet the dust particles thoroughly. Various types, sizes, and patterns of spray nozzles are used, depending on the physical properties of the dust, the type and size of the dust source, and the degree of control desired. Water sprays can be used in combination with other contamination control techniques, and are commonly used for dusty operations such as concrete removal.(10)

Nonflammable, strippable coatings can be used to seal porous surfaces (e.g., concrete) to prevent penetration of contamination into the surfaces. Paint can be used to seal smearable contamination already present on surfaces to prevent subsequent contamination spread.(10) Spraying is generally the easiest and quickest method of application. Painting is especially useful in high-traffic areas, where smearable contamination is likely to be picked up and spread around on shoe covers and equipment wheels.

C.2.3 Collection of Contamination

Collection of radioactive contamination before it can be dispersed (preferably as it is generated) reduces the need for additional decontamination subsequent to some cleanup and decommissioning activities. Various collection methods can be used. Vacuum collection and portable ventilation systems are discussed in this section.

Vacuum Collection

Contaminated materials can be collected as they are generated by using vacuum systems. A dust shield with a vacuum attachment can be installed on the tool (e.g., concrete spaller or scrubber) being used. As the contaminated dust is generated, it is drawn into the vacuum system and deposited in a collection drum. The outlet air is filtered (with roughing and HEPA filters) to prevent the collected contamination from being expelled.

Various designs for vacuum collection systems are possible, depending on the required operating characteristics. One such system, shown schematically in Figure C.2-1, is described in Reference 12. This system, originally designed for collection of contaminated soil, uses a standard 0.21-m^3 waste

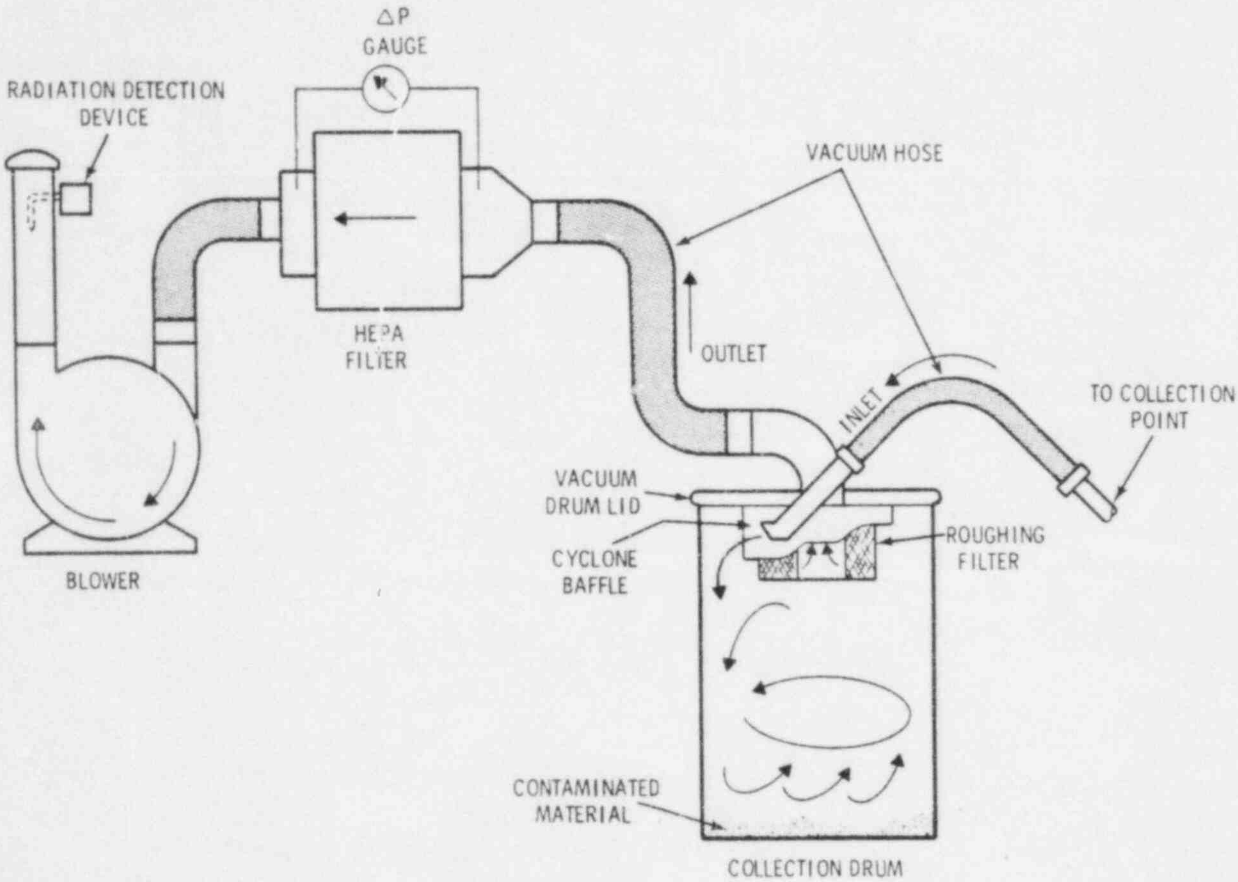


FIGURE C.2-1. Vacuum Collection System Schematic

drum to collect the contaminated material. When the drum is filled, it is capped and sealed for disposal. A special, commercially-available vacuum lid that employs a cyclone baffle arrangement to enhance dust settling is modified to accept an inexpensive, disposable roughing filter. A HEPA filter and power/vacuum-blower unit, mounted on a steel pallet, complete the system. The system is reported to be capable of pulling up to 28 m^3/min of air at 110-mm-Hg vacuum, and is estimated to cost less than $5000.

Portable Ventilation Systems

Portable ventilation systems can be used to confine and collect airborne particulates generated during decommissioning operations. General design information concerning such systems is discussed at length in Reference 13. Two portable ventilation systems, a work enclosure and a fume exhauster, are discussed here.

Portable Filtered Ventilation Enclosure

A typical portable filtered ventilation enclosure unit is illustrated in Figure C.2-2. A large squirrel-cage blower is coupled with a high-efficiency

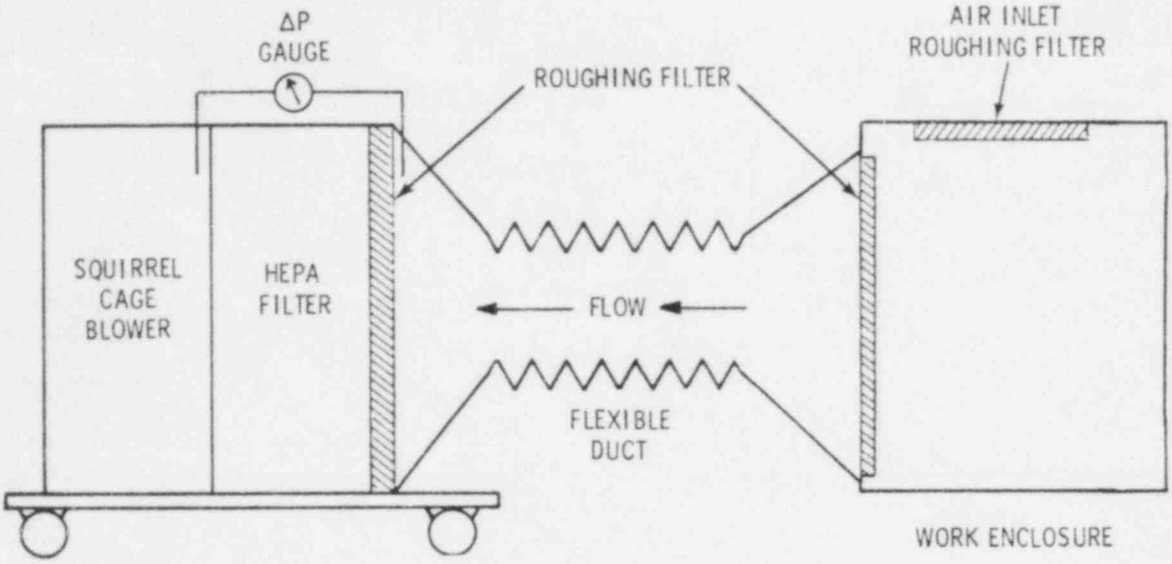


FIGURE C.2-2. Portable Filtered Ventilation Enclosure

particulate air (HEPA) filter preceded by a glass-fiber roughing filter, all mounted on a wheeled cart. A flexible duct couples the cart unit to the enclosure unit that surrounds the work area and confines the materials being emitted. Roughing filters are installed at both the inlet and the outlet of the enclosure unit. The enclosure unit may have whatever shape best performs the required function at a particular location. A simple, rectangular open-faced box will suffice for many applications.

Radiation detection devices are used to monitor the buildup of radioactive material on the filters. A differential pressure gauge is installed across the HEPA filter to monitor the increasing pressure drop as particulates build up on the filter. Filters are changed when either the dose rate from the collected radioactive particles or the differential pressure across the HEPA filter reaches a predetermined level.

Portable Filtered Fume Exhauster

Another type of portable filtered ventilation system, a fume exhauster, is illustrated in Figure C.2-3. This system has an electrostatic precipitator coupled with a roughing filter, HEPA filter, air-handling motor, squirrel-cage blower, and one or two free-standing intake ducts. The fume exhauster is used to collect radioactive and nonradioactive particulates at the point of generation. This high-volume ventilation system captures all types of particulate matter with efficiencies of greater than 97% for the electrostatic unit and at least 99.95% for the HEPA filter. The advantages of this unit are its portability, its ability to handle large volumes of particulate-laden air, and its generation of relatively small amounts of solid wastes (HEPA filters).

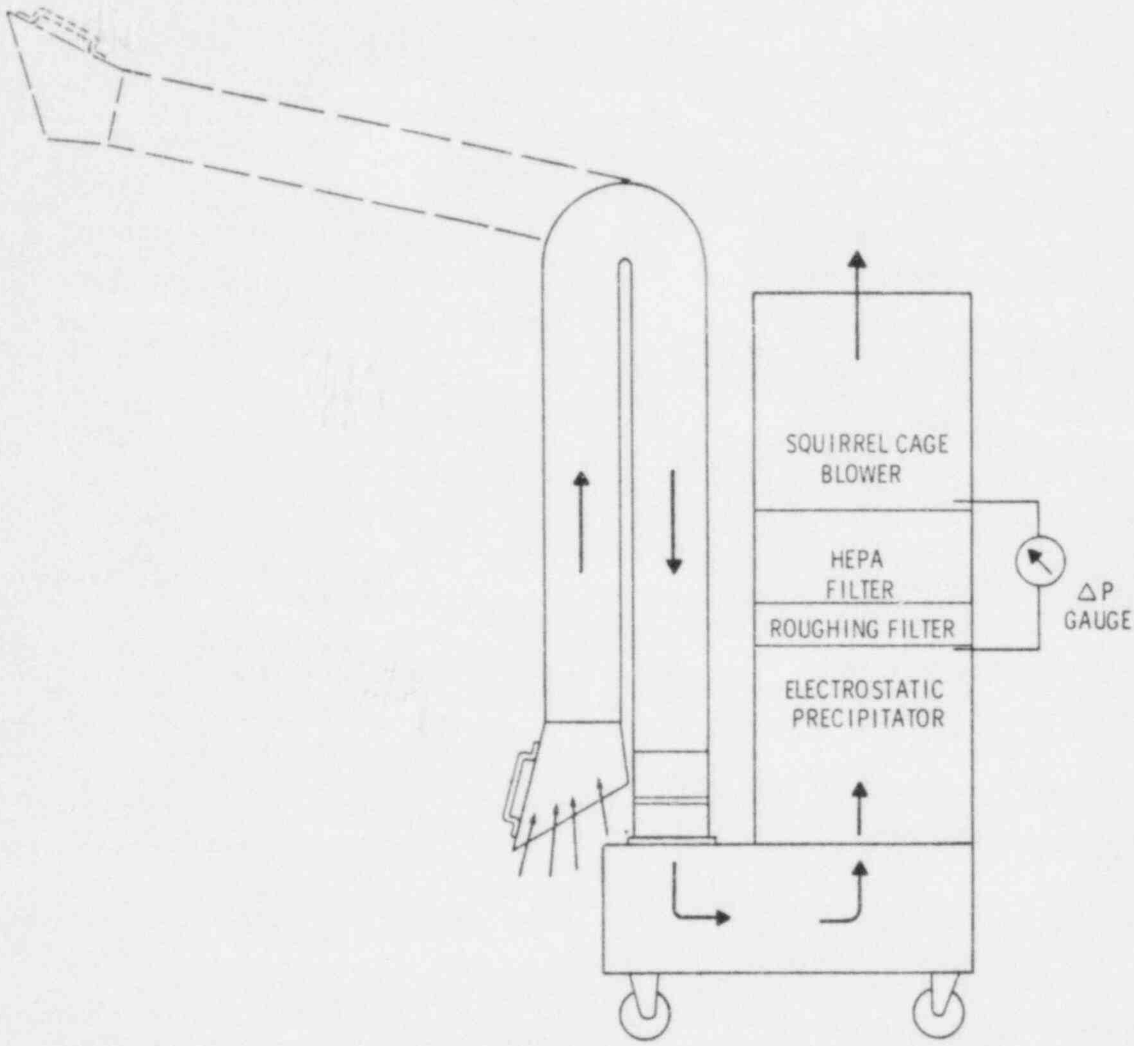


FIGURE C.2-3. Portable Filtered Fume Exhauster

C.3 SPECIAL TOOL AND EQUIPMENT REQUIREMENTS

Special tool and equipment requirements for post-accident cleanup and decommissioning are identified during planning and preparation. Designs and specifications are prepared for each item required. When an item is procured, it is inspected to verify that it meets specifications and complies with applicable Quality Assurance (QA) and safety requirements. It is then tested to ensure that it performs as required. The testing also serves to train personnel in the use of the equipment and to provide data on its operation.

Special tools and equipment items postulated to be needed for accident cleanup and decommissioning are shown in Table C.3-1. The function of each item is given as well as the number required for accident cleanup.

TABLE C.3-1. Special Tools and Equipment for Dismantlement

Time	Number Required	Estimated Unit Cost ($ Thousands)	Functions
Oxyacetylene torch	2	1	Sectioning of glove boxes, tanks. piping, support structures, etc.
Portable plasma cutting torch	4	20	
Arc saw	1	100	
Guillotine pipe saw	2	1	
Tube Cutter	2	0.3	
Ratcheting pipe cutter	6	0.05	
Reciprocating saw	4	0.5	
Nibbler	2	1	Cutting ductwork and other thin gauge materials.
Assorted tools such as impact wrenches, bolt cutters, etc.	as required	5	Disassembly, handling and packaging of contaminated materials
High velocity liquid jet	1	5	Surface decontamination of piping, tanks, and equipment
Low velocity liquid jet	2	2	
Hydraulic concrete surface spalling device	1	2	Removal of contaminated concrete surfaces
Concrete drills	2	0.2	Drilling holes in concrete as required for spalling and volume blasting
Electric/pneumatic hammers	2	0.5	
Portable filtered ventilation ventilation enclosure	1	0.5	Collecting and filtering air, smoke, fumes, etc., from cutting operations on contaminated materials.
Portable fume exhauster	1	3	Same as for portable ventilation enclosure
Supplied air bubble suit	20	0.05	Provide personnel with maximum respiratory and surface protection against contamination
Electropolishing decontamination system	1	100	Final decontamination of piping, tanks, ductwork, glove boxes, etc.
Nuclear waste compactor	1	120	Compact contaminated dry waste by 5:1 ratio

C.4 PACKAGING, TRANSPORTATION, AND DISPOSAL OF WASTES

The cleanup and decommissioning of an accident-damaged reactor results in significant quantities of radioactive wastes requiring treatment, packaging, and disposal. These wastes result from the accident and from decontamination and disassembly operations. The management of these radioactive wastes is described in this section.

C.4.1 Waste Characterization

Large quantities of radioactive wastes are generated during the dismantlement of the reference plants. These wastes must be properly packaged and shipped to an authorized disposal site.

Radioactive wastes generated during the dismantlement include:

- Solidified liquids from chemical decontamination activities
- Concrete rubble from the mechanical decontamination of contaminated floors and walls
- Contaminated process equipment, tanks, hoods, and glove boxes
- Contaminated piping, ducts and fixtures
- HEPA and roughing filters
- Sections of ventilation ductwork
- Combustible and noncombustible trash (protective clothing, contaminated tools, rags, paper, plastic, metal scrap, etc.).

Contaminated Piping and Equipment

Some of the piping and equipment contaminated during normal operation or as a result of the accident cannot be decontaminated and requires packaging and disposal as radioactive waste. Equipment items requiring disposal include tanks, motors, pumps, valves, filters, instrumentation, and other components. Contact exposure rates for these materials range from a few mR/hr to thousands of R/hr.

Water-Based Decontamination Solutions

Post-accident decontamination procedures include the use of water to wash down internal building surfaces and equipment. This water becomes contaminated with the radioactive materials it washes off the surfaces. The chemical and

physical characteristics of the water depend on the contamination levels of the surfaces washed, the procedure used for application of the water, and the extent to which detergents are used. In general, water-based decontamination solutions contain suspended solids, fission products, chemical contaminants, and detergents. The solutions represent a relatively large volume of low-specific-activity liquid waste. Processing of these solutions results in the generation of secondary waste forms, including spent filter cartridges, loaded ion exchange materials, and evaporator bottoms.

Chemical Decontamination Solutions

Post-accident decontamination operations also use chemical solutions (e.g., strong detergent solutions or foam-type decontamination agents). The effectiveness of these solutions may be greater than that of water-based solutions, and the resultant liquid may have higher specific activities than water-based solutions. Processing of these solutions using evaporation results in the generation of secondary waste in the form of evaporator bottoms.

Rubbish and Trash

Radioactive trash generated during post-accident decommissioning operations consists of compactible and noncompactible solid material, some of which is also combustible. The compactible and combustible solids consist of disposable clothing, rags, plastic covers, laydown pads, and miscellaneous trash. Noncompactible solids consist of tools, hoses, safety goggles, miscellaneous construction materials, and other small items of equipment used by decommissioning personnel. The form and specific activity of the solid waste generated by post-accident cleanup and decommissioning crews is comparable to the solid waste generated during decontamination operations at other nuclear facilities.

Spent Filter Cartridges

Spent filter cartridges are a form of secondary waste arising from the treatment of radioactive liquids. Filter cartridge assemblies are typically right-circular cylinders used to remove particulates from liquid waste; the contaminated particulates are deposited on the filter. They represent a form of waste with low to very high specific activity, with their specific activity dependent on the contaminants in the processed waste stream.

Evaporator Bottoms

The use of evaporation techniques to reduce liquid waste volumes results in the generation of process solids in the form of evaporator bottoms or sludges. The physical characteristics of these process solids depend on the solids content of the liquids evaporated and the equipment used for evaporation. These characteristics can range from slurries containing 10-20 wt%

solids to sludges with solids contents in excess of 50 wt%. The specific activities of these process solids also vary over a wide range.

Incinerator Ash

Incinerator ash is produced as a result of the incineration of combustible trash to reduce its waste volume. Incineration results in a volume reduction of about a factor of 50 to 100 with a corresponding increase in the specific activity of the ash.

C.4.2 Alternatives for Waste Management

Waste management alternatives for the wastes from post-accident cleanup and decommissioning, described in Section C.4.1, are shown in Tables C.4-1 through C.4-3. Management of these wastes includes treatment or conditioning as necessary to solidify the wastes and reduce their volumes, and packaging, followed either by onsite storage or by shipment of the wastes to an offsite storage or disposal facility. Shipments may be made in shielded or unshielded containers depending on package surface exposure rates.

Onsite storage of radioactive wastes is assumed to be a temporary measure, since it is unlikely that a facility plant site could qualify as a permanent waste repository because of such factors as nearby population densities and hydrology. Temporary onsite storage of wastes may be necessary if adequate facilities for permanent offsite disposal are not available.

Most radioactive wastes from post-accident cleanup and decommissioning operations are assumed to be disposed of by shallow-land burial. The NRC has amended its rules in Title 10 of the Code of Federal Regulations to add a new Part 61[6,14] which provides licensing procedures, performance objectives, and technical requirements for the issuance of licenses for the land disposal of "low-level" radioactive waste. A waste classification system has been developed and incorporated in Part 61 for the purpose of defining waste concentrations and packaging and disposal requirements so that the health and safety of the public and the long-term protection of the environment is not compromised as a result of shallow-land burial operations.

Three classes of wastes are defined by Part 61 requirements:

1. Class A wastes are wastes for which there are no stability requirements but which must be disposed of separate from other wastes. These wastes are defined in terms of maximum allowable concentrations of certain isotopes and minimum requirements on waste form that are necessary for safe handling.

TABLE C.4-1. Waste Management Alternatives for Solid Wastes from Accident Cleanup and Decommissioning

Waste Management Alternative	Contaminated Piping and Equipment	Rubbish and Trash
Treatment		X
Compaction		X
Incineration		X
Disassembly/sectioning	X[a]	
Packaging		
0.21-m^3 steel drum		X
Disposal steel liner	X	
Plywood box	X	X
Special container	X[b]	
Shipment		
Unshielded	X	X
Shielded	X	
Storage or Disposal		
Interim onsite storage	X	X
LLW burial ground	X	X
Interim storage at federal repository	X	
Deep geologic disposal[c]	X	

(a) X denotes alternative considered for waste type.
(b) Some equipment items are packaged by capping the piping connections and using the equipment outer shell as the container.
(c) This alternative not currently available.

2. Class B wastes are wastes that need to be placed in a stable waste form and disposed of separate from unstable waste forms. These wastes are defined in terms of requirements for stable waste form as well as in terms of allowable concentrations of isotopes and minimum handling requirements.

TABLE C.4-2. Waste Management Alternatives for Liquid Wastes from Accident Cleanup and Decommissioning

	Waste Type	
Waste Management Alternative	Water-Based Decon Solution	Chemical Decon Solution
Treatment		
Filtration	X	
Evaporation	X	X
Conditioning		
Immobilize/cement	X	X
Immobilize/vinyl ester styrene	X	X
Packaging		
$0.21\text{-}m^3$	X	X
Disposal steel liner	X	X
Shipment		
Unshielded	X	X
Shielded	X	X
Storage or Disposal		
Interim onsite storage	X	X
LLW burial ground	X	X

(a) X denotes alternative considered for waste type.
(b) O denotes alternative for tritiated water only.

3. Class C wastes are wastes that need to be placed into a stable waste form, disposed of separately from nonstable waste forms and in such a way that a barrier is provided against potential inadvertent intrusion after institutional controls have lapsed. These wastes are defined in terms of allowable concentration isotopes and requirements for disposal.

Maximum allowable waste concentrations for the three waste classes are shown in Table 1 of 10 CFR Part 61.55. Wastes containing concentrations higher than the upper limits specified in the table would be generally unacceptable

TABLE C.4-3. Waste Management Alternatives for Process Solids from Accident Cleanup and Decommissioning

Waste Management Alternative	Waste Type: Spent Filter Cartridges	Evaporator Bottoms	Incinerator Ash
Conditioning			
Dewatering			
Immobilize/cement		X	X
Immobilize/vinyl ester styrene		X	
Packaging			
0.21-m^3 steel drum	X	X	X
Disposal steel liner	X	X	
Shipment			
Unshielded			
Shielded	X	X	X
Storage or Disposal			
Interim onsite storage	X	X	X
LLW burial ground	X	X	X
Interim storage at federal repository	X		
Deep geologic disposal(b)	X		

(a) X denotes alternative considered for waste type.
(b) This alternative not currently available.

for near-surface disposal. The disposal of such wastes would be subject to case-by-case determinations depending on the specific waste forms and disposal techniques.

The physical and chemical characteristics and the packaging requirements for wastes that are considered acceptable for disposal by shallow-land burial are also defined in Part 61. Table 1 of 10 CFR Part 61.55 indicates that radioactive wastes containing chelating agents in concentrations greater than 0.1% are not permitted for near-surface disposal except as specifically approved by the NRC.

The regulations in 10 CFR 61 can have a direct effect on the choices of decontamination and waste processing methods employed for post-accident cleanup and decommissioning. Choices should ensure that wastes intended for shallow-land disposal meet the waste characteristics, radioisotope concentration limits, and packaging requirements set forth in the regulations.

C.4.3 Packaging of Radioactive Wastes

A variety of containers are used for the packaging of radioactive wastes from accident cleanup and decommissioning operations. Details of packaging requirements are given in subsequent appendices where the specific cleanup and decommissioning alternatives are described.

Only solid wastes are assumed to be transported to a commercial burial ground or federal repository. Radioactive liquids generated during chemical decontamination operations are concentrated by evaporation and solidified by mixing with cement. The resultant solid is packaged for shipment in 208-ℓ (55-gal) steel drums.

Non-TRU waste from decommissioning operations is packaged for shipment in 208-ℓ (55-gal) steel drums or in plywood boxes. Packages of non-TRU waste qualify as low specific activity (LSA) material[a] and can be shipped without shielding.

TRU-contaminated decommissioning wastes are assumed to be shipped in containers that conform to current techniques for the packaging of these wastes. TRU wastes with low external radiation levels are packaged in DOT specification 7A steel boxes,[15] DOT specification 17C 208-ℓ (55-gal) steel drums,[15] and in plywood boxes assumed to require a rigid polyethylene liner in order to satisfy a retrievability requirement at the federal repository. The steel boxes will have outer dimensions of 1.2 x 1.2 x 2.1 m (4 x 4 x 7 ft.). Plywood boxes will

---

(a) Radioactive materials are classified for transportation purposes into one of seven transport groups according to their potential hazard if released to the environment. Transport Group I is the most restrictive. Plutonium and other transuranic elements are in this transport group. Transport Group VII is the least restrictive. Shipments that pose a negligible risk to the public health may be classified as low-specific-activity (LSA) material 10 CFR 71.4(g). If the radioactivity is essentially distributed uniformly, with a concentration of not more than 0.1 Ci/g of Group I material, or 5 Ci/g of Group II material, or 300 Ci/g of Group III or IV material, the waste qualifies as LSA material. Externally contaminated nonradioactive materials may be considered as low-specific-activity provided that the radioactive contamination averaged over 1 m^2 does not exceed 0.1 Ci/cm^2 for Group I radionuclides or 1.0 Ci/cm^2 for others. Basically, only strong, tight packaging that will not leak in normal transport is required for the shipment of LSA material.

normally have the same dimensions, but could be as large as 2.4 x 3.6 x 2.7 m high (8 x 12 x 9 ft. high).[18] The weight of a single package is assumed to be limited to 11,400 kg (25,000 lb).[18]

C.4.4 Shipping of Radioactive Materials

All shipments of radioactive materials must be made in compliance with federal, state, and local regulations. Federal transportation regulations of DOT and NRC establish container regulations, dose rate limits, and handling procedures that ensure the safety of the public and transportation workers during shipment of radioactive materials.[19] Federal regulations applicable to the transport of radioactive materials are:

- Title 49 Code of Federal Regulations Parts 170-199 (49 CFR 170-199)--Department of Transportation regulations governing the transport of hazardous materials.

- 10 CFR 71--NRC regulations governing the packaging and shipment of radioactive materials.

In addition, for highway transport, state agencies regulate vehicle sizes and weights and, in some cases, transportation routes and times of travel.

Dose rates, for shipments in exclusive-use, closed transport vehicles, must not exceed the following values (DOT, 49 CFR 173.393):

1. 1000 millirem per hour at 1 m (3 ft) from the external surface of the package

2. 200 millirem per hour at any point on the external surface of the vehicle

3. 10 millirem per hour at 2 m (6 ft) from the external surface of the vehicle

4. 2 millirem per hour at any normally occupied position in the transport vehicle.

These dose rate limits are illustrated in Figure C.4-1 for truck transport.[20] All of these criteria must be met on a given shipment, with an exclusive-use vehicle, properly placarded.

Shipments of non-TRU waste will be transported to licensed commercial low-level waste burial grounds. Because none of the currently licensed commercial burial grounds has a rail siding, it is assumed that all non-TRU waste shipments will be made by truck in exclusive-use vans.

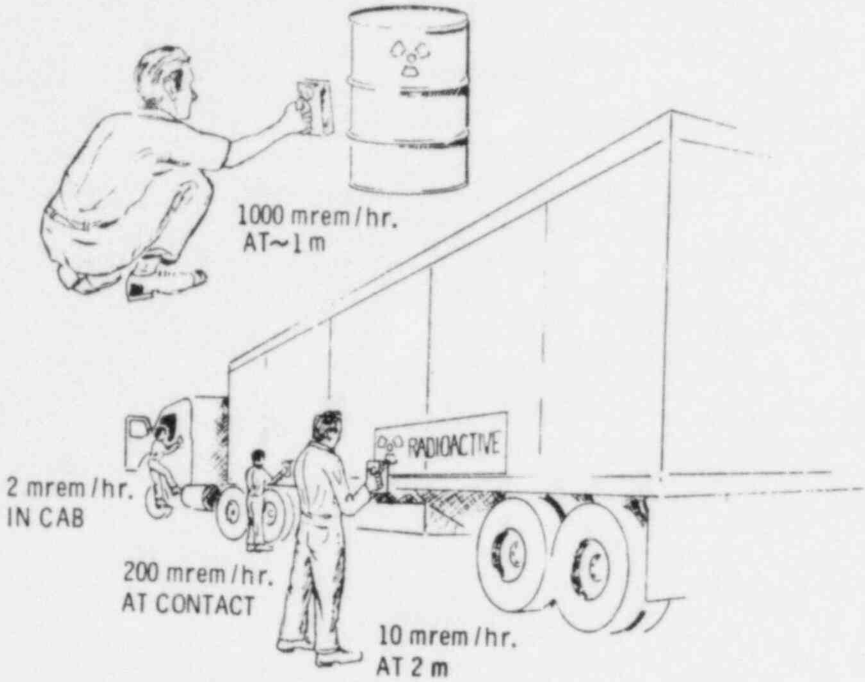


FIGURE C.4-1. Radiation Dose Limits for Closed Exclusive-Use Vehicles (from Reference 25)

Because individual waste packages of TRU waste will probably exceed the 0.001 Ci limitation for Group I radionuclides,[21] all of these shipments are presumed to be made in overpacks that meet type B package standards[22] or their equivalent. To determine transportation costs, in this study it is assumed that drums or boxes are transported in a Super Tiger® container.[23] Figure C.4-2 is a schematic of the Super Tiger container. The Super Tiger is a double-walled steel box with a fire-resistant polyurethane foam filer for shock and thermal insulation. Interior dimensions are 1.93 x 1.93 x 4.36 m (76 x 76 x 192 in.). The empty weight is 6,800 kg, (15,000 lb), and the maximum payload is 13,600 kg (30,000 lb). Total usable volume in the Super Tiger is 16.3 m^3 (575 ft^3). A volumetric load efficiency of 75% (12.0 m^3) is assumed for planning purposes. Shipment may be by truck or rail with one Super Tiger per truck shipment or two Super Tigers per railroad flat car.

C.5 ESSENTIAL SYSTEMS AND SERVICES

All or parts of certain facility systems and services must be available during accident cleanup and decommissioning operations until all radioactive

® Registered trademark of Protective Packaging, Inc., subsidiary of Nuclear Engineering Company, Inc., Jeffersontown, Kentucky.

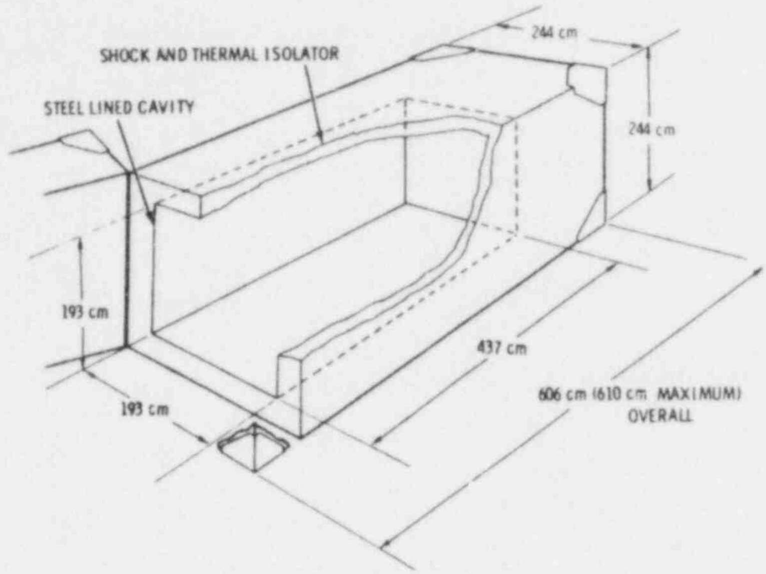


FIGURE C.4-2. Super Tiger®

material is either removed or secured in place, to prevent the release of significant quantities of radionuclides to the environment. Some systems and services are required for cleanup and disassembly activities. Other systems provide health and safety protection to the decommissioning workers and the public. If these essential systems and services have been lost or damaged as a result of the accident, they must be repaired or replaced with temporary systems and services before cleanup and decommissioning can proceed.

The essential systems and services are listed in Table C.5-1 together with the justification for their retention during accident cleanup and decommissioning operations.

C.6 QUALITY ASSURANCE

Quality assurance (QA) is an important part of the accident cleanup and decommissioning effort. A QA program consists of all of the programmed events necessary to ensure that cleanup and decommissioning activities are performed in accordance with established procedures, that proper safety considerations are observed, and that adequate documentation is maintained. QA portions are included during the planning and preparation phase as detailed procedures are developed.

Regulations and guidance pertaining to QA in the construction and operation of nuclear power plants are contained in several documents, including:

TABLE C.5-1. Essential Systems and Services for Accident Cleanup and Decommissioning

System or Service	Justification
Electrical Power	Operation of electrical equipment, including HVAC, lighting, and radiation monitoring
HVAC Systems	Ventilation and radioactive contamination confinement
Water Supply (service & domestic systems)	Decontamination cleanup, fire protection, and potable water
Fire Protection System	Health and safety
Compressed Air Systems (control & service)	Operation of pneumatic controls and tools; personnel fresh air supply
Communications System	Facilitate and coordinate decommissioning activities
Radiation Monitoring Systems	Personnel safety considerations
Radwaste Systems	Treatment of radioactive liquids and solids
Closed Cooling Water Systems	Secondary cooling of other systems
Chemical Feed System	Radwaste handling
Security Systems	Public safety and plant protection considerations

- 10 CFR 50, Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants"
- Regulatory Guide 1.58, Qualifications of Nuclear Power Plant Inspection, Examination and Testing Personnel for the Construction Phase of Nuclear Power Plants
- Regulatory Guide 1.88, Collection and Storage of Nuclear Power Plant Quality Assurance Records

- Regulatory Guide 1.143, Design Guidance for Radioactive Waste Management Systems, Structures, and Components Installed in Light-Water Cooled Nuclear Power Plants

- NRC's Standard Review Plan,[24] Section 17.1, "Quality Assurance During the Operating Phase."

While these documents do not specifically address cleanup and decommissioning fuel cycle facilities, they do contain guidance on such topics as the design, purchase, and fabrication of equipment, the training of personnel, and the maintenance of QA records--topics that are pertinent to these operations.

C.7 ENVIRONMENTAL SURVEILLANCE PROGRAM

Levels of environmental surveillance needed are different for dismantlement operations and for the period of safe storage. The scopes of the necessary programs for these two cases are outlined in the following section.

The objectives of an environmental surveillance program for operating nuclear facilities are generally recognized as valid, and that rationale can be applied to facilities undergoing decommissioning as well. The following objectives are taken from ICRP No. 7.[25]

- Detection of sudden changes and evaluation of long-term trends of concentration in the environment, with the intent to detect failure or lack of adequate control of releases and to initiate appropriate actions.

- Assessment of the actual or potential exposure of man to radioactive materials or radiation present in his environment, or the estimation of the probable upper limits of such exposure.

- Determination of the fate of contaminants released to the environment, especially with the intent of detecting previously unconsidered mechanisms of exposure.

- Demonstration of compliance with applicable regulations and legal requirements concerning releases to the environment.

Basic radiation exposure criteria and radioactive effluent release criteria applicable to population exposure are given in 10 CFR 20, Sections 20.1, 20.105, 20.106, and 20.303. For nonradioactive contaminants, consideration must be given to applicable standards such as Water Quality Criteria[26] and ambient air quality standards listed by the Environmental

Protection Agency (EPA).[27] Local or state air quality criteria would presumably also apply on a site-specific basis.

In addition, the interfaces of the environmental monitoring program between the plant owner, the appropriate state agencies, and the EPA should be stipulated in the application for the amended license, as may be required by 10 CFR, Part 70, Section 70.23(a), 70.32(b), and 70.34.

A suggested minimum program of environmental radiological surveillance to be conducted outside the plant during decommissioning operations for the purpose of establishing population dose is shown in Table C.7-1. This minimum program continues until all radioactive waste shipments from the site have been completed. At that time, the program is reduced in scope.

The analytical detection limits given in Table C.7-1 are based on the practicability of routine radioactivity measurement techniques, and in all cases should be sufficient to quantify radionuclide concentrations that would result in conservatively estimated whole body and individual organ doses in the range of 1 to 50 mrem/year from specific nuclides. These nuclides are identified upon completion of the operational monitoring program. They are then defined in terms of concentrations in environmental media at levels which, if sustained, would result in doses in excess of acceptable limits. The derivation of these levels corresponds with the site-specific method of assessing offsite doses from radioactive materials in estimated gaseous and liquid effluents (if any), and is assumed to be consistent with the recommendations of the Federal Radiation Council[28] and the International Commission on Radiological Protection.[29] The environmental radiological monitoring program is designed to integrate fully with any ongoing programs of the state where the reference plant is located. Quality assurance is achieved, in part, by the site-specific state QA program and by participation in the EPA analytical quality assurance program. Sample collections and radiation measurements required to meet the schedule suggested in Table C.7-1 are assumed to be conducted at locations and in amounts previously established during the operational lifetimes of the reference plant. The program and any changes thereto are reportable items to the NRC and to other appropriate regulatory agencies, as environmental technical specifications, in accordance with the terms of the amended license. Quality control mechanisms are exercised for all procedures involved.

Environmental monitoring during the period of decommissioning activities is carried out by the Health Physics group of the decommissioning organization as a part of their normal duties.

TABLE C.7-1. Recommended Basic Environmental Monitoring Program for the Period of Active Decommissioning Operations

Sample Type	Frequency	Analysis	Analytical Detection Limit[a]	Sampling Stations Onsite	Sampling Stations Offsite
Terrestrial Samples					
Air Particulate	Weekly	Gross Alpha	0.002 pCi/m^3	2	4
	Monthly	Gross Beta	0.002 pCi/m^3	2	4
	Monthly	Gamma Scan[b]	0.3 pCi/m^3/isotope	2	4
Direct Radiation	Quarterly	TLD[c]	1.25 mrem/quarter increase	8	10
Rainfall	Monthly	Gross Alpha	0.5 pCi/ℓ	1	2
	Monthly	Gamma Scan[d]	25 pCi/ℓ/isotope	1	2
Soil	Semiannually	Gamma Scan	0.1 pCi/g/ isotope (dry)	3	3
Vegetation	Semiannually	Gamma Scan	50 pCi/kg/ isotope (wet)	2	3
Animals	Semiannually	Gamma Scan	50 pCi/kg/ isotope (wet)	2	3
Milk	Semiannually	Gamma Scan	50 pCi/ℓ/isotope	0	5[e]
Aquatic Samples					
Surface Water	Monthly	Gross Alpha	0.5 pCi/ℓ	2	3
	Monthly	Gamma Scan[e]	25 pCi/ℓ/isotope	2	3
Well Water	Quarterly	Gross Alpha	0.5 pCi/ℓ	1	3
	Quarterly	Gamma Scan[d]	25 pCi/ℓ/isotope	1	3
Bottom Sediment	Semiannually	Gamma Scan	0.1 pCi/g/ isotope (dry)	1	3
Vegetation	Semiannually	Gamma Scan	100 pCi/kg/ isotope (wet)	1	3
Shoreline Soil	Semiannually	Gamma Scan	0.1 pCi/kg/ isotope (dry)	0	3
Fish	Semiannually	Gamma Scan	100 pCi/kg/ isotope (wet)	1	3

(a) Analytical detection limit is defined here as that concentration that is three standard deviations above the average concentration in a blank sample, and assures accuracy limits of ±25%.

(b) To be performed if gross alpha exceeds 0.1 pCi/m^3.

(c) TLD: thermoluminescent dosimeter.

(d) To be performed if gross alpha exceeds 10 pCi/ℓ

(e) Includes on sample from a local milk processor.

REFERENCES

1. J.A. Ayres, ed., Decontamination of Nuclear Reactors and Equipment, the Ronald Press, New York, New York, 1970.

2. R.L. Dillon, et al., Literature Review of Dilute Chemical Decontamination Processes for Water-Cooled Nuclear Reactors, EPRI NP-1033, Pacific Northwest Laboratory for Electric Power Research Institute, March, 1979.

3. J.A. Partridge and R.E. Lerch, Chemical Decontamination of Metals, HEDL-SA-1880, Hanford Engineering Development Laboratory, Richland, November 1980.

4. W.J. Manion and T.S. LaGuardia, Decommissioning Handbook, DOE/EV/10128-1, Nuclear Energy Services, Inc. for U.S. Department of Energy, November 1980.

5. L.D. Perrigo and J. R. Divine, Decommissioning Methods, PNL-SA-7770 Rev. 1, Pacific Northwest Laboratory, Richland, Washington, May 1980.

6. "Licensing Requirements for Land Disposal of Radioactive Waste," Federal Register, Vol. 46, No. 142, pp. 38081-38100, 24 July 1981.

7. R.P. Allen, et al., Electropolishing as a Decontamination Process: Progress and Application, PNL-SA-6858, Pacific Northwest Laboratory, Richland, Washington, April 1978.

8. M.W. McCoy, H.W. Arrowsmith, and R.P. Allen, Vibratory Finishing as a Decontamination Process, PNL-3336, Pacific Northwest Laboratory, Richland, Washington, October 1980.

9. J.M. Halter and R. G. Sullivan, Contaminated Concrete Surface Layer Removal, presented at Fourth International Conference on Contamination Control, Washington, D.C., September 10-13, 1978.

10. W.D. Kittinger, B.F. Uredia, and J.W. Carroll, Experience and Techniques in Atomics International's Recent Decommissioning Programs, presented at Health Physics Society Annual Meeting, Philadelphia, Pennsylvania, July 8-13, 1979.

11. D.H. Card, Early Waste Retrieval Interim Report, TREE-1047, EG&G Idaho, Inc., Idaho Falls, Idaho, February 1977.

12. C.C. Meinhardt and G.M. Holter, Interim Report on Mini-Vacuum System, RHO-CD-524, Rockwell Hanford Operations, Richland, Washington, May 1978.

13. N.I. Sax, Dangerous Properties of Industrial Materials, Fifth Edition, VanNostrand Reinhold Company, Section 2, "Industrial Air Contaminant Control," by B. Feiner, pp. 40-115, 1979.

14. Draft Environmental Impact Statement on 10 CFR Part 61 "Licensing Requirements for Land Disposal of Radioactive Waste, NUREG-0782, Vol. 1, U.S. Nuclear Regulatory Commission, Washington, D.C., September 1981.

15. D.A. Edling and J.F. Griffin, Certification of ERDA Contractors Packaging with Respect to Compliance with DOT Specification 7A Performance Requirements, MLM 2228, Monsanto Research Corporation, Mound Laboratory, Miamisburg, Ohio, June 1975.

16. R.J. Merlini, D.L. Cash and K. Terada, "Radioactive Waste Package Development at the Rocky Flats Plant," paper presented at the International Seminar on the Design, Construction, and Testing of Packaging for the Safe Transport of Radioactive Materials, Vienna, Austria, August 1976, IAEA-SR-10/26.

17. E. Vejvoda, "Impact of Proposed Waste Criteria on Rocky Flats as a Prime Waste Generator," published in TRU Waste Form and Package Criteria Meeting, SAND-77-1178, Sandia Laboratories, Albuquerque, New Mexico, August 1977.

18. Assessment of TRU Waste Research and Development Programs in Support of Finalizing TRU Waste Acceptance Criteria for the Waste Isolation Pilot Plant, paper presented for the Division of Waste Management, Production, and Reprocessing, U.S. ERDA, September 1, 1977.

19. F.B. Conlon and G.L. Pettigrew, Summary of Federal Regulations for Packaging and Transportation of Radioactive Materials, (BRH/DMRE-71-1) U.S. Department of Health, Education, and Welfare, Public Health Service, Bureau of Radiological Health, Rockville, Maryland, February 1971.

20. Radioactive Materials Transportation Manual, Nuclear Transport Division, Tri-State Motor Transit Co., Joplin, Missouri, 1974.

21. Title 10, Code of Federal Regulations, Part 71.4, Government Printing Office, Washington, D.C., issued annually.

22. Title 10, Code of Federal Regulations, Part 71.36, Government Printing Office, Washington, D.C., issued annually.

23. Director of Packaging for Transportation of Radioactive Material, p. 251, WASH-1279, USAEC Division of Waste Management and Transportation, Washington, D.C., October 1973.

24. Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, NUREG-75/087, U.S. Nuclear Regulatory Commission, Washington, D.C., September 1975.

25. International Commission on Radiological Protection, Principles of Environmental Monitoring Related to the Handling of Radioactive Materials, ICRP Pub. 7, Pergamon Press, Oxford, 1966.

26. Federal Water Quality Administration, Guidelines for State Water Quality Legislation.

27. Title 40, Code of Federal Regulations, Part 50, Government Printing Office, Washington, D.C., issued annually.

28. Federal Radiation Council, Background Material for Development of Protection Standards, Report No. 2, 1961.

29. International Commission on Radiological Protection, Report of Committee II on Permissible Dose for Internal Radiation, Publication No. 2, 1959.

APPENDIX D

DETAILS OF MOX PLANT CLEANUP AND DECOMMISSIONING

APPENDIX D

DETAILS OF MIXED-OXIDE PLANT CLEANUP AND DECOMMISSIONING

To supplement the discussion in Chapter 8 of Volume 1, this appendix provides details of the technical requirements and manpower needs for accident cleanup at the reference mixed oxide (MOX) plant. A discussion of the rationale for accident cleanup is also provided. The accidents postulated in this report result in the severe contamination of the reference MOX plant.

The first activities following stabilization of an accident consist of an accident cleanup campaign with two principal goals:

1. to reduce the initial high levels of radioactive contamination present on building surfaces and equipment, thereby reducing the radiation dose received by workers engaged in cleanup and decommissioning operations

2. to collect, package for disposal, and dispose of the readily dispersible radioactivity present in the plant.

To achieve these goals, the accident cleanup campaign is postulated to include the following tasks:

- processing of contaminated liquids generated by the accident (and by decontamination operations) to remove and immobilize radioactive contaminants

- initial decontamination of building surfaces and decontamination or disposal of some equipment

- solidification and packaging of wastes from accident cleanup operations.

The sequence of accident cleanup tasks and their relationship to decommissioning activities is shown schematically in Figure D.0-1. The rationale for accident cleanup is discussed in Section D.1. Even if a decision were made to refurbish rather than to decommission an accident-damaged plant, the same accident cleanup tasks would be required. In Figure D.0-1, a decision point relating to restarting the plant or completing the decommissioning is shown following the completion of accident cleanup. This decision point could be earlier, but an early decision to restart would probably have minimal impact on the requirements for accident cleanup.

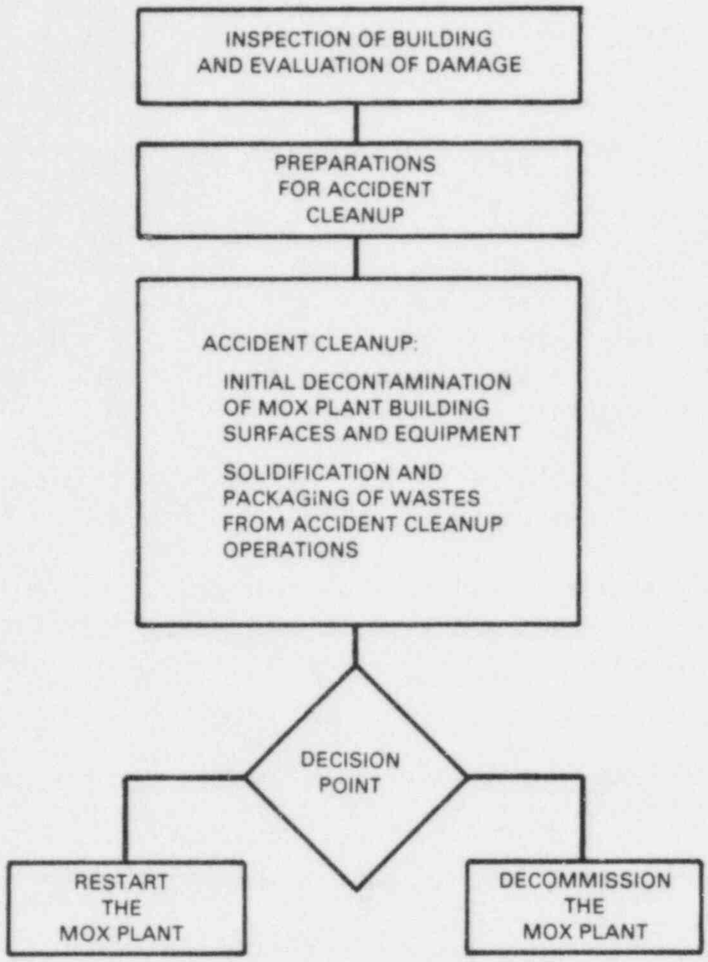


FIGURE D.0-1. Sequence of Accident Cleanup Tasks

Because accident cleanup activities would be similar whether the plant is refurbished for restart or decommissioned, the requirements, costs, and safety analysis given in this report are considered to be a good representation independent of the ultimate use of the plant. However, this study does not include a consideration of activities related to refurbishment or restart of a MOX plant following the accident cleanup period.

Accident cleanup activities are independent of the alternative (DECON, SAFSTOR, or ENTOMB) chosen to decommission the facility, although the methods used to complete certain tasks may vary with the decommissioning alternative.[a] The work required to complete each task will certainly be influenced by the severity of the accident.

(a) In this study, cleanup methods are assumed not to vary substantially with decommissioning alternative.

The rationale for accident cleanup is given in Section D.1. Details of accident cleanup are discussed in Section D.2, including cleanup methods and procedures, schedules and manpower requirements, and occupational radiation doses. The costs of accident cleanup are discussed in Section D.3. Details of activities and manpower requirements for decommissioning are discussed in Section D.4. The costs of decommissioning following an accident are discussed in Section D.5.

D.1 RATIONALE FOR ACCIDENT CLEANUP AT A REFERENCE MIXED-OXIDE PLANT

In this report, cleanup tasks are assumed to be performed prior to other operations of whichever alternative is chosen to decommission the facility. The rationale for their early completion is given in the following paragraphs.

In keeping with ALARA principles, decontamination efforts during accident cleanup are restricted to those operations that result in the greatest reduction in residual radioactive contamination with the least radiation dose to decontamination workers. These operations include washdown of building surfaces using water jet equipment, and installation of temporary shielding around localized hot spots. Hands-on decontamination work using mops and wipes with assorted cleaners is performed in those instances where significant reductions in local area radiation dose rates can be readily achieved.

A decision to decommission or to refurbish a facility does not affect the goals of accident cleanup or the tasks that must be accomplished during cleanup. A decision about future use of the plant might, however, affect the choice of procedures used to accomplish certain cleanup tasks. For example, a decision about whether some equipment was to be disposed of or reused could affect the choice of chemicals used to decontaminate the equipment.

As defined in this study, accident cleanup does not include the extensive hands-on decontamination operations required to reduce surface contamination inside the plant to levels suitable for release of the facility for unrestricted use. That additional decontamination would take place during decommissioning activities. In addition, as defined in this study, accident cleanup does not include the additional hands-on decontamination to reduce radiation levels to low enough values to permit the extensive work necessary during refurbishment of the facility. Accident cleanup also does not include the decontamination or disposal of permanently installed equipment items such as the wet process system and associated piping that would not be removed or refurbished until either the decommissioning or refurbishment of the facility following the completion of accident cleanup.

Based on the above considerations, it is assumed in this report that the tasks included in accident cleanup are necessary and the procedures used to

accomplish these tasks are essentially independent of whether the facility is ultimately restarted or decommissioned, and if decommissioned, of the alternative chosen. The work required to accomplish each accident cleanup task is, however, affected by the severity of the accident. Technical requirements for accident cleanup are discussed in the following subsections.

D.2 DETAILS OF ACCIDENT CLEANUP AT A REFERENCE MIXED-OXIDE PLANT

Details for accident cleanup at the reference MOX plant, including details of the preparation for accident cleanup, are presented in this section.

D.2.1 Details of Preparations for Accident Cleanup

A period of planning and preparation precedes the actual performance of cleanup operations within a MOX facility that has been involved in an accident. Planning and preparation activities and the manpower requirements for their performance are described in this section.

In the studies of decommissioning following normal shutdown, planning and preparation activities for decommissioning were assumed to take place during the final year of operation. Obviously, since accidents are unplanned events, preparations for accident cleanup and for the subsequent decommissioning must begin after the accident has occurred and the plant is shut down. Many planning and preparation tasks must be completed before accident cleanup operations can begin, thereby delaying the start of these operations. Other planning and preparation tasks cannot be completed during the initial preparations phase and must be deferred until some cleanup renders the accident-damaged facility more accessible for detailed examination.

Planning and Preparation Activities

Several planning and preparation activities must be performed prior to the operational phase of cleanup. These activities include:

- contaminated area entry and data acquisition
- prepare documentation for regulatory agencies
- design, fabricate, and install special equipment
- develop detailed work plans and procedures
- select and train accident cleanup staff.

Contaminated Area Entry and Data Acquisition. Data on the post-accident radiological and physical condition of the plant are obtained and analyzed during planning and preparation activities. These data provide a basis for planning accident cleanup operations and for selecting appropriate methods and equipment to perform the cleanup. The data also provide information needed to prepare documentation for regulatory agencies.

Radiation surveys are performed to measure contamination levels and radiation exposure rates inside the damaged area. These surveys provide information on which to base decisions about decontamination requirements and work procedures as well as baseline data for later use in judging the effectiveness of cleanup operations. Initial radiation surveys are made as detailed as possible without excessive exposure to personnel performing the surveys.

Additional data needed for planning cleanup and decommissioning operations include information about the operational status of plant systems and services (such as radiation detectors, ventilation equipment, electrical services, cranes, radwaste equipment, etc).

Initial entries into the reference MOX plant may provide only limited information or information of general nature, especially following a severe accident where radiation levels are high and time of access is limited. More detailed information about the condition of the facility can be obtained after initial decontamination of building surfaces to reduce exposure rates is completed.

Radiation surveys continue during cleanup operations to evaluate the effectiveness of these operations. A comprehensive radiation survey, taken after chemical decontamination of the wet process system is completed, provides the basis for planning final decommissioning operations.

Prepare Documentation for Regulatory Agencies. Existing regulations, guides, and standards that apply to a MOX plant that has been involved in an accident are discussed in Chapter 5 of Volume 1. At the start of planning and preparation activities, the current status of these requirements must be reviewed by the licensee who must accomplish the cleanup and decommissioning in compliance with their provisions. The cleanup and decommissioning of an accident-damaged plant by the licensee is also subject to statements, orders, and amendments to the facility license issued by the NRC pursuant to its statutory authority for regulating nuclear fuel cycle activities.

A major planning task is the preparation by the licensee of the necessary documentation to amend the facility operating license to maintain the plant in a safe shutdown condition and to obtain regulatory approvals to proceed with cleanup operations. Regulations pertaining to termination of the operating license are set forth in Section 50.82. of Part 50 of Title 10 of the Code of Federal Regulations. Regulatory Guide 1.86 describes methods acceptable to the NRC for satisfying the requirements of Section 50.82. Documentation that must be provided by the licensee includes:

- a description of the current facility status
- a description of the ultimate facility status

- proposed changes to the technical specifications
- descriptions of proposed cleanup and decommissioning operations and associated environmental and safety precautions
- safety and environmental analyses of cleanup and decommissioning operations and of any resultant releases of radioactivity
- safety and environmental analyses of the plant and its ultimate status.

Consistent with the intent of 10 CFR 51, Licensing and Regulatory Policy and Procedures for Environmental Protection, and in keeping with the purposes of the National Environmental Policy Act (NEPA), before decommissioning begins, an environmental impact statement or environmental assessment may be needed describing the probable effects of the proposed cleanup and decommissioning actions. The licensee is required to provide supporting information to assist the NRC in the preparation of these documents. As an illustration of the type of documentation required, as of June 1981 (27 months after the accident), the following environmental statements and assessments had been prepared for the decontamination of the damaged reactor plant TMI-2. The requirements for a reactor are probably more stringent than those for a fuel cycle facility, but they provide some indication of possible requirements:

1. Final Programmatic Environmental Impact Statement (PEIS) Related to Decontamination and disposal of Radioactive Wastes from the TMI-2 Accident.(1) The PEIS is an overall study of the activities necessary for decontamination of the facility, defueling, and disposition of the radioactive wastes. It is intended to provide an overall evaluation of the environmental impacts that could result from these activities.

2. Final Environmental Assessment for Decontamination of the TMI-2 Reactor Building Atmosphere.(2) This document provides an assessment of information considered by the NRC in arriving at a recommendation for the preferred method of removing ^{85}Kr from the containment building so that workers can begin the tasks necessary to decontaminate the building and remove the damaged fuel from the reactor core.

3. Environmental Assessment on the Use of EPICOR-II at TMI-2.(3) This is an evaluation of the effect on public health and safety of the use of the EPICOR-II system for the cleanup of radioactive contaminated waste water that had accumulated in the Unit 2 auxiliary building

tanks. The document includes a consideration of the environmental impacts of the use of EPICOR-II and a discussion of alternatives to the EPICOR-II system.

4. Safety Evaluation Report on the Operation of the Submerged Demineralizer System at TMI-2.[4] This is an evaluation of the effect on public health and safety of the decontamination of reactor building sump water and reactor coolant system water using the submerged demineralizer system (SDS) followed by polishing in EPICOR-II. The evaluation only considers the processing of the contaminated water and does not consider the disposition of the processed water.

The cleanup and decommissioning of an accident-damaged MOX plant is also subject to constraints imposed by statements, orders, and amendments to the facility license issued by the NRC subsequent to the accident.

The time requirement for furnishing information to regulatory agencies, issuing environmental statements and assessments, and securing regulatory approvals to go ahead with specific cleanup tasks is a critical factor in determining when actual cleanup operations can begin.

Design, Fabricate, and Install Special Equipment. Planning and preparation includes the identification and procurement of special tools and equipment required for accident cleanup and decommissioning. Some items, such as cutting tools or decontamination equipment, can be identified early in the planning stage before actual cleanup begins. Other items may not be identified until the initial building decontamination is completed.

Major facilities and equipment items required to clean up an accident-damaged MOX plant include the following:

- an evaporator/solidification facility to process the decontamination solutions generated
- a volume reduction incinerator to reduce the total quantities of waste that would need to be disposed of
- shielded and unshielded storage facilities for interim storage of radioactive wastes may be required if there is difficulty in disposing of wastes because of regulatory or political constraints
- a laundry facility.

Many of these facilities and equipment items require design and development work as well as actual fabrication and testing. Evaporator/solidification

facilities, volume reduction incinerators, and laundry facilities are commercially available and can be purchased or rented.

Designs and specifications are prepared for each special equipment item required. When the item is procured, it is inspected to verify that it meets specifications and complies with applicable quality assurance and safety requirements. It is then tested to ensure that it performs as required. The testing also serves to train personnel in the use of the equipment and to provide pertinent data on its operation.

Develop Work Plans and Procedures. Detailed work plans and procedures are developed based on an evaluation of the condition of the plant following an accident and on the requirements for accident cleanup. Work plans are included in documentation provided to the NRC with the request for license amendment. The detailed plans and procedures contain all the information required to actually carry out the accident cleanup tasks. They address the following items:

- regulatory requirements and constraints
- decontamination methods and procedures
- schedules and sequences of events
- manpower requirements
- equipment requirements
- contamination control
- radiological and industrial safety
- packaging and disposal of radioactive wastes
- quality assurance.

Physical security and environmental constraints are also considered. Plans are updated as the accident cleanup work proceeds and additional data on the physical and radiological status of the facility become available.

Select and Train Accident Cleanup Staff. The selection and training of operations staff for accident cleanup is an important part of planning and preparation. Staffing requirements are identified during this period, and key positions are filled with qualified engineering and operating personnel.

Detailed knowledge of and familiarity with the facility being decontaminated increases the effectiveness of the cleanup staff. Consequently, positions are assumed to be filled, whenever possible, with personnel familiar with the construction and operation of the plant, to capitalize on experience and minimize training requirements. Additional training required to perform specific cleanup tasks is provided, with special emphasis given to the use of new and unique equipment and procedures. This results in improvements in efficiency and reduces occupational exposures when actual cleanup operations are performed inside the plant.

Because of the relatively high exposure rates encountered and the need to limit individual radiation doses, large numbers of persons are involved in

accident cleanup operations. Many of these individuals are unfamiliar with the plant, and some are unfamiliar with the basic principles of radiation protection. These persons require an orientation in the layout of the plant and in basic radiation protection procedures as well as specific instruction in the tasks to be performed.

Time Requirements for Preparations for Accident Cleanup

Time requirements for planning and preparation depend on several factors, including the severity of the accident, the time needed to design, fabricate, install, and test special facilities and equipment, and the time required to secure regulatory approvals for specific cleanup tasks.

The time required to secure regulatory approvals for specific cleanup operations is a critical factor in determining when these operations can begin. Delays by the licensee in responding to requests for information and/or delays in the review process that precedes the issuing of regulatory approvals could significantly delay the start of accident cleanup operations.

In this study, planning and preparation activities that precede accident cleanup at the reference MOX plant are estimated to require approximately 0.5 years.

Occupational Doses for Preparations for Accident Cleanup

The major source of occupational radiation dose during preparations for accident cleanup is the dose received by workers who enter the contaminated building area to measure contamination levels and radiation exposure rates, assess the damage to the building and equipment, install monitoring systems, and make minor repairs to essential systems and equipment. The assumed average external whole-body doses received by these workers are summarized in Table D.2-1. Average dose rates are based on accident scenario information presented in Chapter 6 of Volume 1.

Workers are assumed to spend an average of one hour in the contaminated area during each entry. All personnel entering the contaminated areas wear protective clothing and full-face respirators. For entries following the reference accident, the average individual worker dose per entry is 0.02 rem.

Staff Requirements for Preparations for Accident Cleanup

The staff organization for preparations for accident cleanup includes a cleanup planning branch, a plant operations branch, and several site support branches.

TABLE D.2-1. Estimated Occupational Doses to Workers Entering Contaminated Areas During Preparations for Accident Cleanup at the Reference MOX Plant[(a)]

Number of Entries into Contaminated Area	12
Average Time per Entry (hours)	1
Average Dose Rate (rem/yr)	0.02
Number of Workers per Entry	5
Total Accumulated Occupational Dose (man-rem)	1.0

(a) Preparations for accident cleanup are assumed to require 0.5 years following the accident.

Major activities of the cleanup planning branch include:

- preparation of documentation for regulatory agencies
- preparation of design specifications for special facilities and equipment
- preparation of detailed work plans and work schedules
- acquisition of data on the radiological and physical condition of the plant
- testing of equipment and procedures to be used in cleanup operations
- installation or repair of systems required for accident cleanup (e.g., reroute piping connections, install systems for remote monitoring, etc.).

The plant operations branch has the responsibility to maintain the plant in a safe shutdown condition. In addition to operations in the control room, this responsibility entails the following activities:

- maintain and repair systems required to keep the plant in a safe shutdown condition.
- monitor and maintain auxiliary systems such as plant communications, heating, ventilation and air conditioning, etc.

They assist the cleanup planning staff in the acquisition of data on the radiological and physical condition of the building and in the installation and testing of systems required for accident cleanup.

Site support includes radiological health, industrial safety, plant security, procurement and accounting, and quality assurance services.

Estimated staff labor requirements for staff involved in preparations for accident cleanup are shown in Table D.2-2. Labor requirements are given on a total man-year basis.

TABLE D.2-2. Estimated Staff Labor Requirements for Preparations for Accident Cleanup at the Reference MOX Plant

Position	Staff Labor Requirements (man-years) for Preparations for Accident Cleanup[a]
Project Manager	0.50
Project Engineer	0.50
Health and Safety Supervisor	0.50
Contracts and Accounting Specialist	0.50
Q. A. Engineer	0.50
Radioactive Shipment Specialist	0.25
Planning Engineer	0.50
Operations Supervisor	0.50
Foreman	0.50
Secretary	1.00
Total Man-Years	5.25

(a) Based on a preparations for cleanup period of 0.5 years.

In addition to the staff involved in preparations for accident cleanup shown in Table D.2-2 contractors are hired to provide specific services that include the following:

- engineering assistance in preparing documentation for regulatory agencies, designing special tools and equipment, and preparing work plans and work schedules

- specialized waste processing services such as evaporation of contaminated solutions and incineration of combustible wastes

- transportation of radioactive wastes to offsite storage or disposal facilities

- laundry services.

D.2.2 Details of Accident Cleanup

Procedures for accident cleanup at the reference MOX plant following a serious accident are described in this section. Work schedules, estimated occupational doses, and estimated staff labor requirements based on these procedures are also presented.

Procedures for Accident Cleanup in the MOX Building

Accident cleanup in the reference MOX plant is postulated to include the following tasks:

- processing of contaminated liquids
- initial decontamination of the MOX building
- removal of nonessential items
- semiremote decontamination
- refurbish or replace essential support systems
- hands-on decontamination
- shielding of hot spots.

Procedures for accomplishing these tasks are given in this section.

Accident cleanup operations are assumed to reduce general area radiation exposure rates at the reference MOX plant to the values shown in Table D.2-3. For the reference accident, cleanup operations are assumed to reduce the radiation exposure rate to approximately the value that existed during plant operations prior to the accident.

TABLE D.2-3. Average General Area Exposure Rates at the Completion of Accident Cleanup Operations at the Reference MOX Plant

Location	Average Exposure Rate (mR/hr)
Operating Floor Level	2
Basement Floor Level	4

As discussed in Section D.1, decontamination activities during accident cleanup are not designed to reduce exposure rates to levels permitting unrestricted use of the facility, but only to limit the doses to workers engaged in accident cleanup. An additional decontamination would be required during decommissioning (or refurbishment) to limit the doses to workers engaged in these activities.

Processing of Contaminated Liquids. Chemical decontamination solutions from initial cleanup operations have radionuclide concentrations in the range from 1 to 20 Ci/m^3. Evaporation is a suitable alternative for treatment of these wastes. An evaporator/solidification facility is rented from a commercial supplier and is installed in the building during preparations for cleanup. The evaporator bottom liquids are postulated to be solidified with vinyl ester styrene and packaged in stainless steel liners for interim onsite storage in the shielded storage facility that is constructed during preparations for accident cleanup.

Initial Decontamination of the MOX Building. The objective of initial decontamination of the MOX plant is to reduce surface contamination levels and resultant radiation exposure levels to permit reasonable occupancy times for workers engaged in system cleanup operations. In addition to surface decontamination procedures, reduction of general area radiation exposure rates requires the removal of contaminated sludge deposits that remain on the walls and floors after any liquids are removed. The reduction of general area radiation exposure rates may require that "hot spots" be shielded by using lead sheet or lead bricks, high-density concrete blocks, or containers filled with water.

For initial decontamination of the MOX plant, the following sequence of operations is postulated:

1. Remove and package debris and small items of contaminated equipment that are easily disposed of.

2. Employ high-pressure hose wash techniques for semiremote decontamination of building surfaces and equipment.

3. Decontaminate and refurbish or replace essential support systems.

4. Perform hands-on decontamination of selected areas where significant reductions in radiation exposure can be achieved with modest effort. Decontaminate floors by scrubbing.

5. Provide local shielding of "hot spots."

Removal of Nonessential Items. The removal from the building of small, nonessential items and debris serves to reduce the general background radiation level and also clears away materials that can impede the progress of the accident cleanup effort. Nonessential items include contaminated tools, loose equipment, barrels, boxes, staging, cables, hoses, wood pallets, etc. Damaged pipes, cable conduits, and other damaged equipment and fixtures that interfere with decontamination operations are cut into sections and removed. Items that are removed from the building are wrapped in plastic and packaged as low-specific-activity waste for disposal at a shallow-land burial ground.

Semiremote Decontamination. Semiremote decontamination involves the use of equipment that permits the worker to stay some distance from the radiation source. High-pressure hose wash is postulated as the method for semiremote decontamination of the MOX building.

As a decontamination method, hose wash offers several advantages in terms of flow rate control, flow pattern, and directional properties. These factors are especially advantageous for the decontamination of hard-to-reach areas. However, because of low impact force, if the surface being cleaned is covered with oil or grease, ordinary hose wash is ineffective. High-pressure water blasting equipment is commercially available that operates at pressures up to 70 MPa with water delivery rates of the order of 0.1 m^3/min. (A water delivery rate of 0.05 m^3/min is postulated for the high-pressure hose wash equipment in this study.) High-pressure water hoses are effective in removing oil and grease deposits. Depending on conditions and equipment, hose-wash decontamination factors range from 2 to 100.

After completion of the high-pressure hose washdown of building surfaces and equipment, a radiation survey is performed to assess the effectiveness of this decontamination procedure. The survey includes sample removals for laboratory analysis as well as air, water, and area radiation surveys.

Refurbish or Replace Essential Support Systems. Severe contamination of building surfaces and equipment, including the ventilation system, is postulated for the reference accident.

To provide adequate ventilation for cleanup workers, contaminated and damaged ventilation system components must be replaced or decontaminated and repaired. Contaminated filters are replaced. Because of the difficulty of cleaning contaminated ductwork, it is assumed that ventilation ductwork is replaced with new ductwork as required to maintain adequate ventilation inside the building. Building fans and cooling units may be decontaminated or replaced.

Hands-on Decontamination. Hands-on decontamination is minimized by first using remote and semiremote decontamination techniques. During accident

cleanup, hands-on efforts are limited to wiping and scouring that must be performed to reduce radiation exposure to workers.

Decontamination of floors is accomplished by scrubbing with brushes or industrial floor scrubbers and a commercial decontamination agent, and then wet vacuuming or mopping to remove the resulting solution. The wash solution is stored in 0.21-m^3 drums until it is solidified for disposal. A final reagent/rinse mopping completes the effort.

Shielding of "Hot Spots." Shielding may be required to protect workers during accident cleanup operations, or it may be required to reduce radiation exposure from "hot spots" when initial decontamination of an area is completed. A low-density shielding material, such as wood or plastic, can be used as a shield for low-energy beta radiation. To achieve a reduction in gamma radiation, lead blankets, lead sheet, lead brick, or high-density concrete blocks may be interposed between the gamma source and the work area. Containers filled with water may also serve as temporary shielding materials. Shielding materials are packaged or covered with plastic or a strippable coating to prevent their contamination.

Waste Treatment and Disposal

Radioactive wastes from accident cleanup operations can be divided into three categories:

1. Solid Materials. Dry radioactive wastes generated from decontamination. These materials consist of trash, and contaminated equipment and material.

2. Process Solids. Contaminated sludges and process solid wastes that arise from the treatment of water and decontamination liquids. These solid wastes include filter cartridge assemblies and evaporator bottoms.

3. Chemical Decontamination Solutions. Liquid decontamination wastes that have not been treated to generate process solids. These wastes are immobilized by incorporation in cement or in vinyl ester styrene.

Because of the levels of plutonium contamination, all process solids (filters and evaporator bottoms), solidified waste, and miscellaneous wastes are postulated to be unacceptable for near-surface burial according to 10 CFR 61 criteria. Hence, they are assumed to be transported to a federal repository for storage or disposal.

Solidified Decontamination Liquids. The volume of solidified decontamination liquids shipped from the reference small MOX plant to deep geologic

disposal during accident cleanup is shown in Table D.2-4. Decontamination liquids are assumed to be processed by evaporation and solidified by incorporation into cement. Evaporation of flush solutions is assumed to result in a reduction factor of ten in liquid volumes. Cementation of the concentrated liquid is assumed to result in a volume increase by a factor of two, with a net volume reduction factor of five from the flush solution volumes to the packaged solidified waste.

TABLE D.2-4. Sources of Solidified Liquid Wastes Generated During Accident Cleanup at the Reference MOX Plant.

Source	Estimated Volume, m^3 Liquid Generated	Waste Shipped
Flush of Solvent Extractions Columns	1.05	0.20
Flush of Wet Ceramics - Dirty and Clean Scrap Recovery	1.00	0.20
Spray Wash of Heavily Contaminated Glove Boxes	4.00	0.80
Spray Wash of Lightly Contaminated Glove Boxes	1.25	0.25
Total	7.3	1.4

Waste Disposal Requirements. Table D.2-5 gives estimated weights and volumes of decommissioning wastes generated during accident cleanup at the reference MOX plant, together with packaging, shipping, and disposal requirements for these wastes.

Schedules and Cleanup Worker Requirements for Accident Cleanup

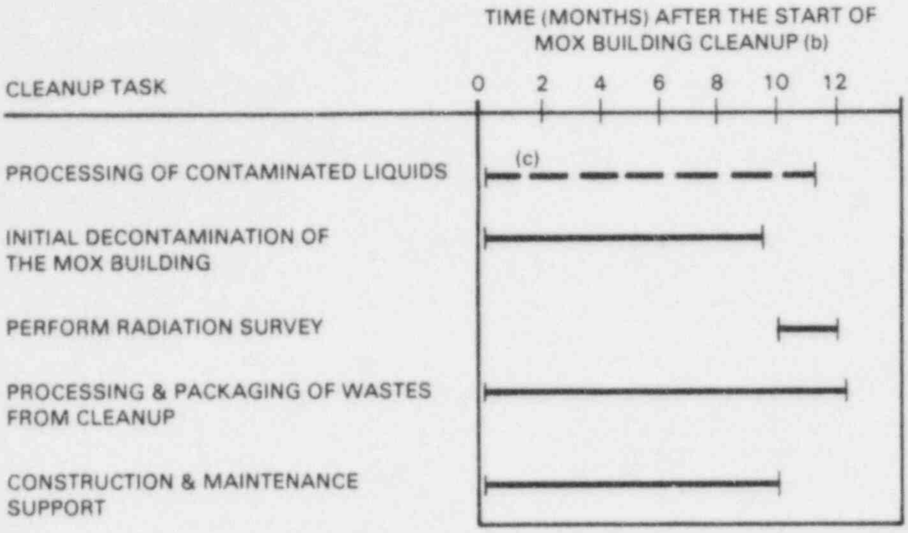
Task schedules and sequences and cleanup worker requirements for accident cleanup at the reference MOX plant following the reference accident are shown in Figure D.2-1. Work schedules and cleanup worker estimates are based on the cleanup procedures described in Section D.4.1. Accident cleanup at the reference MOX plant is estimated to require approximately one year following the reference accident.

Time requirements for accident cleanup are measured from the start of building decontamination operations and do not include the estimated 0.5 years required for preparations for accident cleanup.

TABLE D.2-5. Waste Disposal Requirements of Accident Cleanup at the Reference MOX Plant[a,b]

Waste Category	Shipping Weight (kg)	Shipping Volume (m^3)	Container Type	Number of Containers	Containers per Shipment	Number of Truck Shipments
HEPA and Roughing Filters	10 200	30.0	1.2 x 1.2 x 1.8-m Steel Box	12	3	4
Solidified Decontamination Liquids	30 500	10.0	208-ℓ (55-gal) Drums	60	24[c]	3
Trash	25 500	25.0	208-ℓ (55-gal) Drums	125	42	3
				12 boxes		
Totals	50 000	65.0		185 drums		10

(a) All wastes are disposed of by deep geologic disposal.
(b) Number of figures shown is for computational accuracy, and does not imply precision to three significant figures.
(c) Number of containers per shipment is limited by weight rather than by volume.



(a) SCHEDULE DETAILS ARE GIVEN IN SECTION D.2 OF APPENDIX D.

(b) THE TOTAL TIME REQUIREMENT FOR ACCIDENT CLEANUP IN THE MOX BUILDING FOLLOWING THE REFERENCE ACCIDENT IS 1.0 YEARS

(c) AS REQUIRED DURING THIS TIME PERIOD.

FIGURE D.2-1. Sequence and Schedule for Accident Cleanup at the Reference MOX Plant Following the Reference Accident[a]

The following bases and assumptions are used to estimate time and manpower requirements for accident cleanup in the MOX plant.

1. In general, the time required to perform a particular cleanup task is determined by estimating the time requirement for efficient performance of the task and doubling this time to account for inefficiencies associated with work in high radiation areas.

2. Decontamination workers are assumed to spend only four hours inside the MOX plant during an eight-hour shift. The remaining time is assumed to be required to put on and remove protective clothing, rehearse cleanup procedures, etc.

3. Most accident cleanup tasks are performed on a basis of two-shifts, five days a week. Exceptions to this general rule are noted below.

4. Training time for staff involved in cleanup operations is included in time and manpower estimates for completion of the various cleanup tasks.

5. Cleanup following an accident provides unique opportunities for research in areas related to accident consequences (contamination dispersal mechanisms, waste management requirements, etc.). However, in this report no scheduling allowances are made for research and development activities except those related to the design, fabrication, and testing of the special tools and equipment required for decontamination and defueling operations.

These assumptions provide the bases for the time schedules and cleanup worker requirements shown in Table D.2-6. Cleanup worker requirements shown include only the labor required to actually complete the cleanup tasks and to provide radiation monitoring and craft support to decommissioning workers and do not include the extra labor needed to maintain compliance with occupational radiation dose limits.[5]

Occupational Doses for Accident Cleanup

Estimated occupational radiation doses to cleanup workers during accident cleanup following the reference accident are shown in Table D.2-7. The occupational doses shown in the table are external doses from gamma radiation. Workers are assumed to use respiration devices as necessary to protect against the inhalation of radioactive particulates. Cleanup workers are those workers having work assignments in the MOX plant.

Dose calculations are based on time and manpower requirements shown in the task schedules for accident cleanup in the MOX plant. Exposure hours are estimated on the basis that workers engaged in decontamination operations and in the installation and repair of systems needed for accident cleanup spend an average of four hours inside the plant during an eight-hour shift. Workers who operate the evaporator systems, or are engaged in waste-packaging activities, spend an average of six hours in a radiation area during an eight-hour shift.

The total estimated occupational radiation dose to cleanup workers for accident cleanup is 22.8 man-rem following the reference accident.

Staff Requirements for Accident Cleanup

The postulated staff organization for accident cleanup at the reference MOX is shown in Figure D.2-2. This staff organization includes a plant operations branch and several support branches (e.g., engineering, health and safety, security, contracts and accounting, and quality assurance) as well as the cleanup staff.

Total staff labor requirements for accident cleanup following the reference accident are shown in Table D.2-8. The requirements presented include the management and support staff as well as the cleanup workers but do not include

TABLE D.2-6. Estimated Manpower Requirements During Accident Cleanup at the Reference MOX Plant

Decommissioning Activity[b]	Estimated Man-Weeks[a]				
	Foreman	Technician	Health Physicist	Craftsman	Total
Flush Solvent Extraction System	8	24	6	4	42
Flush Wet Processing and Scrap Recovery Equipment	20	60	15	10	105
Flush Waste Treatment Equipment	4	12	3	2	21
Decontaminate Rooms 121-123, 126	2	12	1	2	17
Decontaminate Room 155	1.5	9	2.5	1	14
Decontaminate Room 156	1	6	1.5	0.5	9
Decontaminate Room 124	6	36	3	6	51
Decontaminate Room 128	10	60	18	6	94
Decontaminate Room 127	6	36	10.5	3.5	56
Decontaminate Rooms 130-133, 135-143	3	18	5	2	28
Decontaminate Room 116	1	6	1.5	0.5	9
Decontaminate Room B01	4.5	27	8	2.5	42
Decontaminate Room B02	3	18	5	2	28
Decontaminate Room 129	1.5	9	2.5	1	14
Decontaminate Rooms 121-123, 126	1	3	1	2.5	7.5
Deactivate Room 124	3	9	2.5	7	21.5
Deactivate Rooms 155 and 156	1.5	4.5	1.5	3.5	11
Deactivate Cold Chemical Processing	1.5	4.5	0.5	3.5	10
Deactivate Room 805	5	15	4.5	10	34.5
Deactivate Wall Storage Tanks	4	12	3.5	10	29.5
Deactivate Room 128	5	15	4.5	10	34.5
Deactivate Room 127	3	9	2.5	7	21.5
Deactivate Room 130-133, 135-143	2	6	1.5	4	13.5
Deactivate Room B01	2.5	7.5	2	6	18
Deactivate Room B02	1.5	4.5	1.5	3.5	11
Deactivate Rooms 129 and 134	1	3	1	2.5	7.5
Deactivate Room 116	0.5	1.5	0.5	1	3.5
Deactivate Miscellaneous Systems	1	3	4	4	12
Deactivate Room 117	4	12	4	15	35
Install and Test Alarm Systems	5.5	16.5	14	22	58
Final Checkout	2	6	20	6	34
Operate Scrap and Waste Treatment	34	136	48.5	39.5	258
Total Man-Weeks	149.5	601	200	200	1150
Total Man-Years[c]	3.0	12.0	4.0	4.0	23.0

(a) Numbers shown are for computational accuracy, and do not imply accuracy to three to five significant figures.
(b) See Section A.2 for functions of the process rooms.
(c) A total of 50 weeks/year is assumed.

TABLE D.2-7. Estimated Occupational Radiation Dose for Accident Cleanup Following the Reference Accident at the Reference MOX Plant

Event Description	Foremen			Operators			H. P. Technicians			Craftsmen			Event Total Dose Man-Rem
	Average Exposure Rate (R/hr)	Total Exposure Man-Hours	Dose Man-Rem	Average Exposure Rate (R/hr)	Total Exposure Man-Hours	Dose Man-Rem	Average Exposure Rate (R/hr)	Total Exposure Man-Hours	Dose Man-Rem	Average Exposure Rate (R/hr)	Total Exposure Man-Hours	Dose Man-Rem	
Flush solvent extraction system	7×10^{-4}	240	0.17	1.4×10^{-3}	720	0.97	1×10^{-3}	135	0.14	1.4×10^{-3}	120	0.16	1.4
Flush wet process and scrap recovery system	5×10^{-4}	600	0.3	9×10^{-4}	1800	1.6	7×10^{-4}	340	0.24	9×10^{-4}	300	0.27	2.4
Flush waste treatment equipment	4×10^{-4}	120	4.8×10^{-2}	8×10^{-4}	360	0.29	6×10^{-4}	65	3.9×10^{-1}	8×10^{-4}	60	4.8×10^{-2}	0.43
Decontaminate Rooms 121-123, 126	1.4×10^{-4}	60	8.4×10^{-3}	3.3×10^{-4}	360	0.12	2.4×10^{-4}	25	6.0×10^{-3}	3.3×10^{-4}	60	2×10^{-2}	0.15
Decontaminate Room 155	2.3×10^{-4}	45	1×10^{-2}	6.7×10^{-4}	270	0.18	4.6×10^{-4}	55	2.5×10^{-2}	6.7×10^{-4}	30	2×10^{-2}	0.24
Decontaminate Room 156	2.3×10^{-4}	30	6.9×10^{-3}	6.7×10^{-4}	180	0.12	4.5×10^{-4}	35	1.6×10^{-2}	6.7×10^{-4}	15	1×10^{-2}	0.15
Decontaminate Room 124	6×10^{-4}	180	0.11	1.1×10^{-3}	1080	1.1	8.3×10^{-4}	65	5.4×10^{-2}	1.1×10^{-3}	180	0.19	1.5
Decontaminate Room 128	5×10^{-4}	300	0.15	1×10^{-3}	1800	1.8	7.5×10^{-4}	405	0.30	1×10^{-3}	180	0.18	2.4
Decontaminate Room 127	4×10^{-4}	180	7.2×10^{-2}	8×10^{-4}	1080	0.86	6×10^{-4}	235	0.14	8×10^{-4}	105	8.4×10^{-2}	1.2
Decontaminate Rooms 130-133, 135-143	6×10^{-5}	90	5.4×10^{-3}	7×10^{-5}	540	3.8×10^{-2}	6.5×10^{-5}	115	7.5×10^{-3}	7×10^{-5}	60	4.2×10^{-3}	5.5×10^{-2}
Decontaminate Room 116	6×10^{-5}	30	1.8×10^{-3}	6×10^{-5}	180	1.1×10^{-2}	6×10^{-5}	35	2.1×10^{-3}	6×10^{-5}	15	9×10^{-4}	1.6×10^{-2}
Decontaminate Room B01	5×10^{-4}	135	6.8×10^{-2}	9×10^{-4}	810	0.73	7×10^{-4}	180	0.13	9×10^{-4}	75	6.8×10^{-2}	0.99
Decontaminate Room B02	4×10^{-4}	90	3.6×10^{-2}	8×10^{-4}	540	0.43	6×10^{-4}	110	6.6×10^{-2}	8×10^{-4}	60	4.8×10^{-4}	0.58
Decontaminate Room 129	6×10^{-5}	45	2.7×10^{-3}	7×10^{-5}	270	1.9×10^{-2}	6.5×10^{-5}	55	3.6×10^{-3}	7×10^{-5}	30	2.1×10^{-3}	2.7×10^{-2}
Deactivate Rooms 121-123, 126	1.4×10^{-4}	30	4.2×10^{-3}	3.2×10^{-4}	90	2.9×10^{-2}	2.3×10^{-4}	25	5.8×10^{-3}	3.2×10	75	2.4×10^{-2}	6.3×10^{-2}
Deactivate Room 124	4×10^{-4}	90	3.6×10^{-2}	8.5×10^{-4}	270	0.23	6.3×10^{-4}	55	3.5×10^{-2}	8.5×10^{-4}	210	0.18	0.48
Deactivate Rooms 155 and 156	2.2×10^{-4}	45	9.9×10^{-3}	6.6×10^{-4}	135	8.9×10^{-2}	4.4×10^{-4}	35	1.5×10^{-2}	6.6×10^{-4}	105	6.9×10^{-2}	0.18
Deactivate Cold Chem. Prep. Room	6×10^{-5}	45	2.7×10^{-3}	6×10^{-5}	135	8.1×10^{-3}	6×10^{-5}	10	6.0×10^{-4}	6×10^{-5}	105	6.3×10^{-3}	1.8×10^{-2}
Deactivate Room B05	4×10^{-4}	150	6×10^{-2}	4×10^{-4}	450	0.18	4×10^{-4}	100	4.0×10^{-2}	4×10^{-4}	360	0.14	0.38
Deactivate Wall Storage Tanks	4×10^{-4}	120	4.8×10^{-2}	8×10^{-4}	360	0.29	6×10^{-4}	80	4.8×10^{-2}	8×10^{-4}	300	0.24	0.63
Deactivate Room 128	4×10^{-4}	150	6×10^{-2}	8.5×10^{-4}	450	0.38	6.3×10^{-4}	100	6.3×10^{-2}	8.5×10^{-4}	360	0.31	0.81
Deactivate Room 127	4×10^{-4}	90	3.6×10^{-2}	8×10^{-4}	270	0.22	6×10^{-4}	55	3.3×10^{-2}	8×10^{-4}	210	0.17	0.43
Deactivate Rooms 130-133, 135-143	6×10^{-5}	60	3.6×10^{-3}	6.5×10^{-5}	180	1.2×10^{-2}	6.3×10^{-5}	35	2.2×10^{-3}	6.5×10^{-5}	150	9.8×10^{-3}	2.8×10^{-2}
Deactivate Room B01	4×10^{-4}	75	3×10^{-2}	8×10^{-4}	225	0.18	6×10^{-4}	45	2.7×10^{-2}	8×10^{-4}	180	0.14	0.38
Deactivate Room B02	3×10^{-4}	45	1.4×10^{-2}	7×10^{-4}	135	9.5×10^{-2}	5×10^{-4}	35	1.8×10^{-2}	7×10^{-4}	105	7.4×10^{-2}	0.20
Deactivate Rooms 129 and 134	6×10^{-5}	30	1.8×10^{-3}	6.5×10^{-5}	90	5.9×10^{-3}	6.3×10^{-5}	25	1.6×10^{-3}	6.5×10^{-5}	75	4.9×10^{-3}	1.4×10^{-2}
Deactivate Room 116	6×10^{-5}	15	9×10^{-4}	6×10^{-5}	45	2.7×10^{-3}	6×10^{-5}	10	6.0×10^{-4}	6×10^{-5}	30	1.8×10^{-3}	6.0×10^{-3}
Deactivate misc. unneccessary systems	3×10^{-4}	30	9×10^{-3}	7×10^{-4}	90	6.3×10^{-2}	5×10^{-4}	90	4.5×10^{-2}	7×10^{-4}	120	8.4×10^{-2}	0.20
Deactivate Room 117	6×10^{-5}	120	7.2×10^{-3}	6×10^{-5}	360	2.2×10^{-2}	6×10^{-5}	90	5.4×10^{-3}	6×10^{-5}	480	2.9×10^{-2}	6.4×10^{-2}
Check safety systems, install alarms, etc.	3×10^{-4}	165	5×10^{-2}	7×10^{-4}	495	0.35	5×10^{-4}	495	0.25	7×10^{-4}	660	0.46	1.1
Final checkout of safety, security, operating systems	3×10^{-4}	60	1.8×10^{-2}	7×10^{-4}	180	0.13	5×10^{-4}	450	0.23	7×10^{-4}	240	0.17	0.54
Operate scrap recovery and waste treatment	4.5×10^{-4}	1020	0.46	8.5×10^{-4}	4080	3.5	6.5×10^{-4}	1090	0.71	8.5×10^{-4}	1185	1	5.7
Totals		4485	1.84		18,030	14.1		4680	2.62		6240	4.14	22.8

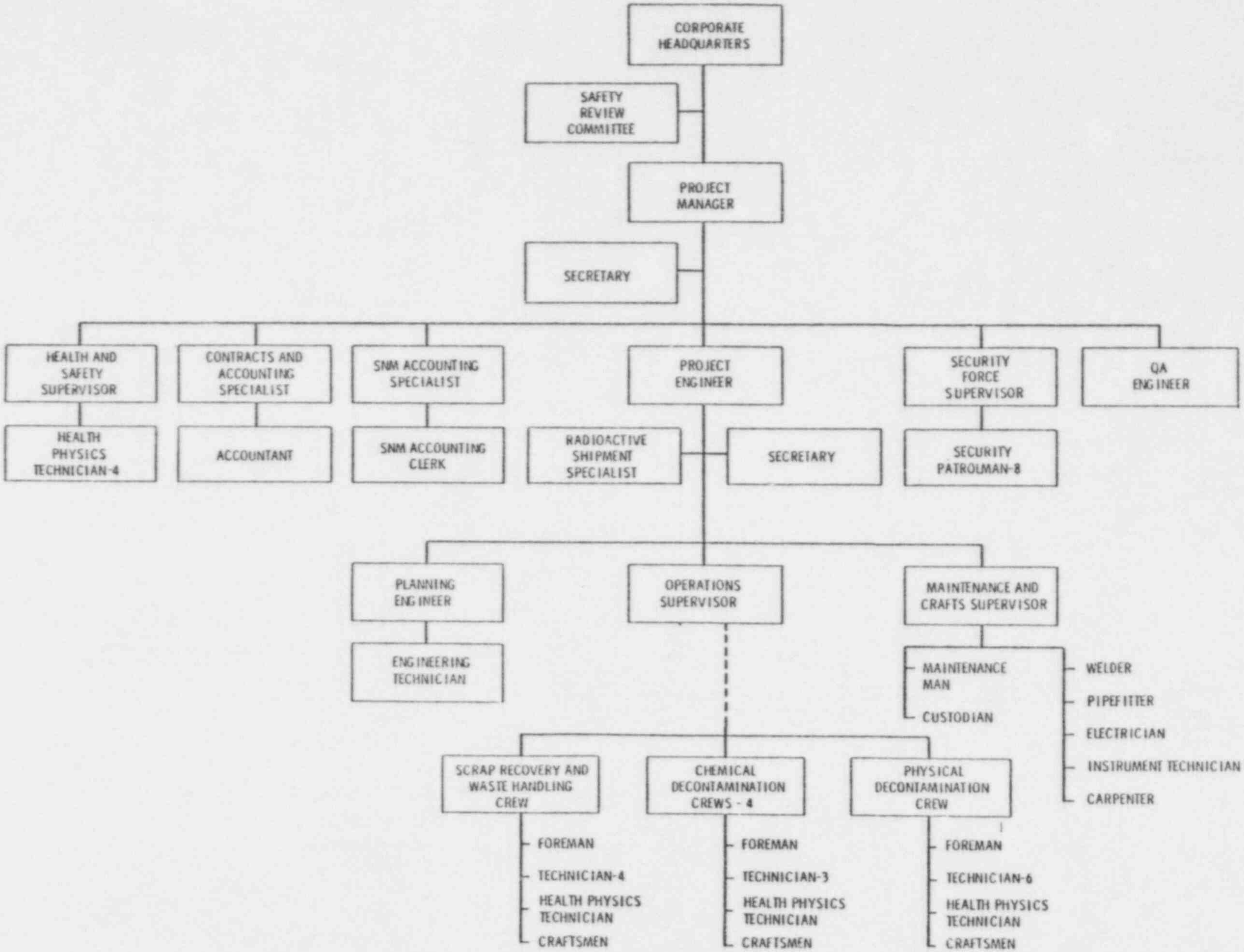


FIGURE D.2-2. Postulated Staff Organization for Accident Cleanup at the Reference MOX Plant

TABLE D.2-8. Estimated Staff Labor Requirements for Accident Cleanup at the Reference MOX Plant

Position	Staff Labor Requirements (man-years) for Cleanup Following the Reference Accident[a]
Project Manager	1.00
Project Engineer	1.00
Health and Safety Supervisor	1.00
Health Physics Technician	3.00
Security Force Supervisor	1.00
Security Patrolman	8.00
Contracts and Accounting Specialist	1.00
Accountant	0.50
SNM Accounting Specialist	1.00
Q. A. Engineer	1.00
Radioactive Shipment Specialist	1.00
Planning Engineer	1.00
Maintenance and Crafts Supervisor	1.00
Maintenance Man	1.00
Custodian	1.00
Craftsman	4.00
Operations Supervisor	1.00
Foreman	3.00
Technician	12.00
Secretary	2.00
Total Man-Years	45.5

(a) Cleanup staff labor requirements are adjusted to limit individual radiation doses to 5 rem/yr.

contractor personnel. Management and support staff man-years are directly related to the time required for accident cleanup. Cleanup staff man-years shown in the table are the requirements adjusted to comply with occupational

dose limitations. The staff labor man-years shown in Table D.2.8 are used in Appendix D.3 to compute labor costs for accident cleanup in the reference MOX plant.

D.3 DETAILS OF COSTS OF ACCIDENT CLEANUP AT A REFERENCE MIXED-OXIDE PLANT

Details of the costs of accident cleanup at the reference MOX plant are presented in this section. Costs are based on the technical requirements, manpower needs, and cleanup schedules presented in Section D.2 and are given in 1981 dollars.

Costs of activities related to refurbishment and restart of a MOX plant beyond the accident cleanup activities are not included in this study.

Unit cost information used as bases for these cost estimates is given in Appendix H.

D.3.1 Costs of Accident Cleanup

The estimated costs of accident cleanup at the reference MOX plant are presented in this section and summarized in Table D.3-1. Accident cleanup in the references MOX plant is estimated to require one year and to cost approximately \$4.6 million following the reference accident.

Labor costs and waste management costs are the major cost items for accident cleanup of the reference MOX plant. Staff labor costs account for about 60% of the total cost of accident cleanup.

Contractor costs for engineering support contribute an additional 3% to the total cost of accident cleanup. Waste management costs account for about 10% of cleanup costs.

D.3.2 Total Waste Management Costs

Details of total waste management cost calculations for radioactive wastes generated during accident cleanup are shown in Table D.3-2. These calculations are based on estimated waste quantities described in Section D.2 and on unit cost data for packaging, transportation, and waste disposal given in Appendix H. All radioactive wastes from these activities are assumed to be shipped to a federal repository for deep geologic disposal.

For a particular waste form, the total waste management cost is the sum of the total packaging cost plus the total transportation cost plus the burial cost.

TABLE D.3-1. Summary of Estimated Costs of Accident Cleanup at the Reference MOX Plant

Cost Category	Cost in Millions of 1981 Dollars[(a)]	Percent of Total
Manpower -		
Planning and Preparation	0.328	8.9
Accident Cleanup	1.916	51.7
Equipment and Supplies	0.526	14.2
Disposal of Radioactive Material	0.360	9.7
Miscellaneous Owner Expense	0.536	14.5
Specialty Contractors	0.037	1.0
Subtotal	3.703	100.0
25% Contingency	0.926	
Total Costs of Accident Cleanup	4.629	

(a) Number of figures shown is for computational accuracy and does not imply precision to the nearest thousand dollars.

Total packaging costs are the sum of disposable container costs and reusable overpack rental charges. In calculating the reusable overpack charge, a total time of 4 days is assumed for the 4800-km (3000-mi) round trip between the MOX plant and the federal repository. A second driver is assumed to be required for this trip.

The total transportation cost is the sum of the basic transportation cost plus the overweight charge plus the charge for a second driver. Overweight charges are based on charges for the state of Washington. In some instances, the quantity of waste per shipment is limited by weight restrictions (i.e., the 33.1 MT limit) rather than by volume limits.

D.4 DETAILS OF ACTIVITIES AND MANPOWER REQUIREMENTS FOR DECOMMISSIONING AT A REFERENCE MOX PLANT

This section provides the details of post-accident decommissioning activities at the reference MOX plant following completion of the accident cleanup

TABLE D.3-2. Details of Estimated Costs of Radioactive Waste Management from Accident Cleanup at the Reference MOX Plant[a]

Waste Category	Disposable Container Cost ($)	Reusable Overpack Rental Charge ($)	Total Packaging Cost ($)	Basic Transportation Cost ($)	Overweight Charge ($)	Charge for Second Driver ($)	Total Transportation Cost ($)	Burial Cost ($)	Total Waste Management Cost ($)
To Deep Geologic Disposal									
HEPA and Roughing Filters	18 800	5 400	24 200	19 800	2 900	3 100	25 800	102 000	152 000
Solidified Decontamination Liquids	1 400	7 500	8 900	27 300	10 400	4 200	41 900	29 100	79 900
Trash	4 400	4 300	8 700	15 800	3 600	2 400	21 800	97 400	127 900
Totals			41 800				89 500	228 500	359 800

(a) Number of significant figures shown is for computational accuracy only.

campaign. A comparison of normal and post-accident decommissioning requirements is provided in Section D.4.1. The details of the post-accident decommissioning of the reference MOX plant by the DECON alternative is given in Section D.4.2. The costs associated with these decommissioning activities are presented in Section D.5.

The post-accident decommissioning analyses in this study use the results of previous analyses of MOX plant decommissioning following normal plant shutdown, presented in References 6, with appropriate modifications as necessary to account for post-accident conditions.

A basic assumption of this analyses is that all radioactive waste materials resulting from accident cleanup and from decommissioning are shipped offsite for disposal at the time of decommissioning.

D.4.1 Comparison of Normal Versus Post-Accident Decommissioning

Under normal circumstances, decommissioning of a MOX plant follows the orderly shutdown of the facility at the end of its planned operating life. However, the situation at a facility that has experienced an accident is significantly different from normal, with moderate to severe contamination of the plant buildings, and possible physical damage to plant equipment and services. As a result, decommissioning following an accident may differ significantly from that following normal shutdown.

It is assumed in this study that the accident cleanup activities are completed prior to the start of the actual decommissioning effort. These cleanup activities are discussed in detail in Section D.2. The principal goals of accident cleanup are:

- to provide initial decontamination of certain plant systems and of selected building surfaces and equipment so as to reduce to ALARA levels the radiation doses to workers engaged in subsequent decommissioning activities

- to remove and process the accident liquids in the facility.

The tasks that must be performed to accomplish these goals are postulated to be independent of the alternative (DECON, SAFSTOR, or ENTOMB) chosen to complete the decommissioning, although the methods used to complete certain tasks may vary with the decommissioning alternative. The work required to complete each task will certainly be influenced by the severity of the accident.

In carrying out the accident cleanup activities, certain tasks that would be part of the decommissioning process following normal shutdown are completed, and significant portions of other such tasks are undertaken.

The requirements of carrying out the accident cleanup activities also result in certain new tasks that must be completed during the decommissioning process. In general, these new tasks are limited to the removal of new equipment installed to process accident water and the decommissioning of the temporary onsite waste storage structures specially constructed for the management of wastes resulting from accident cleanup activities.

A number of decommissioning tasks are independent of accident cleanup activities and, thus, are common to both post-accident and normal-shutdown decommissioning. However, the changes in the physical and radiological condition of the plant resulting from an accident lead to substantial qualitative changes in a number of these decommissioning tasks. Manpower requirements for carrying out specific tasks are related to a number of factors (e.g., the physical condition of the equipment and structures, local radiation dose rates, and the methods used to complete tasks) that may be affected by the accident and the subsequent cleanup program. Radiation doses to decommissioning workers are likely to be higher than those following normal shutdown because of the increased contamination of equipment, piping, and structural surfaces caused by the accident. The schedule and sequence of events for any particular decommissioning alternative may need to be revised to account for these changes and for the addition and deletion of specific tasks as a result of accident cleanup, as discussed previously. Furthermore, the requirements for special decommissioning tools and equipment may vary somewhat because of changes in specific tasks and because some of these tools and equipment items may be available for reuse as a result of the accident cleanup campaign that precedes the decommissioning. In summary, even tasks common to both post-accident and normal-shutdown decommissioning can be expected to differ significantly between the two situations.

Although the accident cleanup activities remove a large portion of the accident-generated contamination in the plant, accident severity will likely have some impact on the decommissioning tasks subsequent to cleanup. Radiation doses to decommissioning workers are likely to increase with accident severity because of the increased level and spread of radioactive damage to the plant resulting from the accident. In addition, physical damage to the plant from more severe accidents may compromise certain systems, structural features, and equipment items that are required to carry out the decommissioning tasks, thus necessitating repairs and/or substitutions and resulting in delays and additional expenses. In areas of extensive plant damage, different methods may be required to accomplish certain decommissioning tasks. It should be noted that the effects of accident severity on the level of effort required to complete the decommissioning activities are much less than the corresponding effects on the cleanup activities.

D.4.2 Details of Post-Accident DECON

In general, DECON is the decommissioning alternative used to remove from the facility, as soon as practicable following final shutdown, all materials with radioactive contamination above unrestricted release levels. For a plant that has experienced an accident, DECON begins following accident cleanup and is postulated to be completed within about 1.8 years. After DECON is completed and the radioactive materials are shipped from the site, the nuclear license can be terminated and the facility and the site can be released for unrestricted use.

Details of post-accident DECON at the reference MOX plant are discussed in this section, including schedules and manpower requirement and external occupational radiation doses. These details are based largely on the analysis of DECON at the reference plant following normal shutdown, presented in Appendix G and Chapter 9 of Reference 6, because, after cleanup is completed, many of the requirements for DECON are similar whether or not the plant has experienced an accident. Where the postulated accident results in significant changes in the DECON requirements, the differences in the requirements are identified and new information is developed to support the analysis. The analysis presented is based on the assumption that the plant has experienced the reference accident for MOX plants described in Chapter 6.

The facility description given in Appendix A provides the basic information that supports the development of the tasks, schedules, manpower loadings, and occupational radiation exposure estimates presented here. Additional details pertinent to specific DECON activities come from engineering drawings, manufacturers' data, and Reference 6.

The information in this section forms the basis for the estimated costs and safety impacts of post-accident DECON at the reference plant that are developed in Section D.5 and Appendix I, respectively, and for the comparison of post-accident and normal-shutdown DECON of the reference plant that is presented in Chapter 13 of Volume 1.

In choosing to decommission a MOX facility by DECON, the owner trades potential further use of the facility for the relatively rapid release of the site for unrestricted use.

D.4.3 DECON Activities

DECON of a reference MOX facility can be divided into three general areas of effort: planning and preparation, decontamination, and disassembly and transport.

It is estimated that approximately 1.8 years are required for DECON (not including seven weeks for building demolition and site restoration activities). The time and work estimates assume reasonable success, with a minimum of delays and/or major unanticipated problems.

Planning and Preparation Activities

Essential to the results of this study is the assumption that the facility owner/operator is also the prime contractor of the DECON. Otherwise, a more extensive training program would be necessary to acquaint workers with details of the facility. Approximately one year prior to start of DECON, work begins in the engineering and operations departments of the parent organization to perform the planning needed to convert an operating license to a possession-only license, to plan decommissioning operations, and to receive a decommissioning license. The proposed sequence and time schedule for the planning and preparation phase of decommissioning at the reference MOX facility is illustrated in Figure D.4-1.

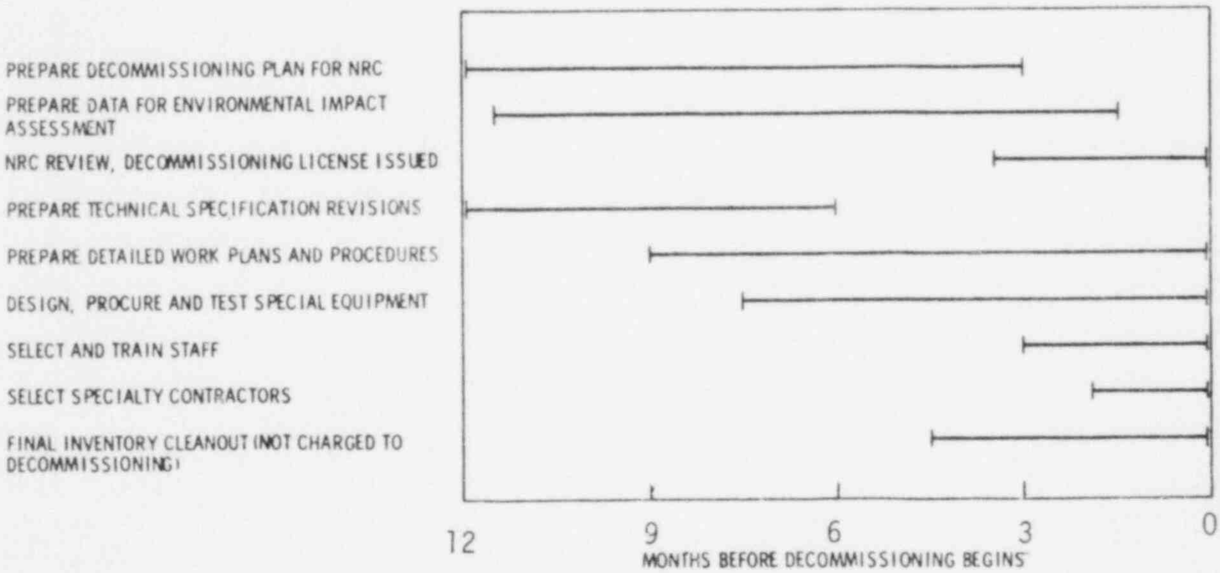


FIGURE D.4-1. Sequence and Schedule of the Planning and Preparation Phase of DECON at the Reference MOX Plant

An important part of the planning involves a review of all regulations and guides applicable to decommissioning. Included in the regulations are the requirements for preparation of changes in technical specifications, deleting those related to plant operation; preparation and submittal of a decommissioning plan for NRC review and approval; preparation of detailed plans and procedures for physical and chemical decontamination of intact systems; sectioning

and disposal of contaminated glove box equipment; and detailed sequences for equipment and systems removal. In addition, design, procurement and testing of special devices and equipment must be initiated during the year before start of DECON to assure that work can proceed without undue delay.

Creation of a decommissioning organization within the present organization is initiated during cleanup operations, with the structure and staffing requirements identified, and commitments obtained from key engineering and operating personnel to fill critical positions. Orientation and training of personnel identified as members of the decommissioning organization are carried on during the final six months of cleanup operations. Selection of the various specialty contractors required for the DECON effort is accomplished during the cleanup operations.

Also included in the planning and preparation effort are such things as the shipment of TRU-contaminated wastes to a federal repository, and the installation of compaction equipment in the facility. Another preparatory step is the installation of a set of open-top tanks in the former Fuel Fabrication Room to provide a final stage of electrochemical (electropolishing) contamination for piping, sectioned glove boxes, tank walls, tanks, valves, and similar metallic materials that have significant salvage value.

The final preparatory step is a comprehensive survey of radiation dose rates and contamination levels within the facility, taken after final inventory cleanout and plant shutdown. This survey provides the baseline data for decisions on chemical and physical decontamination. It also provides initial data on radiation dose rates and contamination levels likely to be encountered during the various DECON activities.

Decontamination

Decontamination can involve both chemical and physical attacks to remove radioactive materials. In this plan, major chemical decontamination is performed in all wet processing areas, and physical decontamination is the major technique used in all dry and many wet processing areas. The objectives of the decontamination effort are two-fold: first, to reduce the contamination levels throughout the facility in order to minimize potential worker and potential public exposure during the remaining decommissioning activities; and second, to attempt to clean contaminated material to levels that either permit salvage of valuable material or reduce the quantities of material that must be packaged and shipped to a deep geologic disposal site (i.e., to allow more waste materials to be sent to a less-expensive shallow-land burial ground).

For accounting purposes, physical and chemical decontamination generally follow existing plant procedures for plutonium cleanout. Selected plant

operating personnel are retained to assist in these decommissioning operations. Records of previous plant decontamination campaigns are reviewed to identify potential problem areas and to make maximum beneficial use of past plant experience.

Since this decontamination campaign takes place just prior to disassembly, damage to the wet processing systems and equipment from the decontamination solutions is of secondary concern. Chemical solutions are used that remove the surfaces of the stainless steel in the tanks and piping, resulting in decontamination factors (DF) of about two to three, a DF factor greater than can be achieved by noncorroding acid flushes.

For this study, nitric acid combined with hydrofluoric acid is selected to chemically decontaminate the wet processing areas. The use of this acid in chemical decontamination is discussed in Appendix C.

In the dry processing area, corrosive acids and chemicals are generally avoided to prevent damage to mild steel equipment, components, electrical connections, etc., that would later interfere with their disassembly.

Following decontamination, the systems are disassembled. Equipment such as glove-boxes that cannot be decontaminated internally to meet shallow-land burial requirements is cut up and decontaminated by electropolishing, prior to shipment to a shallow-land burial site. Ductwork, valves, piping, and glove box plate material are also decontaminated after disassembly in the electropolishing station. Electropolishing systems have proven to be capable of rapidly removing stubborn surface contamination to background levels.

Decontamination of the floors, walls, and other surfaces within the facility structures is accomplished using the standard techniques described in Appendix C. Removal of the surfaces of concrete walls and floors is a relatively time-consuming operation. Therefore, the surface removal method is assumed to remove most of the contaminated material in one operation, with repeated operations needed only in isolated instances.

The removal of the contaminated concrete is accomplished using mechanical techniques (e.g., jackhammers, rock splitters). The removed contaminated rubble is packaged as radioactive waste and shipped to a deep geologic disposal site.

Disassembly and Transport

Disassembly and disposal of contaminated and potentially contaminated equipment and materials are accomplished by the facility's decommissioning staff. The initial disassembly work begins in the Shipping and Final Inspection Rooms (Rooms 121 and 122), the Fuel Fabrication Room (Room 123), and the Storage Vault (Room 126). The Shipping and Inspection and Storage Vault rooms

are used to package and store contaminated wastes being shipped to shallow-land burial and deep geologic disposal sites, respectively. The electropolishing station is installed in the Fuel Fabrication Room to take advantage of the ventilation system and the overhead hoist. The disassembly work sequences are designed to ensure that essential services, such as plutonium scrap recovery lines, remain in service as long as needed. As a given section of the facility is disassembled, the extension of the essential services into those areas is removed.

For this study, all initially contaminated materials are assumed to remain contaminated to greater than unrestricted use levels, even after final decontamination by electropolishing, and are packaged for disposal as radioactive waste. All electropolished metals are disposed of in a shallow-land burial ground. Nonmetallic contaminated wastes are sent to deep geologic disposal.

Packaging of contaminated materials for disposal is accomplished in accordance with DOT regulations published in 49 CFR, Parts 173 through 178; NRC regulations published in 10 CFR, Part 71; and Regulatory Guide 7.1. Containers could be lined with shielding material if necessary to reduce surface dose rates to acceptable levels. It is assumed that none of the contaminated waste shipments from the MOX facility will require shielding.

Shipping of packaged contaminated materials from the facility to a waste disposal site (shallow-land or deep geologic disposal) is accomplished using trucking companies that specialize in transporting special materials.

Work Schedule Estimates

The proposed overall schedule and sequence of events for the DECON effort is presented in Figure 8.4-1 of Volume 1. Initial work begins during cleanup operation with: 1) preparation of a decommissioning plan for NRC approval, 2) preparation of the revisions to the facility technical specifications necessary to change from an operating license to a possession-only license, 3) preparation of the data needed to make an assessment of the environmental impact of the DECON work, 4) preparation of detailed work plans and procedures for accomplishing DECON, 5) design, procurement, and testing of all special equipment needed for DECON, and 6) selection and training of the personnel for the decommissioning staff.

Initial decommissioning efforts center around the physical and chemical decontamination of the contaminated areas within the facility. DECON begins with the Fuel Fabrication Room (Room 123), where all but the equipment needed to install and operate the electropolishing station is removed, and generally progresses from the dry processing zones into the wet processing areas.

Removal of the MOX building, backfilling, grading, plowing, and landscaping of the site completes DECON. As can be seen in Figure 8.4-1, about 1.8 years of effort is required after plant shutdown to complete the DECON effort.

DECON Staff Organization

The decommissioning work force organizational chart for DECON is shown in Figure 8.4-2 of Volume 1. The work force is described in two parts: 1) the decommissioning support staff that plans, supervises, and provides supporting activities for the decommissioning activities, and 2) the decommissioning workers who perform the actual decommissioning activities.

Actual decommissioning activities are carried out by decommissioning crews that consist of a foreman, two to six decommissioning technicians, and health physics technicians and craftsmen who are added to the crews as the work situation demands.

A key assumption in estimating the manpower and time for the basic events is that the decommissioning work force is composed primarily of former plant operating and maintenance personnel. The decommissioning workers are therefore familiar with plant facilities and equipment and experienced with radiation working procedures.

Detailed estimates of the decommissioning worker manpower required to perform DECON of the reference MOX plant are shown in Table D.4-1.

DECON Waste Management Requirements

Estimates are made of the quantities of radioactive wastes generated during DECON at the reference MOX plant and of packaging, transportation and disposal requirements, and costs for managing these wastes. Large quantities of radioactive wastes are generated during DECON at a MOX fuel fabrication plant. These wastes must be properly packaged and shipped to an authorized disposal site.

Radioactive wastes generated during DECON include:

- solidified liquids from chemical decontamination activities
- concrete rubble from the mechanical decontamination of contaminated floors and walls
- HEPA and roughing filters
- sections of ventilation ductwork

TABLE D.4-1. Estimated Decommissioning Worker Manpower Requirements for DECON at the Reference MOX Plant

Decommissioning Activity[b]	Estimated Man-Weeks[a] Foreman	Technician	Health Physicist	Craftsman	Total
Flush Solvent Extraction System	8	24	7.5	15.5	55.0
Flush Wet Process Equipment	20	60	18.5	39	137.5
Flush Waste Treatment	4	16	3.5	8	31.5
Set Up Electropolishing, Incineration, Packaging	3	12	1.5	12	28.5
Decontaminate Rooms 121, 123, and 126	2	12	1	2	16
Dismantle Rooms 121, 123, and 126	4	16	2	8	30
Decontaminate Room 155	1.5	9	1.5	1.5	13.5
Dismantle Room 155	1.5	6	1.5	3	12
Decontaminate Room 124	7	42	6.5	7	62.5
Dismantle Room 124	8	32	7.5	15.5	63
Decontaminate Room 805	5	30	4.5	10	49.5
Dismantle Room 805	25	100	23	98	246
Decontaminate Room 128	12	72	11	12	107
Dismantle Room 128	17	68	17	33	135
Decontaminate Room 127	7	42	6.5	7	62.5
Dismantle Room 127	14	56	14	27	111
Decontaminate Room 156	1	6	1	1	9
Dismantle Room 156	1	4	1	2	8
Decontaminate Rooms 130-133, 135-143	3	18	1.5	3	25.5
Dismantle Rooms 130-133, 135-143	7	,28	7	13.5	55.5
Decontaminate Room 116	0.5	3	0.5	0.5	4.5
Dismantle Room 116	1.5	6	1.5	3	12
Dismantle Cold Chemical Prep Room	2	8	--	--	30
Decontaminate Wall Storage Tanks	--	30	--	--	30
Dismantle Wall Storage Tanks	30	120	30	59	239
Decontaminate Room 801	5	30	4.5	5	44.5
Dismantle Room 801	10	40	10	19.5	79.5
Decontaminate Room 801	3	18	3	3	27
Dismantle Room 802	6	24	6	12	48
Decontaminate Room 129	1.5	9	1.5	1.5	13.5
Dismantle Rooms 129 and 134	4.5	18	4.5	9	36
Dismantle Electropolishing Station	2	8	2	8	20
Final Decontamination of Rooms 121, 123,126	2	12	2	--	16
Decontaminate and Dismantle Rooms 108-111	2	8	2	2	14
Dismantle Room 117	3	12	--	12	27
Decontaminate Room 201	3	12	3	3	21
Dismantle Rooms 201 and 202	7	28	7	13.5	55.5
Decontaminate Sewage Lagoon	9	36	9	--	54
Operate Electropolishing Station	128.5	514	132	252	1026.5
Operate Packaging and Shipping	140	280	145	137	702
Operate Scrap Recovery and Waste Treatment	38	152	34	74	298
Package and Ship Contaminated Rubble	1.5	9	3	--	13.5
Total Man-Weeks	551	2030	538	936	4055
Total Man-Years[c]	11.0	40.6	10.8	18.7	81.1

(a) Numbers shown are for computational accuracy, and do not imply accuracy to three to five significant figures.
(b) See Section A.2 for functions of the process rooms.
(c) A total of 50 weeks/year is assumed.

• combustible and noncombustible trash (protective clothing, contaminated tools, rags, paper, plastic, metal scrap, etc.)

• possibly, sludge from the sewage lagoons.

The bulk of the material that must be packaged for disposal will be contaminated with plutonium and uranium. The NRC has adopted a rule requiring that all wastes contaminated with more than 10 nanocuries of transuranic elements per gram of waste be classified as TRU wastes[7] and shipped to a federal repository. Non-TRU wastes are assumed to be disposed of at shallow-land burial sites.

In this study, it is assumed that most decommissioning wastes initially have levels of plutonium contamination that would require the wastes to be disposed of at a federal repository. Electropolishing is used in this study to reduce plutonium contamination levels on some of these wastes so that they can be disposed of by shallow-land burial. Details of assumed waste volumes for contaminated process equipment, tanks, and glove box sections postulated to require disposal at a federal repository or a shallow-land burial site are given in Reference 6. All of the contaminated ductwork and piping is electropolished. The level of plutonium contamination in the sludge from the sewage lagoons is assumed to be low enough to leave the sludge in place. Alternatively, if sludge removal is required, it is assumed to be disposed of by shallow-land burial. All other decommissioning wastes are postulated to require disposal at a federal repository.

Only solid wastes are assumed to be transported to a commercial burial ground or federal repository. Radioactive liquids generated during chemical decontamination activities are concentrated by evaporation and solidified by mixing with cement. The resultant solid is packaged in 208-ℓ (55-gal) steel drums and shipped to deep geologic disposal.

Non-TRU wastes from decommissioning operations are packaged for shipment in 208-ℓ (55-gal) steel drums or in plywood boxes. Package surface dose rates vary from a few micro-roentgen per hour to a few milli-roentgen per hour. Shipment is by truck in sole-use closed vans. The distance from the MOX plant to a shallow-land burial site is assumed to be 800 km (500 mi).

TRU-contaminated decommissioning wastes are packaged in DOT specification 7A steel boxes[8] or in DOT specification 17C 208-ℓ (55-gal) steel drums.[8] Drums and boxes are placed in a Super Tiger® overpack and shipped by truck to a federal repository. The Super Tiger® is described in Figure C.4-2. The distance from the MOX plant to the federal repository is assumed to be 2400 km (1500 mi).

All shipments of decommissioning wastes are made in compliance with federal, state, and local regulations as described in Reference 7.

Table D.4-2 gives estimated weights and volumes of decommissioning wastes from DECON at the reference MOX fuel fabrication plant, together with packaging, shipping, and disposal requirements for these wastes. It is assumed that the sludge from the sewage lagoon would not require removal. However, an estimate of packaging and shipping requirements for removal of contaminated sludge from the sewage lagoon is given separately, in the event that sludge removal is required.

D.5 DETAILS OF COSTS OF DECOMMISSIONING AT A REFERENCE MIXED-OXIDE PLANT

This section presents the estimated costs of decommissioning the reference MOX plant via the DECON decommissioning alternative following an accident and the subsequent accident cleanup campaign. The costs developed here are based on the detailed descriptions of the decommissioning activities and requirements presented previously in Section D.4 and on the cost estimating bases presented in Appendix H. Cost information, from Reference 6, for the decommissioning of the reference MOX plant following normal shutdown is also used where applicable. The decommissioning costs are all adjusted to 1981 dollars and are developed on a consistent basis with the costs of accident cleanup presented in Section D.3.

The costs of decontaminating and disposing of systems and facilities required for accident cleanup are included in the estimates presented in this section.

D.5.1 Cost Estimates for DECON

The estimated costs for DECON at the reference small MOX plant following the reference accident and the subsequent cleanup campaign are summarized in Table D.5-1. DECON is estimated to require about 1.8 years (plus one year for planning and preparation) at a cost of approximately $11.4 million.

Manpower costs include both support staff and decommissioning workers and represent about 58% of the total cost of DECON. In Table D.5-1, manpower costs are shown separately for the planning and preparation and the decommissioning phases of DECON. These costs include onsite labor for packaging radioactive waste materials for shipment. Labor costs related to radioactive waste transportation are included in waste management costs since transportation is performed by a specialty contractor.

TABLE D.4-2. Waste Disposal Requirements for DECON at the Reference MOX Plant[a]

Waste Category	Shipping Weight (kg)	Shipping Volume (m^3)	Container Type	Number of Containers	Containers per Shipment	Truck Shipments
Deep Geologic Disposal						
Glove Boxes and Hoods	45 000	40.6	1.2 x 1.2 x 1.8-m Steel Box	16	3	6
Tanks and Equipment	7 000	6.4	1.2 x 1.2 x 1.8-m Steel Box	3	3	1
HEPA and Roughing Filters	11 000	34.3	1.2 x 1.2 x 1.8-m Steel Box	14	3	5
Concrete Rubble	24 000	20.0	208-ℓ (55-gal) Steel Drum	100	42	3
Solidified Decontamination Liquids	46 000	14.4	208-ℓ (55-gal) Steel Drum	72	24[b]	3
Trash	38 900	48.6		243	42	6
Totals	172 000	164		33 boxes 415 drums		24
Disposal by Shallow-Land Burial						
Glove Boxes and Hoods	106 000	94.2	2.6-m^3 Plywood Box	36	6	6
Tanks and Equipment	114 000	101.8	2.6-m^3 Plywood Box	40	6	7
Piping, Valves and Ductwork	80 000	71.0	2.6-m^3 Plywood Box	28		5
Totals	300 000	267.0		104		18
Sludge from Sewage Lagoon[c]	3 500 000	2 930	2.6-m^3 Plywood Box	1 127	6	188

(a) Number of figures shown is for computational accuracy and does not imply accuracy to three or four significant figures.
(b) Number of containers per shipment is limited by weight rather than by volume.
(c) Listed for information purposes in the event that sludge removal is required. Not included in totals.

TABLE D.5-1. Summary of Estimated Cost of Post-Accident DECON at the Reference MOX Plant[(a)]

Cost Category	Cost in Millions of 1981 Dollars[(b)]	Percent of Total
Staff Labor		
Planning and Preparation	0.946	10.3
Decommissioning	5.269	57.5
Equipment and Supplies	1.217	13.3
Disposal of Radioactive Material	0.820	9.0
Miscellaneous Owner Expense	0.670	7.3
Specialty Contractors	0.238	2.6
Subtotal	9.160	100.0
Contingency (25%)	2.290	
Total Decommissioning Costs	11.450	

(a) Summary does not include the cost of packaging and disposal to shallow-land burial of the sludge from the sewage lagoons that would add an additional $0.75 million in waste disposal and contingency costs.
(b) Number of figures shown is for computational accuracy and does not imply precision to the nearest thousand dollars.

D.5.2 Costs of Staff Labor

Table D.5-2 shows staff labor cost estimates for the planning and preparation phase of DECON, and Table D.5-3 shows staff labor costs for the decommissioning phase. For planning and preparations, the labor cost is about $0.9 million. For decontamination and removal of contaminated materials, the labor cost is about $5.3 million. The total labor cost for DECON is therefore about $6.2 million without contingencies. Manpower costs shown in Table D.5-3 include labor costs for packaging radioactive waste materials for shipment. These costs do not include specialty labor costs.

D.5.3 Material and Equipment Costs for DECON

Estimates of material and equipment costs for DECON are shown in Table D.5-4. Costs of decontamination chemicals are calculated on the basis of quantities required for decontamination and unit costs given in Appendix H.1.

Cleaning supplies represent a major cost item and include assorted cleaning agents, rags, mops, brushes, plastic bags, plastic sheeting, etc. The cost

TABLE D.5-2. Summary of Manpower Costs for Planning and Preparation Phase of DECON at the Reference MOX Plant

Title or Function	Cost ($ Millions)[a,b]
Project Manager	0.103
Project Engineer	0.088
Health and Safety Supervisor	0.066
Contracts and Accounting Specialist	0.044
Accountant	0.033
Radioactive Shipment Specialist	0.044
Q. A. Engineer	0.053
Planning Engineer	0.061
Engineering Technician	0.112
Operations Supervisor	0.122
Foreman	0.136
Secretary	0.084
Total Cost	0.946

(a) Number of figures shown is for computational accuracy and does not imply precision to the nearest thousand dollars.
(b) Contingency of 25% is not included in these costs.

of protective clothing includes the cost of laundering the clothing by an outside contractor and is estimated to be about $1385 per week. The total cost of material and equipment for DECON at the reference MOX plant is estimated at about $1.2 million without contingency.

D.5.4 Waste Management Costs

The estimated costs of container, transportation, and disposal of the radioactive wastes from the reference MOX plant are summarized in Table D.5-5. Cost estimates are based on projected packaging and shipping requirements in Section D.4 and on waste management cost data in Appendix H.

TABLE D.5-3. Summary of Manpower Costs for DECON at the Reference MOX Plant

Title or Function	Cost ($ Millions)[a,b,c]
Project Manager	0.181
Project Engineer	0.153
Health and Safety Supervisor	0.115
Health Physics Technician	0.355
Security Force Supervisor	0.083
Security Patrolman	0.413
Contracts and Accounting Specialist	0.078
Accountant	0.029
SNM Accounting Specialist	0.094
SNM Accounting Clerk	0.029
Radioactive Shipment Specialist	0.079
Q. A. Engineer	0.106
Planning Engineer	0.106
Engineering Technician	0.064
Maintenance and Crafts Supervisor	0.197
Maintenance Man	0.126
Custodian	0.058
Craftsman	0.673
Operations Supervisor	0.212
Foreman	0.524
Technician	1.496
Secretary	0.098
Total Cost	5.269

(a) Number of figures shown is for computational accuracy and does not imply precision to the nearest thousand dollars.
(b) Information given is for support staff and decommissioning workers.
(c) Contingency of 25% is not included here.

TABLE D.5-4. Estimated Material and Equipment Costs for DECON at the Reference MOX Plant

Description	Quantity	Estimated Total Cost ($ thousands)[(a)]
Oxyacetylene Torch	2 ea	2.8
Portable Plasma Cutting Torch	4 ea	110.8
Arc Saw	1 ea	138.5
Guillotine Pipe Saw	2 ea	2.8
Tube Cutter	2 ea	0.8
Ratcheting Pipe Cutter	6 ea	0.4
Reciprocating Saw	4 ea	2.8
Nibbler	2 ea	2.8
High-Velocity Liquid Jet	1 ea	6.9
Low-Velocity Liquid Jet	2 ea	5.5
Hydraulic Concrete Surface Spalling Device	1 ea	6.9
Concrete Drill	2 ea	0.6
Electric/Pneumatic Hammer	2 ea	1.4
Portable Filtered Ventilation Enclosure	1 ea	2.1
Supplied Air bubble Suit	200 ea	13.8
Electropolishing System	1 ea	138.5
Portable Fume Exhaustor	1 ea	9.7
Waste Compactor	1 ea	16.6
HEPA Filter	50 ea	10.4
Roughing Filter	50 ea	3.5
Decontamination Chemicals		36.7
Cleaning supplies		346.0
Expendable Tools		138.5
Protective Clothing (including laundry)		113.6
Office Supplies		
Planning and Preparation		69.2
Decommissioning		34.6
Cement	10 m^3	0.9
Total		1217

(a) Contingency of 25% is not included here.

TABLE D.5-5. Estimated Costs for Packaging, Transportation, and Disposal of Radioactive Material from DECON at the Reference MOX Plant.

Waste Category	Costs in Thousands of 1981 Dollars[a]			
	Container	Transportation	Burial	Total[b]
Deep Geologic Disposal				
Glove Boxes and Hoods	28.8	33.4	121.0	183.2
Tanks and Equipment	5.3	5.5	27.7	33.5
HEPA and Roughing Filters	24.9	26.3	105.8	157.1
Concrete Rubble	6.1	17.6	61.1	84.8
Solidified Decontamination Liquids	5.3	18.6	44.0	67.9
Trash	13.4	33.4	148.5	195.3
Subtotals	83.8	134.8	503.2	721.6
Disposal by Shallow-Land Burial				
Glove Boxes and Hoods	6.48	7.95	12.2	26.6
Tanks and Equipment	7.20	9.28	13.55	30.1
Piping, Valves, and Ductwork	5.04	6.62	9.47	21.1
Subtotals	18.7	23.8	35.2	77.7
Totals w/o Sludge	102.5	158.6	538.3	799
Sludge from Sewage Lagoons[c]	202.9	249.3	381.4	834
Totals with Sludge	305.4	407.9	919.8	1633

(a) Number of figures shown is for computational accuracy and does not imply three- or four-place accuracy in waste management cost figures.
(b) Contingency of 25% is not included here.
(c) Listed for information purposes in the event that sludge removal is required.

The total waste management cost for DECON is estimated to be about \$0.8 million without contingency. If packaging and disposal of the sludge in the sewage lagoon is required, it would add about \$0.6 million (without contingency) to this cost.

Waste management costs for wastes shipped to deep geologic disposal are significantly higher than they are for wastes sent to shallow-land burial. For example, the total cost of the container, transportation, and disposal of a

2.6-m^3 plywood container of contaminated glove box sections sent to shallow-land burial is estimated to be about $734. The total cost of the container, transportation, and disposal of a 2.6-m^3 steel container of contaminated glove box sections sent to deep geologic disposal is estimated to be about $11,500. Most of this cost differential is due to the greater disposal cost assumed for deep geologic disposal ($3900/$m^3$) compared to the disposal cost assumed for shallow-land burial ($130/$m^3$).

D.5.5 Miscellaneous Owner Expenses

Estimated miscellaneous owner expenses for DECON are shown in Table D.5-6.

TABLE D.5-6. Estimated Miscellaneous Owner Expenses for DECON at the Reference MOX Plant

Cost Category	Cost in Thousands of 1981 Dollars[a,b]
Utilities	138.5
Taxes	24.9
License Fee	300.0
Insurance	207.8
Total	670.3

(a) Number of figures shown is for computational accuracy and does not imply precision to the nearest thousand dollars.
(b) Contingency of 25% is not included here.

Utilities' costs and property tax charges are based on actual experience at the reference plant. Utilities' costs are based on an average charge of about $2000 per month, and property taxes are based on a charge of approximately $16,600 for calendar year 1981.

The operating license fee for a MOX plant is currently set by the NRC at $300,000 per year.[9] The amount of this fee that would have to be paid during the decommissioning period has not been determined. For estimating decommissioning costs, it is assumed that the full fee would be paid during the first year, while the scrap recovery and waste treatment facilities of the plant are being used to recover plutonium from decommissioning wastes. Thereafter, the

fee for a possession-only license ($830 per year),[9] or a modified operating license is assumed to be applicable.

The cost of nuclear liability insurance for a facility being decommissioned has also not been determined. An allowance of $200,000 is included for the annual insurance premium for nuclear liability and conventional insurance.

D.5.6 Specialty Contractor Costs

Specialized services are required to accomplish the DECON of the reference small MOX plant. These services are assumed to be supplied by the specialty contractors listed below. Costs shown do not include the 25% contingency used when adding the total decommissioning costs in this study.

Electropolishing

An electropolishing unit is installed in Room 123 to decontaminate piping, ductwork, tank sections, and glove box sections to levels that allow disposal by shallow-land burial. Electropolishing of some larger tanks is carried out in place. It is assumed that a consultant is hired for a period of three months to assist in setting up the electropolishing unit, train the crew, and supervise the initial operation of the system. Total cost of the consultant is estimated to be $22,000 based on a fee of $350 per day.

Removal of Wall Tanks

A crane is used to lift the vault storage tanks and the large liquid waste tanks in Room B02 through openings in the roof of the building. Estimated costs of the crane and of operating personnel are presented below. Labor costs are taken from Reference 10 and have been increased by 30% to allow for inflation to 1981 dollars. Work is assumed to be performed on a two-shift per day basis, the same as for other decommissioning activities.

Crane Rental -	$4850/wk x 16 wk =	$78 000
Foreman (2) -	$1250/wk x 16 wk =	39 900
Equipment Operator (2) -	$1050/wk x 16 wk =	33 000
Laborer (4) -	$760/wk x 16 wk =	48 800
	Total	$200 000

Decommissioning of Sanitary Lagoon

The Sanitary Lagoon is decommissioned by allowing the water in the ponds to evaporate, after which the polyvinyl chloride liner is punctured to provide a path for water to pass through the liner. The ponds are backfilled with soil

to a total thickness of about 0.6 m (2 ft) above grade level, and the soil cap is compacted and mounded. Grass is planted to reduce erosion and control water runoff.

Estimated costs of decommissioning the sanitary lagoon are presented in Table D.5-7. Labor costs are taken from Reference 10 and have been increased by 30% to allow for inflation to 1981 dollars.

TABLE D.5-7. Subcontractor Costs to Decommission the Sanitary Lagoon at the Reference MOX Plant

Activity	Basis	Cost ($)[a]
Backfilling	\$7400 m^3 at \$0.70/m^3	5 100
Grader	\$700/wk for one week	700
Dump Truck	\$700/wk for one week	700
Loader	\$1400/wk for one week	1 400
Foreman	\$1200/wk for one week	1 200
Equipment Operator	Two men at \$1000/wk for one week	2 000
Laborer	Two men at \$750/wk for one week	1 500
Grade, Seed, Fertilize	3700 m^2 at \$1.10/m^2	4 100
Total		16 700

(a) Contingency of 25% is not included here.

REFERENCES

1. Final Programmatic Environmental Impact Statement Related to Decontamination and Disposal of Radioactive Wastes Resulting from March 28, 1979, Accident - Three Mile Island Nuclear Station, Unit 2, NUREG-0683, U.S. Nuclear Regulatory Commission, Washington, D.C., March 1981.

2. Final Environmental Assessment for Decontamination of the Three Mile Island Unit 2 Reactor Building Atmosphere, NUREG-0662, U.S. Nuclear Regulatory Commission, Washington, D.C., May 1980.

3. Environmental Assessment - Use of Epicor II at Three Mile Island, Unit 2, NUREG-0591, U.S. Nuclear Regulatory Commission, Washington, D.C. October 1979.

4. Safety Evaluation Report Related to the Operation of the Submerged Demineralizer System at Three Mile Island Nuclear Station, Unit 2, NUREG-0796, U.S. Nuclear Regulatory Commission, Washington, D.C., June 1981.

5. U.S. Code of Federal Regulations, Title 10, Part 20.101, "Radiation Dose Standards for Individuals in Restricted Areas," (10 CFR 20.101), U.S. Government Printing Office, Washington, D.C., 1980.

6. C. E. Jenkins, E. S. Murphy, and K. J. Schneider, Technology, Safety and Costs of Decommissioning a Reference Small Mixed Oxide Fuel Fabrication Plant. NUREG/CR-0129, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, February 1979.

7. Proposed Rulemaking on Transuranic Waste Disposal. Published in Federal Register, Volume 39, No. 32922, September 12, 1974.

8. D. A. Edling and J. F. Griffin, Certification of ERDA Contractors Packaging with Respect to Compliance with DOT Specification 7A Performance Requirements, MLM 2228, Monsanto Research Corporation, Mound Laboratory, Miamisburg, Ohio, June 1975.

9. Title 10, U.S. Code of Federal Regulations. Part 170.21, Revised January 1977.

10. R. S. Godfrey, ed., Building Construction Cost Data 1975, R. S. Means Co., Duxbury, Massachusetts, 1975.

APPENDIX E

DETAILS OF U-FAB PLANT CLEANUP AND DECOMMISSIONING

APPENDIX E

DETAILS OF URANIUM FUEL FABRICATION PLANT CLEANUP AND DECOMMISSIONING

To supplement the discussion in Chapter 9 of Volume 1, this appendix provides details of the technical requirements and manpower needs for accident cleanup at the reference uranium fuel fabrication (U-Fab) plant. A discussion of the rationale for accident cleanup is also provided. The accident postulated in this report results in the severe contamination of the U-Fab plant.

The first activities following stabilization of an accident consist of an accident cleanup campaign with the following goals:

1. to reduce the initial high levels of radioactive contamination present on building surfaces and equipment, thereby reducing the radiation dose received by workers engaged in cleanup and decommissioning operations

2. to collect, package for disposal, and dispose of the readily dispersible radioactivity present in the plant.

To achieve these goals, the cleanup campaign is postulated to include the following tasks:

- processing of contaminated liquids generated by the accident (and by decontamination operations) to remove and immobilize radioactive contaminants

- initial decontamination of building and decontamination or disposal of some equipment

- solidification and packaging of wastes from accident cleanup operations.

The rationale for accident cleanup is discussed in Section E.1. Even if a decision is made to refurbish rather than to decommission an accident-damaged plant, the same accident cleanup tasks would be required whether the plant was refurbished for restart or decommissioned. A decision point relating to restarting the plant or completing the decommissioning must be made following the completion of accident cleanup. This decision point could be earlier, but an early decision to restart would probably have minimal impact on the requirements for accident cleanup.

Because accident cleanup activities would be similar whether the plant is restarted or decommissioned, the requirements, costs, and safety analysis given in this report are considered to be representative. This study does not include consideration of activities related to restart of a U-Fab plant following the accident cleanup period. Accident cleanup activities are independent of the alternative (DECON or SAFSTOR) chosen to decommission the facility, although the methods used to complete certain tasks may vary with the decommissioning alternative.[a]

Details of accident cleanup are discussed in Section E.2, including cleanup methods and procedures, schedules and manpower requirements, and occupational radiation doses. The costs of accident cleanup are discussed in Section E.3. Decommissioning activities that follow accident cleanup are discussed in Section E.4. The costs of decommissioning are discussed in Section E.5.

E.1 RATIONALE FOR ACCIDENT CLEANUP AT A REFERENCE URANIUM FUEL FABRICATION PLANT

Cleanup tasks are assumed to be performed prior to other operations of whichever alternative is chosen to decommission the facility. The rationale for their early completion is given in the following paragraphs.

In keeping with ALARA principles, decontamination efforts during accident cleanup are restricted to those operations that result in the greatest reduction in residual radioactive contamination with the least radiation dose to decontamination workers. These operations include washdown of building surfaces using water jet equipment, and installation of temporary shielding around localized hot spots. Hands-on decontamination work using mops and wipes with assorted cleaners is performed in those instances where significant reductions in local area radiation dose rates can be readily achieved.

A decision to decommission or to refurbish a facility does not affect the goals of accident cleanup or the tasks that must be accomplished during cleanup. A decision about future use of the plant might, however, affect the choice of procedures used to accomplish certain cleanup tasks. For example, a decision about whether some equipment was to be disposed of or reused could affect the choice of chemicals used to decontaminate the equipment.

As defined in this study, accident cleanup does not include the extensive hands-on decontamination operations required to reduce surface contamination

---

(a) In this study, cleanup methods are assumed not to vary substantially with decommissioning alternative.

inside the plant to levels suitable for release of the facility for unrestricted use. That additional decontamination would take place during decommissioning activities. In addition, as defined in this study, accident cleanup does not include the additional hands-on decontamination to reduce radiation levels to low enough values to permit the extensive work necessary during refurbishment of the facility.

E.2 DETAILS OF ACCIDENT CLEANUP AT A REFERENCE URANIUM FUEL FABRICATION PLANT

Details for accident cleanup at the reference U-Fab plant, including details of the preparation for accident cleanup, are presented in this section.

E.2.1 Details of Preparations for Accident Cleanup

A period of planning and preparation precedes the actual performance of cleanup operations within a U-Fab facility that has been involved in an accident. Planning and preparation activities and the manpower requirements for their performance are described in this section.

In the studies of decommissioning following normal shutdown, planning and preparation activities for decommissioning were assumed to take place during the final seven months of plant operation. Following an accident, several planning and preparation tasks must be completed before accident cleanup operations can begin, thereby delaying the start of these operations. Other planning and preparation tasks cannot be completed during the initial preparations phase and must be deferred until some cleanup renders the accident-damaged facility more accessible for detailed examination.

Planning and Preparation Activities

Several planning and preparation activities must be performed prior to the operational phase of cleanup. These activities include:

- contaminated area entry and data acquisition
- prepare documentation for regulatory agencies
- design, fabricate, and install special equipment
- develop detailed work plans and procedures
- select and train accident cleanup staff.

Contaminated Area Entry and Data Acquisition. Data on the post-accident radiological and physical condition of the plant are obtained and analyzed during planning and preparation activities. These data provide a basis for planning accident cleanup operations and for selecting appropriate methods and equipment to perform the cleanup. The data also provide information needed to prepare documentation for regulatory agencies.

Radiation surveys are performed to measure contamination levels and radiation exposure rates inside the damaged area. These surveys provide information on which to base decisions about decontamination requirements and work procedures as well as baseline data for later use in judging the effectiveness of cleanup operations. Initial radiation surveys are made as detailed as possible without excessive exposure to personnel performing the surveys.

Additional data needed for planning cleanup and decommissioning operations include information about the operational status of plant systems and services (such as radiation detectors, ventilation equipment, electrical services, cranes, radwaste equipment, etc.).

Initial entries into the U-Fab plant may provide only limited information or information of a general nature, especially following a severe accident where radiation levels are high and time of access is limited. More detailed information about the condition of the facility can be obtained after initial decontamination of building surfaces to reduce exposure rates is completed.

Radiation surveys continue during cleanup operations to evaluate the effectiveness of these operations. A comprehensive radiation survey, taken after accident decontamination is completed, provides the basis for planning final decommissioning operations.

Prepare Documentation for Regulatory Agencies. At the start of planning and preparation activities, the current status of all existing regulations, guides, and standards that apply to a U-Fab plant that has been involved in an accident must be reviewed by the licensee who must accomplish the cleanup and decommissioning in compliance with their provisions. The cleanup and decommissioning of an accident-damaged plant by the licensee is also subject to statements, orders, and amendments to the facility license issued by the NRC pursuant to its statutory authority for regulating nuclear fuel cycle activities.

A major planning task is the preparation by the licensee of the necessary documentation to amend the facility operating license to maintain the plant in a safe shutdown condition and to obtain regulatory approvals to proceed with cleanup operations. Regulations pertaining to termination of the operating license are set forth in Section 50.82 of Part 50 of Title 10 of the Code of Federal Regulations. Regulatory Guide 1.86 describes methods acceptable to the NRC for satisfying the requirements of Section 50.82. Documentation that must be provided by the licensee includes:

- a description of the current facility status
- a description of the ultimate facility status

- proposed changes to the technical specifications
- descriptions of proposed cleanup and decommissioning operations and associated environmental and safety precautions
- safety and environmental analyses of cleanup and decommissioning operations and of any resultant releases of radioactivity
- safety and environmental analyses of the plant in its ultimate status.

Consistent with the intent of 10 CFR 51, Licensing and Regulatory Policy and Procedures for Environmental Protection, and in keeping with the purposes of the National Environmental Policy Act (NEPA), before decommissioning begins, an environmental impact statement or environmental assessment may be needed describing the probable effects of the proposed cleanup and decommissioning actions. The licensee is required to provide supporting information to assist the NRC in the preparation of these documents. As an illustration of the type of documentation required, the requirements for the damaged reactor plant TMI-2 are outlined in Section D.2 of Appendix D. The requirements for a reactor would probably be more stringent than for a fuel cycle facility.

The cleanup and decommissioning of an accident-damaged plant is also subject to constraints imposed by statements, orders, and amendments to the facility license issued by the NRC subsequent to the accident. The time requirement for furnishing information to regulatory agencies, issuing environmental statements and assessments, and securing regulatory approvals to go ahead with specific cleanup tasks is a critical factor in determining when actual cleanup operations can begin.

Design, Fabricate, and Install Special Equipment. Planning and preparation includes the identification and procurement of special tools and equipment required for accident cleanup and decommissioning. A list of special tools and equipment is given in Table 9.3-3 in Chapter 9. Some items, such as cutting tools or decontamination equipment, can be identified early in the planning stage before actual cleanup begins. Other items may not be identified until the initial building decontamination is completed.

Major facilities and equipment items required for cleanup of an accident-damaged U-Fab plant include an evaporator/solidification facility to process the decontamination solutions generated, and a laundry facility.

Many of these facilities and equipment items require design and development work as well as actual fabrication and testing. Evaporator/solidification facilities, and laundry facilities are commercially available and can be purchased or rented.

Designs and specifications are prepared for each special equipment item required. When the item is procured, it is inspected to verify that it meets specifications and complies with applicable quality assurance and safety requirements. It is then tested to ensure that it performs as required. The testing also serves to train personnel in the use of the equipment and to provide pertinent data on its operation.

Develop Work Plans and Procedures. Detailed work plans and procedures are developed based on an evaluation of the condition of the plant following an accident and on the requirements for accident cleanup. Work plans are included in documentation provided to the NRC with the request for license amendment. The detailed plans and procedures contain all the information required to actually carry out the accident cleanup tasks. They address the following items:

- regulatory requirements and constraints
- decontamination methods and procedures
- schedules and sequences of events
- manpower requirements
- equipment requirements
- contamination control
- radiological and industrial safety
- packaging and disposal of radioactive wastes
- quality assurance.

Physical security and environmental constraints are also considered. Plans are updated as the accident cleanup work proceeds and additional data on the physical and radiological status of the facility becomes available.

Select and Train Accident Cleanup Staff. The selection and training of operations staff for accident cleanup is an important part of planning and preparation. Staffing requirements are identified during this period, and key positions are filled with qualified engineering and operating personnel.

Detailed knowledge of and familiarity with the facility being decontaminated increases the effectiveness of the cleanup staff. Consequently, positions are assumed to be filled, whenever possible, with personnel familiar with the construction and operation of the plant, to capitalize on experience and minimize training requirements. Additional training required to perform specific cleanup tasks is provided, with special emphasis given to the use of new

and unique equipment and procedures. This results in improvements in efficiency and reduces occupational exposures when actual cleanup operations are performed inside the plant.

Because of the relatively high exposure rates encountered and the need to limit individual radiation doses, large numbers of persons are involved in accident cleanup operations. Many of these individuals are unfamiliar with the plant, and some are unfamiliar with the basic principles of radiation protection. These persons require an orientation in the layout of the plant and in basic radiation protection procedures as well as specific instruction in the tasks to be performed.

Time Requirements for Preparations for Accident Cleanup

Time requirements for planning and preparation depend on several factors including the severity of the accident, the time needed to design, fabricate, install, and test special facilities and equipment, and the time required to secure regulatory approvals for specific cleanup tasks.

The time required to secure regulatory approvals for specific cleanup operations is a critical factor in determining when these operations can begin. Delays by the licensee in responding to requests for information and/or delays in the review process that precedes the issuing of regulatory approvals could significantly delay the start of accident cleanup operations. In this study, planning and preparation activities that precede accident cleanup at the U-Fab plant are estimated to require approximately 0.5 years.

Occupational Doses for Preparations for Accident Cleanup

The major source of occupational radiation dose during preparations for accident cleanup is the dose received by workers who enter the contaminated building area to measure contamination levels and radiation exposure rates, assess the damage to the building and equipment, install monitoring systems, and make minor repairs to essential systems and equipment. The assumed average external whole-body doses received by these workers are summarized in Table E.2-1. Average dose rates are based on accident scenario information presented in Chapter 6 in Volume 1.

Workers are assumed to spend an average of one hour in the contaminated area during each entry. All personnel entering the contaminated areas wear protective clothing and full-face respirators. For entries following the reference accident, the average individual worker dose per entry is 0.02 rem.

Staff Requirements for Preparations for Accident Cleanup

The staff organization for preparations for accident cleanup includes a cleanup planning branch, a plant operations branch, and several site support branches.

TABLE E.2-1. Estimated Occupational Doses to Workers Entering Contaminated Areas During Preparations for Accident Cleanup at the Reference U-Fab Plant[a]

Number of Entries into Contaminated Area	4
Average Time per Entry (hours)	1
Average Dose Rate (rem/hr)	0.02
Number of Workers per Entry	4
Total Accumulated Occupational Dose (man-rem)	0.32

(a) Preparations for accident cleanup are assumed to require 0.5 years following the accident.

Major activities of the cleanup planning branch include:

- preparation of documentation for regulatory agencies
- preparation of design specifications for special facilities and equipment
- preparation of detailed work plans and work schedules.
- acquisition of data on the radiological and physical condition of the plant
- testing of equipment and procedures to be used in cleanup operations
- installation or repair of systems required for accident cleanup (e.g., reroute piping connections, install systems for remote monitoring, etc.).

The plant operations branch has the responsibility to maintain the plant in a safe shutdown condition. In addition to operations in the control room, this responsibility entails the following activities:

- maintain and repair systems required to keep the plant in a safe shutdown condition
- monitor and maintain auxiliary systems such as plant communications, heating, ventilation and air conditioning, etc.

They assist the cleanup planning staff in the acquisition of data on the radiological and physical condition of the building and in the installation and testing of systems required for accident cleanup.

Site support includes radiological health, industrial safety, plant security, procurement and accounting, and quality assurance services.

Estimated staff labor requirements for staff involved in preparations for accident cleanup are shown in Table 9.2-1 of Chapter 9 in Volume 1.

In addition to the staff involved in preparations for accident cleanup, shown in Table 9.2-1, contractors are hired to provide specific services that include the following:

- engineering assistance in preparing documentation for regulatory agencies, designing special tools and equipment, and preparing work plans and work schedules
- specialized waste processing services such as evaporation of contaminated solutions and incineration of combustible wastes
- transportation of radioactive wastes to offsite storage or disposal facilities
- laundry services.

E.2.2 Details of Accident Cleanup

Procedures for accident cleanup in the U-Fab plant following a serious accident are described in this section. Work schedules, estimated occupational doses, and estimated staff labor requirements based on these procedures are also presented.

Procedures for Accident Cleanup

Accident cleanup in the U-Fab plant is postulated to include the following tasks:

- process decontamination solutions
- initial decontamination
- remove nonessential items
- semiremote decontamination
- refurbish or replace essential support systems
- hands-on decontamination
- shielding of hot spots.

Accident cleanup operations are assumed to reduce general area radiation exposure rates in the U-Fab plant to the values shown in Table E.2-2. For the reference accident, cleanup operations are assumed to reduce the radiation exposure rate to approximately the value that existed during plant operations prior to the accident.

TABLE E.2-2. Average General Area Exposure Rates at the Completion of Accident Cleanup Operations at the Reference U-Fab Plant

Location	Average Exposure Rate (mR/hr) Cleanup Following Reference Accident
Operating Floor Level	2
Basement Floor Level	4

As discussed in Section E.1, decontamination activities during accident cleanup are not designed to reduce exposure rates to levels permitting unrestricted use of the facility, but only to limit the doses to workers engaged in accident cleanup. An additional decontamination would be required during decommissioning (or refurbishment) to limit the doses to workers engaged in these activities.

Following are descriptions of the tasks to complete accident cleanup.

Process Decontamination Solutions. Chemical decontamination solutions from initial cleanup operations have radionuclide concentrations in the range of 1 Ci/m^3. Evaporation is a suitable alternative for treatment of these wastes. An evaporator/solidification facility is rented from a commercial supplier and installed in the U-Fab plant during preparations for cleanup. The evaporator bottom liquids are postulated to be solidified with vinyl ester styrene and packaged in stainless steel liners for interim onsite storage in the shielded storage facility that is constructed during preparations for accident cleanup.

Initial Decontamination. The objective of initial decontamination of the U-Fab plant is to reduce surface contamination levels and resultant radiation exposure levels to permit reasonable occupancy times for workers engaged in system cleanup operations. In addition to surface decontamination procedures, reduction of general area radiation exposure rates requires the removal of contaminated sludge deposits that remain on the walls and floors after any liquids are removed. The reduction of general area radiation exposure rates may require that "hot spots" be shielded by using lead sheet or lead bricks, high-density concrete blocks, or containers filled with water.

A general discussion of procedures for the physical cleaning of surfaces and equipment is given in Appendix C. For initial decontamination, the following sequence of operations is postulated:

1. Remove and package debris and small items of contaminated equipment that are easily disposed of.

2. Employ high-pressure hose wash techniques for semiremote decontamination of building surfaces and equipment.

3. Decontaminate and refurbish or replace essential support systems.

4. Perform hands-on decontamination of selected areas where significant reductions in radiation exposure can be achieved with modest effort. Decontaminate floors by scrubbing.

5. Provide local shielding of "hot spots."

Remove Nonessential Items. The removal from the building of small, nonessential items and debris serves to reduce the general background radiation level and also clears away materials that can impede the progress of the accident cleanup effort. Nonessential items include contaminated tools, loose equipment, barrels, boxes, staging, cables, hoses, wood pallets, etc. Damaged pipes, cable conduits, and other damaged equipment and fixtures that interfere with decontamination operations are cut into sections and removed. Items that are removed from the building are wrapped in plastic and packaged as low-specific-activity waste for disposal at a shallow-land burial ground.

Semiremote Decontamination. Semiremote decontamination involves the use of equipment that permits the worker to stay some distance from the radiation source. High-pressure hose wash is postulated as the method for semiremote decontamination of the U-Fab plant.

As a decontamination method, hose wash offers several advantages in terms of flow rate control, flow pattern, and directional properties. These factors are especially advantageous for the decontamination of hard-to-reach areas. However, because of low impact forces, if the surface being cleaned is covered with oil or grease, ordinary hose wash is ineffective. High-pressure water hoses are effective in removing oil and grease deposits. Depending on conditions and equipment, hose-wash decontamination factors range from 2 to 100.

After completion of the high-pressure hose washdown of building surfaces and equipment, a radiation survey is performed to assess the effectiveness of this decontamination procedure. The survey includes sample removals for laboratory analysis as well as air, water, and area radiation surveys.

Refurbish or Replace Essential Support Systems. Severe contamination of building surfaces and equipment, including the ventilation system, is postulated for the reference accident. To provide adequate ventilation for cleanup workers, contaminated and damaged ventilations system components must be replaced or decontaminated and repaired. Contaminated filters are replaced. Because of the difficulty of cleaning contaminated ductwork, it is assumed that

ventilation ductwork is replaced with new ductwork as required to maintain adequate ventilation inside the building. Building fans and cooling units may be decontaminated or replaced.

Hands-On Decontamination. Hands-on decontamination is minimized by first using remote and semiremote decontamination techniques. During accident cleanup, hands-on efforts are limited to wiping and scouring that must be performed to reduce radiation exposure to workers.

Decontamination of floors is accomplished by scrubbing with brushes or industrial floor scrubbers and a commercial decontamination agent, and then wet vacuuming or mopping to remove the resulting solution. The wash solution is stored in 0.21-m^3 drums until it is solidified for disposal. A final reagent/-rinse mopping completes the effort.

Shielding of "Hot Spots." Shielding may be required to protect workers during accident cleanup operations, or it may be required to reduce radiation exposure from "hot spots" when initial decontamination of an area is completed. A low-density shielding material, such as wood or plastic, can be used as a shield for low-energy beta radiation. A thin layer of aluminum or steel can be used as a shield for high-energy beta radiation. To achieve a reduction in gamma radiation, lead blankets, lead sheet, lead brick, or high-density concrete blocks may be interposed between the gamma source and the work area. Containers filled with water may also serve as temporary shielding materials. Shielding materials are packaged or covered with plastic or a strippable coating to prevent their contamination.

Waste Management Details for Accident Cleanup

Detailed estimates of volume and weights of contaminated HEPA and roughing filters, solidified decontamination liquids, and trash from accident cleanup are presented in this section. These estimates form the bases for the packaging and shipping requirements.

HEPA and Roughing Filters. The number and volume of HEPA and roughing filters disposed of during accident cleanup activities and the method of their disposal are shown in Table E.2-3.

HEPA and roughing filters attached to hoods are 0.2 x 0.2 x 0.1 m thick. All of these filters are assumed to be incinerated, and the residue is processed to recover the uranium.

Ventilation HEPA filters are 0.6 x 0.6 x 0.3 m thick. Ventilation roughing filters are 0.6 x 0.6 x 0.15 m thick. Ventilation HEPA and roughing filters that are not incinerated are assumed to be packaged in plywood boxes and shipped to a low-level waste burial site for disposal.

TABLE E.2-3. Estimated Sources of HEPA and Roughing Filters for Disposal During Accident Cleanup at the Reference U-Fab Plant[(a)]

Filter Location	Number of Filters		Number[(b)]	Number Shipped		Volume Shipped
	HEPA	Roughing	Incinerated	HEPA	Roughing	(m^3)
Intermediate-Stage Filters for Hoods	120	200	300	6	6	1
Room Ventilation Filters	355	355	614	48	48	8
Exhaust Air Filters	250	250	--[(c)]	250	250	41
Filter Changes	10	100	110	--	--	--
Total						50

(a) Number of significant figures shown is for computational completeness and does not imply accuracy to the number of figures shown.

(b) Incinerated filters are processed to recover the uranium.

(c) A dash indicates that this information is not applicable.

The average bulk density of the filters is assumed to be 320 kg/m^3.

Solidified Decontamination Liquids. The volume of solidified decontamination liquids shipped from the reference plant to low-level waste burial during accident cleanup is 8 m^3. Decontamination liquids are assumed to be processed by evaporation and solidified by incorporation into cement. Evaporation of flush solutions is assumed to result in a reduction factor of ten in liquid volumes. Cementation of the concentrated liquid is assumed to result in a volume increase by a factor of two, with a net volume reduction factor of five from the flush solution volumes to the packaged solidified waste.

The average bulk density of solidified decontamination liquids is assumed to be 3200 kg/m^3 (200 lb/ft^3), based on shipping volumes.

Trash. Trash includes the following used and contaminated materials:

- rags, paper, plastic
- tools and equipment
- protective clothing
- incinerator ash
- laboratory glassware and plastic, etc.

Contaminated trash is assumed to be packaged for disposal in 208-ℓ (55-gal) drums and shipped to a low-level waste burial ground.

The amount of trash requiring disposal is difficult to estimate, but because of the nature of the decommissioning activities, the volume of trash

generated during accident cleanup is expected to be large. In this study, the untreated volume of contaminated trash is assumed to equal the total shipping volume of all of the glove boxes in the plant. Eighty percent of the trash generated during accident cleanup is assumed to be compactible by a volume reduction of 5:1, and is so treated. The final shipping volume is thereby estimated to be 12.0 m^3.

The average bulk density of the treated trash is assumed to be 800 kg/m^3 (50 lb/ft^3).

Schedules and Cleanup Worker Requirements for Accident Cleanup

Task schedules and sequences and cleanup worker requirements for accident cleanup at the U-Fab plant following the reference accident are shown in Figure 9.2-1. Accident cleanup in the building is estimated to require approximately one-half year following the reference accident. Time requirements for accident cleanup are measured from the start of building decontamination operations and do not include the estimated 0.5 years required for preparations for accident cleanup.

The following bases and assumptions are used to estimate time and manpower requirements for accident cleanup in the U-Fab plant.

1. In general, the time required to perform a particular cleanup task is determined by estimating the time requirement for efficient performance of the task and doubling this time to account for inefficiencies associated with work in high radiation areas.

2. Decontamination workers are assumed to spend only four hours inside the U-Fab plant during an eight-hour shift. The remaining time is assumed to be required to put on and remove protective clothing, rehearse cleanup procedures, etc.

3. Most accident cleanup tasks are performed on a basis of two shifts, five days a week. Exceptions to this general rule are noted below.

4. Training time for staff involved in cleanup operations is included in time and manpower estimates for completion of the various cleanup tasks.

5. Cleanup following an accident provides unique opportunities for research in areas related to accident consequences (contamination dispersal mechanisms, waste management requirements, etc.). However, in this report, no scheduling allowances are made for research and development activities except those related to the design, fabrication, and testing of the special tools and equipment required for decontamination and defueling operations.

Cleanup worker requirements include only the labor required to actually complete the cleanup tasks and to provide radiation monitoring and craft support to decommissioning workers and do not include the extra labor needed to maintain compliance with occupational radiation dose limits.

Occupational Doses for Accident Cleanup

Estimated occupational radiation doses to cleanup workers during accident cleanup following the reference accident are shown in Table E.2-4. The occupational doses shown in the table are external doses from gamma radiation. Workers are assumed to use respiration devices as necessary to protect against the inhalation of radioactive particulates. Cleanup workers are those having work assignments in the building.

Dose calculations are based on time and manpower requirements shown in the task schedules for accident cleanup. Exposure hours are estimated on the basis that workers engaged in decontamination operations and in the installation and repair of systems needed for accident cleanup spend an average of four hours inside the U-Fab plant during an eight-hour shift. Workers who operate the evaporator systems or are engaged in waste-packaging activities spend an average of six hours in a radiation area during an eight-hour shift.

Total estimated occupational radiation doses to cleanup workers for accident cleanup are 32.95 man-rem following the reference accident.

E.3 DETAILS OF COSTS OF ACCIDENT CLEANUP AT A REFERENCE URANIUM FUEL FABRICATION PLANT

Details of the costs of accident cleanup at the reference U-Fab plant are presented in this section. Costs are based on the technical requirements, manpower needs, and cleanup schedules presented in Section E.2 and are given in 1981 dollars.

Costs of activities related to refurbishment and restart of a plant beyond the accident cleanup activities are not included in this study. Unit cost information used as bases for these cost estimates is given in Appendix H.

E.3.1 Costs of Accident Cleanup

The estimated costs of accident cleanup at the reference plant are presented in this section, and are summarized in Table E.3-1. Accident cleanup in the U-Fab plant is estimated to require one year and to cost approximately 2 million following the reference accident.

Labor costs and waste management costs are major cost items for accident cleanup at the U-Fab plant. Staff labor costs account for about 43% of the

TABLE E.2-4. Estimated Occupational Radiation Dose for Accident Cleanup Following the Reference Accident at the Reference U-Fab Plant

Event Description	Foremen			H. P. Technicians			Operators			Craftsmen			
	Average Exposure Rate (R/hr)	Total Exposure (man-hours)	Dose (man-rem)	Average Exposure Rate (R/hr)	Total Exposure (man-hours)	Dose (man-rem)	Average Exposure Rate (R/hr)	Total Exposure (man-hours)	Dose (man-rem)	Average Exposure Rate (R/hr)	Total Exposure (man-hours)	Dose (man-rem)	Event Total Dose (man-rem)
Decontaminated UF_6 Cylinder Storage Room	4.1×10^{-4}	100	3.7×10^{-3}	3.7×10^{-5}	40	1.5×10^{-3}	3.7×10^{-5}	480	1.8×10^{-2}	3.7×10^{-5}	100	3.7×10^{-3}	3.0×10^{-1}
Decontaminate Vaporization Room	4.1×10^{-4}	220	8.1×10^{-3}	1.2×10^{-4}	80	9.6×10^{-3}	2.1×10^{-4}	1 360	0.29	2.1×10^{-4}	200	4.2×10^{-2}	3.9
Decontaminate Chemical and Powder Processing Area	3.0×10^{-4}	2 140	0.32	2.1×10^{-4}	880	0.18	2.6×10^{-4}	12 720	3.3	2.6×10^{-4}	2 460	0.64	8.8
Decontaminate Powder Storage and Feed Room	3.0×10^{-4}	180	2.7×10^{-2}	4.9×10^{-4}	80	3.9×10^{-2}	8.2×10^{-4}	1 240	1.0	8.2×10^{-4}	80	6.6×10^{-2}	2.2
Decontaminate Pelleting Room	3.0×10^{-4}	260	3.9×10^{-2}	4.9×10^{-4}	100	4.9×10^{-2}	8.2×10^{-4}	1 800	1.5	8.2×10^{-4}	300	0.25	3.6
Decontaminate Sintering Room	3.0×10^{-4}	380	5.7×10^{-2}	2.1×10^{-4}	160	3.4×10^{-2}	2.6×10^{-4}	2 440	0.63	2.6×10^{-4}	300	7.8×10^{-2}	1.6
Decontaminate Grinding Room	3.0×10^{-4}	240	3.6×10^{-2}	4.9×10^{-4}	100	4.9×10^{-2}	8.2×10^{-4}	1 360	1.1	8.2×10^{-4}	260	0.21	2.8
Decontaminate Rodding Area	8.5×10^{-5}	200	7.4×10^{-3}	6.6×10^{-5}	80	5.3×10^{-3}	9.4×10^{-5}	1 240	0.12	9.4×10^{-5}	360	3.4×10^{-2}	0.39
Decontaminate Gadolinia Shim Rod Production Facility	3.0×10^{-4}	300	4.5×10^{-2}	2.1×10^{-4}	120	2.5×10^{-2}	2.6×10^{-4}	1 600	0.42	2.6×10^{-4}	520	0.14	1.2
Decontaminate Rad Waste Room	6.0×10^{-4}	80	1.2×10^{-4}	4.9×10^{-4}	40	2.0×10^{-2}	8.2×10^{-4}	600	0.49	8.2×10^{-4}	40	3.3×10^{-2}	2.2
Decontaminate Decontamination Facility	9.3×10^{-5}	40	1.5×10^{-3}	1.2×10^{-4}	20	2.4×10^{-3}	2.1×10^{-4}	240	5.0×10^{-2}	2.1×10^{-4}	40	8.4×10^{-3}	1.6×10^{-1}
Decontaminate HEPA Filter	1.5×10^{-3}	240	3.6×10^{-2}	2.1×10^{-4}	100	2.1×10^{-2}	2.6×10^{-4}	1 800	0.47	2.6×10^{-4}	200	5.2×10^{-2}	5.8

TABLE E.3-1. Summary of Estimated Costs of Accident Cleanup at the Reference U-Fab Plant

Cost Category	Cost in Millions of 1981 Dollars[a]	Percent of Total
Manpower		
Planning and Preparation	0.266	15.3
Accident Cleanup	0.657	37.9
Equipment and Supplies	0.230	13.3
Disposal of Radioactive Material	0.240	13.8
Miscellaneous Owner Expense	0.302	17.4
Specialty Contractors	0.040	2.3
Subtotal	1.735	100.0
25% Contingency	0.434	
Total Cost of Accident Cleanup	2.169	

(a) Number of figures shown is for computational accuracy and does not imply precision to the nearest thousand dollars.

total cost of accident cleanup. Contractor costs for engineering support contribute an additional 3% of the total cost of accident cleanup. Waste management costs account for about 14% of accident cleanup costs.

E.3.2 Total Waste Management Costs

Details of total waste management cost calculations for radioactive wastes generated during accident cleanup are are shown in Table E.3-2. These calculations are based on estimated waste quantities described in Section E.2 and on unit cost data for packaging, transportation, and waste disposal given in Appendix H. All radioactive wastes from these activities are assumed to be shipped to a low-level waste burial ground.

For a particular waste form, the total waste management cost is the sum of the total packaging cost, the total transportation cost, and the burial cost.

Total packaging costs are the sum of disposable container costs and reusable overpack rental charges. In calculating the reusable overpack charge, a total time of four days is assumed for the 4800-km (3000-mi) round trip between the plant and the burial ground. A second driver is assumed to be required for this trip.

The total transportation cost is the sum of the basic transportation cost, the overweight charge, and the charge for a second driver. Overweight charges

TABLE E.3-2. Details of Estimated Costs for Radioactive Waste Management from Accident Cleanup at the Reference U-Fab Plant

Waste Category	Total Packaging Cost ($)	Total Transportation Cost ($)	Burial Cost ($)	Total Waste Management Cost ($)
HEPA and Roughing Filters	38.1	40.6	47.9	126.6
Solidified Decontamination Liquids	5.8	27.9	13.2	46.9
Trash	5.8	14.6	46.1	66.5
Totals	49.7	83.1	10.72	240

are based on charges for the state of Washington. In some instances, the quantity of waste per shipment is limited by weight restrictions (i.e., the 33.1 MT limit) rather than by volume limits.

E.4 DETAILS OF ACTIVITIES AND MANPOWER REQUIREMENTS FOR DECOMMISSIONING AT A REFERENCE URANIUM FUEL FABRICATION PLANT

This section provides the details of post-accident decommissioning activities at the reference U-Fab plant following completion of the accident cleanup campaign. A comparison of normal and post-accident decommissioning requirements is provided in Section E.4.1. The details of the post-accident decommissioning at the reference U-Fab plant by the DECON alternative are given in Section E.4.2. The costs associated with these decommissioning activities are presented in Section E.5.

The post-accident decommissioning analyses in this study use the results of previous analyses of U-Fab plant decommissioning following normal plant shutdown, presented in Reference 1 with appropriate modifications as necessary to account for post-accident conditions.

A basic assumption of the analyses presented in this appendix is that all radioactive waste materials resulting from accident cleanup and from decommissioning are shipped offsite for disposal at the time of decommissioning.

E.4.1 Comparison of Normal Versus Post-Accident Decommissioning

Under normal circumstances, decommissioning of a U-Fab plant follows the orderly shutdown of the facility at the end of its planned operating life. However, the situation at a facility that has experienced an accident is significantly different from normal, with moderate to severe contamination of the

plant buildings, and possible physical damage to plant equipment and services. As a result, decommissioning following an accident may differ significantly from that following normal shutdown.

It is assumed in this study that the accident cleanup activities are completed prior to the start of the actual decommissioning effort. These cleanup activities are discussed in detail in Section E.2.

The tasks that must be performed to accomplish the decommissioning goals are postulated to be independent of the alternative (DECON or SAFSTOR) chosen to complete the decommissioning, although the methods used to complete certain tasks may vary with the decommissioning alternative. The work required to complete each task will certainly be influenced by the severity of the accident.

In carrying out the accident cleanup activities, certain tasks that would be part of the decommissioning process following normal shutdown are completed, and significant portions of other such tasks are undertaken.

The requirements of carrying out the accident cleanup activities also result in certain new tasks that must be completed during the decommissioning process. In general, these new tasks are limited to the removal of new equipment installed to process accident water and the decommissioning of the temporary onsite waste storage structures specially constructed for the management of wastes resulting from accident cleanup activities.

A number of decommissioning tasks are independent of accident cleanup activities and, thus, are common to both post-accident and normal-shutdown decommissioning. However, the changes in the physical and radiological condition of the plant resulting from an accident lead to substantial qualitative changes in a number of these decommissioning tasks. Manpower requirements for carrying out specific tasks are related to a number of factors (e.g., the physical condition of the equipment and structures, local radiation dose rates, and the methods used to complete tasks) that may be affected by the accident and the subsequent cleanup program. Radiation doses to decommissioning workers are likely to be higher than those following normal shutdown because of the increased contamination of equipment, piping, and structural surfaces caused by the accident. The schedule and sequence of events for any particular decommissioning alternative may need to be revised to account for these changes and for the addition and deletion of specific tasks as a result of accident cleanup, as discussed previously. Furthermore, the requirements for special decommissioning tools and equipment may vary somewhat because of changes in specific tasks and because some of these tools and equipment items may be available for reuse as a result of the accident cleanup campaign that precedes the decommissioning.

In summary, even tasks common to both post-accident and normal-shutdown decommissioning can be expected to differ significantly between the two situations.

Although the accident cleanup activities remove a large portion of the accident-generated contamination in the plant, accident severity will likely have some impact on the decommissioning tasks subsequent to cleanup. Radiation doses to decommissioning workers are likely to increase with accident severity because the increased level and spread of radioactive damage to the plant from more severe accidents may compromise certain systems, structural features, and equipment items that are required to carry out the decommissioning tasks, thus necessitating repairs and/or substitutions and resulting in delays and additional expenses. In areas of extensive plant damage, different methods may be required to accomplish certain decommissioning tasks. It should be noted that the effects of accident severity on the level of effort required to complete the decommissioning activities are much less than the corresponding effects on the cleanup activities.

E.4.2 DECON

In general, DECON is the decommissioning alternative used to remove from the facility, as soon as practicable following final shutdown, all materials with radioactive contamination above unrestricted release levels. For a plant that has experienced an accident, start of DECON follows accident cleanup and is postulated to be completed within about one year. After DECON is completed and the radioactive materials are shipped from the site, the nuclear license can be terminated and the facility and the site can be released for unrestricted use.

Details of post-accident DECON at the reference plant are discussed in this section, including schedules and manpower requirements, and external occupational radiation doses. These details are based largely on the analysis of DECON at the reference plant following normal shutdown, presented in Appendix G and Section 9 of Reference 1 because, after cleanup is completed, many of the requirements for DECON are similar whether or not the plant has experienced an accident. Where the postulated accident results in significant changes in the DECON requirements, the differences in the requirements are identified and new information is developed to support the analysis. The analysis presented is based on the assumption that the plant has experienced the reference accident for U-Fab plants described in Chapter 6.

The facility description given in Appendix A provides the basic information that supports the development of the tasks, schedules, manpower loadings, and occupational radiation exposure estimates presented here. Additional details pertinent to specific DECON activities come from engineering drawings, manufacturers' data, and Reference 1.

The information in this section forms the basis for the estimated costs and safety impacts of post-accident DECON at the reference plant which are developed in Section 9.5 and Section E.5, respectively, and for the comparison of post-accident and normal-shutdown DECON of the reference plant that is presented in Chapter 13.

In choosing to decommission a facility by DECON, the owner trades potential further use of the facility for the relatively rapid release of the site for unrestricted use.

DECON Activities

DECON of the reference facility can be divided into three general areas of effort: planning and preparation, decontamination, and disassembly and transport.

It is estimated that approximately one year is required for DECON. The time and work estimates assume reasonable success, with a minimum of delays and/or major unanticipated problems.

Planning and Preparation Activities

Essential to the results of this study is the assumption that the facility owner/operator is also the prime contractor of the DECON. Otherwise, a more extensive training program would be necessary to acquaint workers with details of the facility. Approximately one year prior to start of DECON, work begins in the engineering and operations departments of the parent organization to perform the planning needed to convert an operating license to a possession-only license, to plan decommissioning operations, and to receive a decommissioning license. The proposed sequence and timing schedule for the planning and preparation phase of decommissioning the reference U-Fab plant is illustrated in Figure E.4-1.

An important part of the planning includes a review of all regulations and guides applicable to decommissioning. Included in the regulations are the requirements for preparation of changes in technical specifications, deleting those related to plant operation; preparation and submittal of a decommissioning plan for NRC review and approval; preparation of detailed plans and procedures for physical and chemical decontamination of intact systems; sectioning and disposal of contaminated glove box equipment; and detailed sequences for equipment and systems removal. In addition, design, procurement, and testing of special devices and equipment must be initiated during the year before start of DECON to assure that work can proceed without undue delay.

Creation of a decommissioning organization within the present organization is initiated during cleanup operations with the structure and staffing requirements identified, and commitments obtained from key engineering and operating

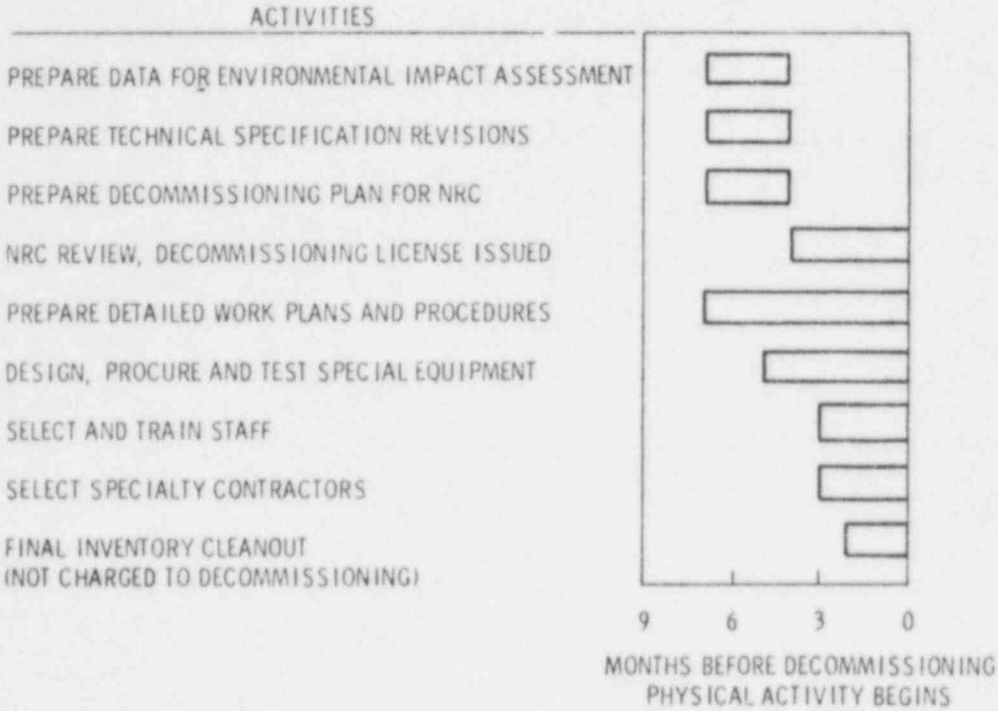


FIGURE E.4-1. Sequence and Schedule of the Planning and Preparation Phase of DECON at the Reference U-Fab Plant

personnel to fill critical positions. Orientation and training of personnel identified as members of the decommissioning organization are carried on during the final six months of cleanup operations. Selection of the various specialty contractors required for the dismantlement effort is accomplished during the cleanup operations.

The final preparatory step is a comprehensive survey of radiation dose rates and contamination levels within the facility, taken after final inventory cleanout and plant shutdown. This survey provides the baseline data for decisions on chemical and physical decontamination. It also provides initial data on radiation dose rates and contamination levels likely to be encountered during the various activities.

Work Schedule Estimates

The proposed overall schedule and sequence of events for the DECON efforts is presented in Figure E.4-2. Initial work begins during cleanup operations with the following steps: 1) preparation of a decommissioning plan for NRC approval, 2) preparation of the revisions to the facility technical specifications necessary to change from an operating license to a possession-only

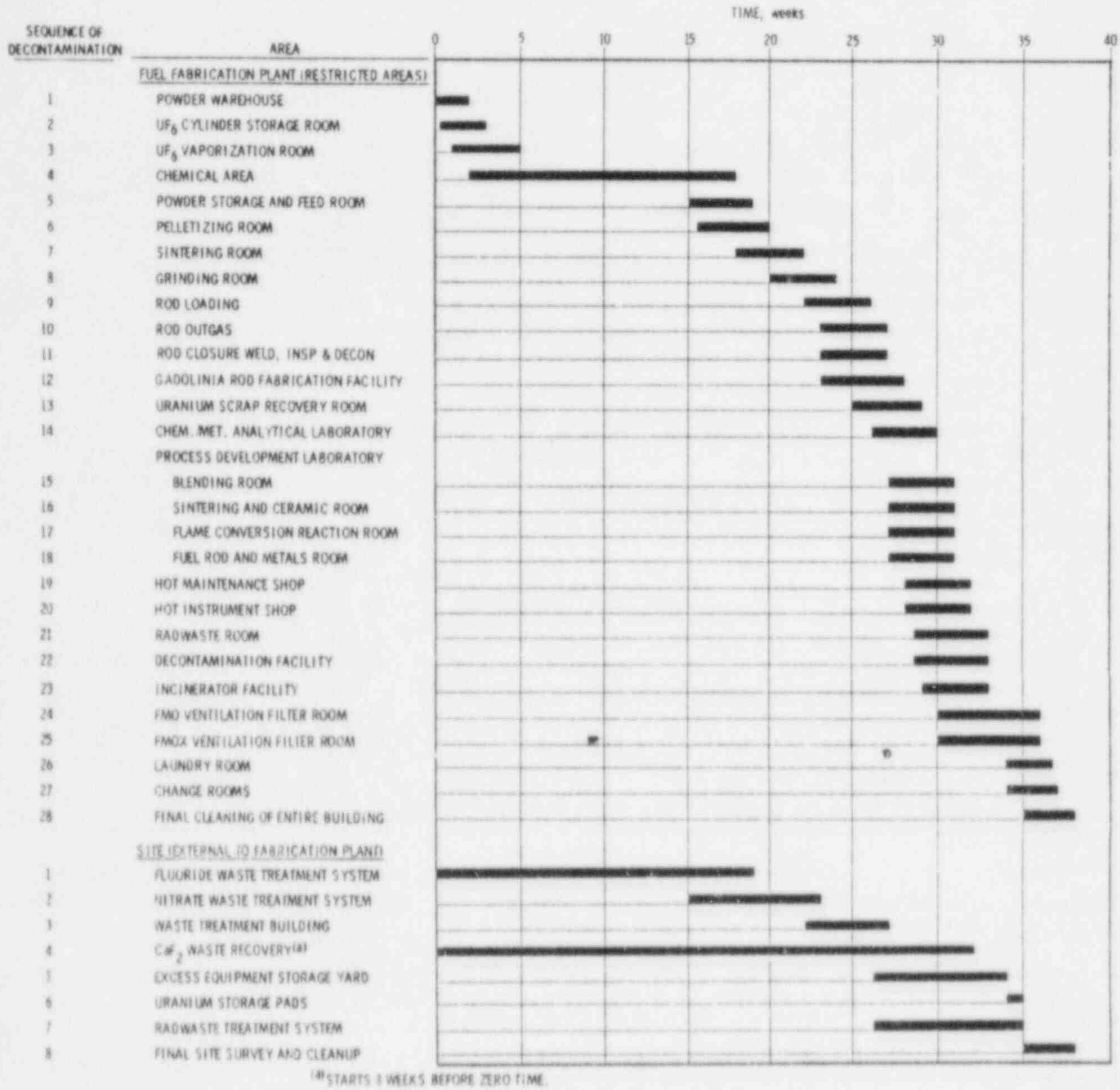


FIGURE E.4-2. Schedule and Sequence for DECON Activities at the Reference U-Fab Plant

license, 3) preparation of the data needed to make an assessment of the environmental impact of the DECON work, 4) preparation of detailed work plans and procedures for accomplishing the DECON of the facility, 5) design, procurement and testing of all special equipment needed for DECON, and 6) selection and training of the personnel for the decommissioning staff.

DECON Staff Organization.

The decommissioning work force organizational chart for DECON is shown in Figure 9.4-2 of Volume 1. The work force is described in two parts: 1) the decommissioning support staff that plans, supervises, and provides supporting activities for the decommissioning activities, and 2) the decommissioning workers who perform the actual decommissioning activities.

Actual decommissioning activities are carried out by decommissioning crews that consist of a foreman, two to six decommissioning technicians, and health physics technicians and craftsmen who are added to the crews as the work situation demands.

A key assumption in estimating the manpower and time for the basic events is that the decommissioning work force is composed primarily of former plant operating and maintenance personnel. The decommissioning workers are, therefore, familiar with plant facilities and equipment and experienced with radiation working procedures.

Decommissioning Worker Manpower Requirements

Detailed estimates of the decommissioning worker manpower required to perform DECON of the reference plant are shown in Table E.4-1. These estimates for the decommissioning workers, plus those for the support staff, are summarized in Table E.4-1.

Waste Management Requirements

Detailed estimates of volumes and weights of contaminated hoods, tanks and equipment, piping and ductwork, HEPA and roughing filters, concrete rubble, contaminated soil and liners, and miscellaneous contaminated scrap from DECON at the reference plant are presented in this section. These estimates form the bases for determining packaging and shipping requirements and costs.

Hoods, Tanks, and Equipment. Table E.4-2 summarizes shipping volumes for contaminated hoods and equipment in terms of the volumes of material shipped to low-level waste burial.

HEPA and Roughing Filters. The number and volume of HEPA and roughing filters disposed of during DECON activities and the method of their disposal are shown in Table E.4-3.

HEPA and roughing filters attached to hoods are 0.2 x 0.2 x 0.1 m thick. All of these filters are assumed to be incinerated and the residue is processed to recover the uranium.

TABLE E.4-1. Estimated Decommissioning Worker Manpower Requirements for DECON at the Reference U-Fab Plant

Decommissioning Activity	Estimated Man-Weeks[a] Foremen	Technicians	Health Physicists	Craftsmen	Total
Inside Building					
Dismantle and Decontaminate Powder Warehouse	2	12	1	1	16
Dismantle and Decontaminate UF_6 Cylinder Storage	2.5	12	1	2.5	18
Dismantle and Decontaminate UF_6 Vaporization Room	5.5	34	2	5	46.5
Dismantle and Decontaminate Chemical and Powder Processing Area					
Hydrolysis	2.5	13.5	1	7.5	24.5
Precipitation and Digestion	2	12	1	4	19
First Stage Centrifuge	1.5	10	0.5	2	14
Second Stage Centrifuge	1.5	6.5	0.5	2.5	11
Reduction Calcination	9	56.5	4	7.5	77
Hammer Milling	5	31	2	4	42
Slug Pressing	2.5	15	1	2.5	21
Granulating	3.5	18.5	1.5	4	27.5
Bucket Filling	3.5	22	1.5	2	29
Flame Conversion Reaction	3.5	18.5	1.5	6.5	30
Uranium Purificaiton System	10.5	56	4	9.5	80
Main Hood Exhaust Systems	2.5	17.5	1	3	24
Miscellaneous Items and Final Cleaning	6	41	2.5	6.5	56
Dismantle and Decontaminate Powder Storage and Feed Room	4.5	31	2	2	39.5
Dismantle and Decontaminate Pelletizing Room	6.5	45	2.5	7.5	61.5
Dismantle and Decontaminate Sintering Room	9.5	61	4	7.5	82
Dismantle and Decontaminate Grinding Room	6	34	2.5	6.5	49
Dismantle and Decontaminate Rodding Room	5	31	2	9	47
Dismantle and Decontaminate Gadolinia Facility	7.5	40	3	13	63.5
Dismantle and Decontaminate Uranium Scrap Recovery Room	2.5	17	1	5	25.5
Dismantle and Decontaminate Chemical and Metallurgical Analytical Laboratory	3	19	1	5	28
Dismantle and Decontaminate Process Development Laboratory	5.5	37	2	9	53.5
Dismantle and Decontaminate Hot Maint. and Instr. Shops	3.5	17	1.5	13	35
Dismantle and Decontaminate Radwaste Room	2	15	1	1	19
Dismantle and Decontaminate Decontamination Facility	1	6	0.5	1	8.5
Dismantle and Decontaminate Incinerator Facility	3	21	1	4	29
Dismantle and Decontaminate HEPA Filter Rooms and Ducts	6	45	2.5	5	58.5
Dismantle and Decontaminate Laundry Room	1	7	0.5	0.5	9
Dismantle and Decontaminate Change Rooms	1	7	0.5	1	9.5
Miscellaneous	3.5	22	1.5	6.5	33.5
Overall Cleanup and Survey of Entire Building	3	22	1	2	28
Outside Building					
Dismantle and Decontaminate Fluoride Waste Effluent Treatment System	20.5	148	8	13	189.5
Dismantle and Decontaminate Nitrate Waste Effluent Treatment System	5	32	2	6.5	45.5
Dismantle and Decontaminate Waste Treatment Building	2.5	17	1	4	24.5
Recovery of CaF_2 Waste	7.5	61	3	0	71.5
Clean Up Excess Equipment Storage Yard	7.5	54	3	6.5	71
Uranium Storage Pad Survey	0.5	2	0.5	0	3
Dismantle and Decontaminate Liquid Radwaste Effluent Treatment System	5	26	2	18	46
Overall Cleanup and Survey of Entire Site	4	31	1.5	0	36.5
Total man-weeks	198	1 224	77	211.5	1 702.5
Total man-years[b]	3.8	24.48	1.54	4.23	34.05

(a) Number of significant figures shown is for computational completeness and does not imply accuracy to the number of figures shown.
(b) A total of 50 weeks/year is assumed.

TABLE E.4-2. Shipping Volumes of Hoods, Equipment, Pipes, Ducts, and Other Equipment at the Reference U-Fab Plant[(a)]

Plant Location	Hoods, Equipment, and Components (m^3): To Sanitary Landfill or Unrestricted Use[(b)]	Hoods, Equipment, and Components (m^3): to Licnsed Low-Level Waste Burial[(c)]	Pipe, Conduit, Duct, Trays, and Fixtures (m^3): To Sanitary Landfill or Unrestricted Use[(b)]	Pipe, Conduit, Duct, Trays, and Fixtures (m^3): to Licensed Low-Level Waste Burial[(c)]
Powder Warehouse	209.78	0	21.24	0
UF_6 Cylinder Storage	169.40	0	22.96	0
UF_6 Vaporization Room	38.72	182.38	0	13.05
Chemical and Powder Processing Area	583.86	202.35	88.86	64.48
Powder Storage and Feed Room	53.73	9.17	35.49	0
Pelletizing Room	128.63	22.71	63.92	1.56
Sintering Room	234.30	58.57	235.00	0
Grinding Room	128.07	5.32	33.42	0
Rodding Room	288.11	0	67.68	0
Gadolinia Facility	76.11	17.79	146.76	0
Uranium Scrap Recovery Room	4.86	27.44	30.33	1.70
Chemical and Metallurgical Analytical Laboratory	107.22	10.79	33.90	0
Process Development Laboratory	186.58	30.22	88.25	0
Hot Maint. and Instr. Shops	129.57	0	44.27	0
Radwaste Room	135.29	0	10.17	0
Decontamination Facility	20.10	0	23.31	0
Incinerator Facility	18.74	25.86	0	11.56
HEPA Filter Rooms and Ducts	(d)	(d)	0	2.82
Laundry Room	6.77	20.33	0	3.58
Change Rooms	7.50	0	0	0
Miscellaneous	183.83	0	7.25	0
Fluoride Waste Treatment System	1 680.17[(e)]	84.33	65.36	16.34
Nitrate Waste Treatment System	457.00[(e)]	2.89	13.70	3.43
Waste Treatment Building	57.29	10.11	6.97	0
Excess Equipment Storage Area	316.51	35.17	0	0
Uranium Storage Pads	0	0	0	0
Radwaste Treatment System	56.92	18.97	14.47	0
Totals	5 279.06	764.40	1 053.29	118.52

(a)Number of significant shown is for computational completeness and does not imply accuracy to the number of figures shown.
(b)Items not compacted in volume.
(c)Items are assumed with compacted volumes for shipment.
(d)Fans, main ducts, and exhaust chimneys reinstalled after cleanup.
(e)Comprised mostly of large tanks.

TABLE E.4-3. Estimated Sources of HEPA and Roughing Filters for Disposal During DECON[a]

Filter Location	Number of Filters		Number[b] Incinerated	Number Shipped		Volume Shipped (m^3)
	HEPA	Roughing		HEPA	Roughing	
Intermediate-Stage Filters for Hoods	120	200	308	6	6	1.02
Room Ventilation Filters	355	355	614	48	48	8.16
Exhaust Air Filters	250	250	--[c]	250	250	42.48
Filter Changes	10	100	110	--	--	--
Total						51.66

(a) Number of significant figures shown is for computational completeness and does not imply accuracy to the number of figures shown.
(b) Incinerated filters are processed to recover the uranium.
(c) A dash indicates that this information is not applicable.

Ventilation HEPA filters are 0.6 x 0.6 x 0.3 m thick. Ventilation roughing filters are 0.6 x 0.6 x 0.15 m thick. Ventilation HEPA and roughing filters that are not incinerated are assumed to be packaged in plywood boxes and shipped to a low-level waste burial site for disposal.

The average bulk density of the filters is assumed to be 320 kg/m^3.

Concrete Rubble. The volume of potentially contaminated concrete assumed to be removed from floors and walls at the reference plant and shipped to low-level waste burial is shown in Table E.4-4. The estimated volumes shown in the table assume concrete would be removed to a depth of 0.05 m. A fraction of the surface area of each room (based on the type of operation in a specific room) is estimated to calculate the volume of concrete removed.

The shipping volume of the concrete rubble is assumed to be twice the volume of the concrete removed from the walls. The average bulk density of the concrete rubble as shipped is thus assumed to be 1200 kg/m^3.

E.5 DETAILS OF COSTS OF DECOMMISSIONING AT A REFERENCE URANIUM FUEL FABRICATION PLANT

This section presents the estimated costs of decommissioning the reference plant via the DECON decommissioning alternative following a reference accident and the subsequent accident cleanup campaign. The costs developed here are based on the detailed descriptions of the decommissioning activities and requirements presented previously in Section E.4 and on the cost-estimating bases presented in Appendix H. Cost information for the decommissioning of the reference plant following normal shutdown, from Reference 1, is also used where applicable. The decommissioning costs are all adjusted to 1981 dollars and are developed on a consistent basis with the costs of accident cleanup presented in Section E.3.

The costs of decontaminating and disposing of systems and facilities required for accident cleanup are included in the estimates presented in this section.

E.5.1 Cost Estimates for DECON

The estimated costs for DECON at the reference U-Fab plant following the reference accident and the subsequent cleanup campaign are summarized in Table E.5-1. DECON is estimated to require about one year (plus year for planning and preparation) at a cost of approximately $5.4 million.

Manpower costs include both support staff and decommissioning workers and represent about 65% of the total cost of DECON. In Table E.5-1, manpower costs

TABLE E.4-4. Estimated Sources of Concrete Rubble Generated During DECON at the Reference U-Fab Plant[a]

Location	Floor Area (m^3)	Estimated Percent of Area Removed	Volume Removed (m^3)	Rubble Weight (kg)	Shipping Volume (m^3)
Fuel Manufacturing Building					
Vaporization	193.6	5	0.49	590	0.98
Chemical and Powder Processing	2 120.0	4	4.32	5 180	8.64
Powder Storage and Feed	486.9	3	0.74	890	1.48
Pelletizing	390.4	2	0.40	480	0.80
Sintering	599.2	1	0.31	370	0.62
Grinding	195.1	1	0.10	120	0.20
Incinerator Facility	222.9	2	0.23	280	0.46
Remainder of Building	6 207.0	0.4	1.27	1 520	2.54
Outside Fuel Manufacturing Building					
Fluoride Waste Treatment	--[b]	--	3.24	3 890	6.48
Nitrate Waste Treatment	--	--	2.08	2 500	4.16
Waste Treatment Building	--	--	1.20	1 440	2.40
Equipment Storage Pads	--	--	1.00	1 200	2.00
Uranium Storage Pads	--	--	0.41	490	0.82
Radwaste Treatment	--	--	3.00	3 600	6.00
Remainder of Site	--	--	1.04	1 250	2.08
Totals			19.83	23 800	39.66

(a) Number of significant figures shown is for computational completeness and does not imply accuracy to the number of figures shown.

(b) A dash indicates that this information is not applicable.

TABLE E.5-1. Summary of Estimated Cost of Post-Accident DECON at the Reference U-Fab Plant[a]

Cost Category	Cost in Millions of 1981 Dollars[a]	Percent of Total
Manpower		
Planning and Preparation	0.398	9.3
Decommissioning	2.334	54.6
Equipment and Supplies	0.174	4.1
Disposal of Radioactive Material	0.273	6.4
Miscellaneous Owner Expense	1.030	23.7
Specialty Contractors	0.084	2.0
Subtotal	4.293	100.0
25% Contingency	1.073	
Total Decommissioning Cost	5.366	

(a) Number of figures shown is for computational accuracy and does not imply precision to the nearest thousand dollars.

are shown separately for the planning and preparation and the decommissioning phases of DECON. These costs include onsite labor for packaging radioactive waste materials for shipment.

E.5.2 Costs of Staff Labor

Table E.5-2 shows staff labor cost estimates for the planning and preparation phase of DECON, and Table E.5-3 shows staff labor costs for the decommissioning phase. For planning and preparations, the labor cost is about $0.4 million. For decontamination and removal of contaminated materials, the labor cost is about $2.3 million. The total labor cost for DECON is, therefore, about $2.7 million without contingencies. Manpower costs shown in Table E.5-3 include labor costs for packaging radioactive waste materials for shipment. These costs do not include specialty labor costs.

E.5.3 Material and Equipment Costs for DECON

Estimates of material and equipment requirements and costs for DECON are shown in Table E.5-4. Costs of decontamination chemicals are calculated on the basis of quantities required for decontamination and unit costs given in Appendix H. Cleaning supplies represent a major cost item and include assorted cleaning agents, rags, mops, brushes, plastic bags, plastic sheeting, etc. The

TABLE E.5-2. Summary of Manpower Costs for Planning and Preparation Phase of DECON at the Reference U-Fab Plant

Title or Function	Cost ($ Millions)[a,b]
Project Manager	0.053
Project Engineer	0.051
Health and Safety Supervisor	0.017
Contracts and Accounting Specialist	0.022
Radioactive Shipment Specialist	0.011
Q. A. Engineer	0.030
Planning Engineer	0.090
Engineering Technician	0.020
Operations Supervisor	0.030
Foreman	0.046
Secretary	0.028
Total Cost	0.398

(a) Number of figures shown is for computational accuracy and does not imply precision to the nearest thousand dollars.
(b) Contingency of 25% is not included in these costs.

cost of protective clothing includes the cost of laundering the clothing onsite and is estimated to be about $1350 per week. The total cost of material and equipment for DECON at the reference plant is estimated at about $174,000 without contingency.

E.5.4 Waste Management Costs

The estimated costs for containers, transportation, and disposal of the radioactive wastes from DECON at the reference U-Fab plant are summarized in Table E.5-5. Cost estimates are based on projected packaging and shipping data summarized in Tables E.4-2 through E.4-4 and on waste management cost data in Section E.4. The total waste management cost for DECON is estimated to be about $273,000 without contingency.

Only about 3% (1100 m^3) of the theoretically compacted radioactive waste volume of 36,900 m^3 is assumed to be shipped to low-level waste burial. The remainder is assumed to be decontaminated and sent to commercial waste disposal or processed to recover the uranium.

TABLE E.5-3. Summary of Manpower Costs for DECON at the Reference U-Fab Plant

Title or Function	Cost ($ Millions)[a,b,c]
Project Manager	0.103
Project Engineer	0.088
Health and Safety Supervisor	0.066
Health Physics Technician	0.053
Security Force Supervisor	0.048
Security Patrolman	0.104
Contracts and Accounting Specialist	0.045
SNM Accounting Specialist	0.053
Radioactive Shipment Specialist	0.035
Q. A. Engineer	0.060
Planning Engineer	0.060
Engineering Technician	0.037
Maintenance and Crafts Supervisor	0.057
Custodian	0.025
Craftsman	0.168
Operations Supervisor	0.061
Foreman	0.182
Technician	1.047
Secretary	0.042
Total Cost	2.334

(a) Number of figures shown is for computational accuracy and does not imply precision to the nearest thousand dollars.

(b) Information given is for support staff and decommissioning workers.

(c) Contingency of 25% is not included here.

TABLE E.5-4. Estimated Material and Equipment Costs for DECON at the Reference U-Fab Plant

Description	Quantity	Estimated Total Cost ($ thousands)[a,b]
Oxyacetylene Torch	4 ea	5.5
Guillotine Pipe Saw	2 ea	2.8
Tube Cutter	2 ea	0.8
Ratcheting Pipe Cutter	6 ea	0.4
Reciprocating Saw	4 ea	2.8
Nibbler	2 ea	2.8
High-Velocity Liquid Jet	1 ea	6.9
Low-Velocity Liquid Jet	2 ea	5.5
Hydraulic Concrete Surface Spalling Device	1 ea	6.9
Concrete Drill	3 ea	0.8
Electric Pneumatic Hammer	2 ea	1.4
Portable A-Frames	2 ea	8.3
Portable Wash Sinks	2 ea	5.5
Portable Spray Clean Booth	1 ea	5.5
Portable Greenhouse Erection Kit	1 ea	2.8
Portable Powered Brushes	20 ea	4.2
HEPA Filter	10 ea	2.1
Roughing Filter	100 ea	6.9
Decontamination Chemicals		13.9
Cleaning Supplies		27.7
Expendable Tools		13.9
Protective Clothing (including laundry)		24.9
Office Supplies: Planning and Preparation		13.9
Decommissioning		8.3
Total		174

(a) Number of figures, shows is for computational accuracy and does not imply accuracy to the nearest thousand dollars.
(b) Contingency of 25% is not included.

TABLE E.5-5. Estimated Waste Management Costs for DECON at the Reference U-Fab Plant

Waste Category	Costs in Thousands of 1981 Dollars[a]			
	Container	Transportation	Burial	Total[b]
To Low-Level Waste Burial:				
Hoods, Equipment, and Components	52.9	23.9	99.2	176.0
Pipe, conduit, Duct, Trays, Fixtures, etc.	8.2	10.1	15.3	33.6
HEPA and Roughing Filters	3.6	1.3	6.7	11.7
Concrete Rubble	5.5	2.3	5.1	12.9
Contaminated Liner and Soil Materials	12.7	5.8	11.8	30.4
Miscellaneous	1.7	1.3	1.7	4.7
Miscellaneous	0.9	1.2	1.6	3.7
Totals	85.5	45.9	141.4	273.0

(a) Number of figures is for computational accuracy and does not imply accuracy to three or more significant figures.
(b) Contingency of 25% is not included.

E.5.5 Miscellaneous Owner Expenses for DECON

Estimated miscellaneous owner expenses for DECON are given in Table E.5-6.

TABLE E.5-6. Estimated Miscellaneous Owner Expenses for DECON at the Reference U-Fab Plant

Cost Category	Cost in Thousands of 1981 Dollars[a,b]
Utilities	360
Taxes	220
Inspections and License Amendments	100
Insurance	350
Total	1030

(a) Number of figures shown is for computational accuracy and does not imply accuracy to the nearest thousand dollars.
(b) Contingency of 25% is not included.

The inspection fees for safety and safeguards inspections at the operating U-Fab plant are estimated to be $70,000.[2] In addition, fees for license amendments for decommissioning could total $30,000. Thus, the license-related costs during the first year following shutdown of operations are estimated to be about $1 million.

The cost of nuclear liability insurance for a facility being decommissioned has also not been determined. An allowance of $350,000 is included for the annual insurance premium for nuclear liability and conventional insurance.

E.5.6 Specialty Contractor Costs for DECON

Specialized services are required to accomplish the DECON of the reference plant. These services are assumed to be supplied by the specialty contractors listed below. Costs shown do not include the 25% contingency.

Excavate and Refill Pipe Trenches

A contractor is hired to uncover the pipelines for the fluoride, nitrate, and radwaste treatment systems. The trench is filled back in after the pipe has been removed. There are approximately 2.7 km of trench, averaging 1.5 m in depth. The excavation and refilling of the trench cost about $\$1.80/m^3$ for 3800 m^3, a total of about $6900.

Waste Treatment Lagoon Reclamation

Reclamation of the waste treatment lagoons involves puncturing the liners and filling the lagoons with indigenous material. The sites are then leveled and planted with native vegetation.

The two fluoride and two fluoride aeration lagoons are emptied earlier during the final cleanup operation by the uranium recovery contractor. The lagoon sites are then cleaned to acceptable levels by the decontamination and final cleanup crews.

The two nitrate lagoons will have been emptied earlier during final inventory cleanup and the residual materials shipped to an offsite contractor for recovery of the uranium. The decontamination and final cleanup crews prepared the site for reclamation. The aeration lagoon and two chemical lagoons are assumed to be drained and the residual material left to be covered in the reclamation operations.

The estimated costs for reclamation of the waste treatment lagoons are presented in Table E.5-7.

TABLE E.5-7. Subcontractor Costs for Reclamation of the Waste Treatment Lagoons at the Reference U-Fab Plant

Activity	Basis	Cost ($)[a]
Puncture Liners	15 900 m^2 at $0.14/$m^2$	2 200
Backfilling	38 900 m^3 at $0.70/$m^3$	27 000
Grader Rental	$700/wk for 4 weeks	2 800
Dump Truck Rental	$700/wk for 4 weeks	2 800
Loader Rental	$1400/wk for 4 weeks	5 500
Foreman	$1250/wk for 4 weeks	5 000
Equipment Operators	Two men at $1040/wk for 4 weeks	8 300
Laborers	Two men at $760/wk for 4 weeks	6 100
Grade, Seed, Fertilize	15 900 m^2 at $1.10/$m^2$	17 600
Total		77 300

(a) Contingency of 25% is not included.

REFERENCES

1. H. K. Elder and D. E. Blahnik, Technology, Safety and Costs of Decommissioning a Reference Uranium Fuel Fabrication Plant. NUREG/CR-1266, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, October 1980.

2. Title 10 Code of Federal Regulations Parts 140.31 and 170.32, September 1978.

APPENDIX F

DETAILS OF DECOMMISSIONING OF REFERENCE NON-FUEL CYCLE FACILITIES

APPENDIX F

DETAILS OF DECOMMISSIONING OF REFERENCE NON-FUEL CYCLE FACILITIES

This appendix provides manpower, waste management, and cost details for the decommissioning by the DECON alternative of the materials licensee laboratory facilities following an accident. The reference laboratory for which data are given is described in Chapter 5.

Estimates of manpower requirements and costs for both the planning and preparation phase and the actual decommissioning phase of facility decommissioning are given in this appendix. Planning and preparation activities include the preparation of documentation for regulatory agencies, an initial radiation survey of the facility, and the development of detailed work plans.

Decommissioning of the reference laboratories is assumed to be performed by a work crew consisting of a foreman and three technicians, assisted by a health physicist. Craftsmen (electricians, pipefitters, etc.) are added to this crew on a part-time basis to perform specific tasks. The members of the work crew are recruited from the staff of the facility owner. Manpower costs are postulated to include the salary of a supervisor on a half-time basis.

The final decommissioning activity is a comprehensive radiological survey to document levels of radioactivity remaining in the facility after DECON procedures are completed and to verify that these levels are less than those specified for unrestricted release. The procedures and instrumentation for performing this radiological survey are described in Appendix J.

F.1 DETAILS OF DECOMMISSIONING OF FACILITY COMPONENTS

This section provides manpower and cost details for DECON of facility components by the options of 1) decontamination of the component to unrestricted release levels or 2) disassembly and packaging of the component and disposal at a shallow-land burial ground. Facility descriptions are given in Chapter 5.

The facility components for which decommissioning details are given, and the DECON options evaluated for each component, are shown in Table F.1-1.

The following key bases and assumptions are used for estimating manpower requirements and costs:

TABLE F.1-1. DECON Options for Facility Components

Facility Component	DECON Option: Clean to Unrestricted Release Levels	DECON Option: Dismantle and Package for Disposal
Fume Hood	x[a]	x
Glove Box	x	x
Laboratory Workbench	x	x
Ventilation Ductwork		x
Building Surfaces(b)	x	

(a) An "x" indicates that the facility component can be decommissioned by the indicated option.
(b) Some contaminated material, such as floor tiles or concrete shipped from walls, might be packaged and shipped for disposal.

1. To determine the total time required to decommission a facility component, an estimate is made of the time required for efficient performance of the work by a postulated work crew. This time estimate is then increased by 50% to provide for preparation and set-up time, rest periods, etc. (ancillary time).

2. One important factor that affects time and manpower estimates for decontamination of a component is the amount of residual contamination that must be removed from the surface. Residual surface contamination levels on facility components are taken from the facility descriptions of Chapter 5. Allowable contamination levels for unrestricted release are based on the NRC guidelines for the decontamination of facilities and equipment prior to release for unrestricted use.[1]

3. An individual decontamination step, such as steam-cleaning, spraying and rinsing, mopping, scrubbing, etc., is assumed to reduce the level of surface contamination on a component by one or two orders of magnitude. This is an average value based on experience and is used as a guide for estimating the time required to decontaminate a component to release levels.

4. Several small equipment items, such as wet-dry vacuum cleaners, power scrubbers, and steam generators, are used for decontaminating facility components. Because an equipment item is only used for a few days, it is not reasonable to charge its entire cost to the decommissioning of one component. To estimate equipment costs, a one-year

equipment lifetime is assumed and a charge of x/250 of the cost of the item is made, where x is the number of days required to decontaminate the component.

5. Radiation survey equipment and equipment for the analysis of wipe samples is assumed to be readily available and not chargeable to decommissioning because such equipment is in routine use during the operation of a facility.

6. All radioactive wastes from the decommissioning of facility components are shipped by truck a distance of 800 km to a shallow-land burial ground. Radioactive wastes from the decontamination option include solidified decontamination liquids, protective clothing, and cleaning supplies from decontamination operations. Radioactive wastes from the packaging and disposal option include the facility component. Transportation charges are based on the fraction of a truckload required to transport the wastes. It is assumed that one truckload consists of one hundred-twenty 208-ℓ steel drums or 30 m^3 of plywood boxes.

7. Because transport and waste disposal operations are contracted activities, manpower costs for the transportation and disposal of radioactive wastes are included in the total costs of these items.

8. The base-case scenario for determining the requirements and costs of packaging and disposal of contaminated facility components assumes that large components, such as fume hoods and glove boxes, are shipped intact with a minimum of sectioning. Volume reduction procedures such as compaction and incineration are not used. To provide a basis for cost comparisons, a second scenario is evaluated that assumes sectioning of the component and compaction or incineration of appropriate wastes. Compaction is estimated to reduce the waste volume by a factor of five. Incineration is assumed to reduce the waste volume by a factor of ten.

9. Cost estimates are based on unit costs for manpower, equipment, supplies, and waste management that are given in Appendix H.

For ease in evaluating time and manpower requirements of the decontamination option and the packaging and disposal option, each option is divided into a series of tasks or steps. The steps in the decontamination option are as follows:

- Remove equipment and material and perform initial radiation survey.
- Decontaminate component.
- Monitor for compliance with release limits.

- Reclean hot spots and monitor.
- Dispose of radioactive wastes.

The steps in the packaging and disposal option are as follows:

- Remove equipment and material and perform initial radiation survey.
- Remove loose contamination and fix residual contamination.
- Disconnect service lines and ductwork and prepare component for packaging.
- Package component.
- Ship packaged component to shallow-land burial ground.

F.1.1 Fume Hoods

Estimated costs for decommissioning a fume hood by the DECON options of 1) decontamination to unrestricted release levels or 2) packaging and disposal of the contaminated hood at an authorized disposal site are shown in Table F.1-2. Total costs include manpower, equipment and supplies, and waste management costs. Costs for the packaging and disposal option are shown for the case in which the hood is sectioned and other wastes are compacted or incinerated to reduce the volume of radioactive material shipped to a shallow-land burial ground.

Time and manpower requirements for the DECON of a fume hood are shown in Table F.1-3.

For the decontamination option, time and manpower requirements are based on reducing the levels of contamination in the fume hoods from residual levels to unrestricted release levels. These contamination levels are shown in Table F.1-4. Postulated decontamination procedures are listed in Table F.1-5. A decontamination step that reduces the surface contamination by a factor of about 100 is assumed to require three hours for completion for hoods contaminated with ^{3}H or ^{14}C. For hoods contaminated with ^{125}I of ^{137}Cs, a single decontamination step is assumed to reduce surface contamination by a factor of 50. For hoods contaminated with ^{241}Am, a single decontamination step is assumed to reduce surface contamination by a factor of 50 and to require six hours for completion. A work crew consisting of a foreman and two technicians is postulated to perform the work.

For the packaging and disposal option, the manpower requirements shown in Table F.1-3 include only those needed to prepare and package the hood for shipment to the shallow-land burial ground. Craftsmen (an electrician and a pipefitter) are added to the work crew on a temporary basis to disconnect services and prepare the hood for packaging.

TABLE F.1-2. Estimated Costs for DECON of a Fume Hood

Cost Item	Cost ($ thousands) for DECON of a Component Contaminated by ^{241}Am[(a)]
Decontamination	
Manpower	3.05
Equipment & Supplies	1.90
Waste Management	
Packaging	0.35
Transportation	0.09
Disposal	0.31
Subtotals	5.70
25% Contingency	1.43
Totals	7.13
Packaging & Disposal w/o Volume Reduction	
Manpower	2.28
Equipment & Supplies	1.38
Waste Management	
Packaging	0.61
Transportation	0.26
Disposal	5.67
Subtotals	5.67
25% Contingency	1.42
Totals	7.09

(a) Number of figures shown is for computational accuracy only.

Material costs for the decontamination option are assumed to include the costs of replacement filters. Waste management costs for this option include the costs of packaging, transportation, and disposal of the decontamination liquids and cleaning supplies used to clean the hoods to unrestricted release levels. Decontamination wastes are packaged in 208-ℓ steel drums and are postulated to include three drums of solid waste (including filters) and two drums of solidified liquid waste.

Waste management costs for the packaging and disposal option include the costs of disposal of the hood and of the roughing and HEPA filters and 1 m of

TABLE F.1-3. Details of Estimated Time and Manpower Requirements for DECON of a Fume Hood

DECON Option	Requirements for DECON of a Component Contaminated by ^{241}Am	
	Time (days)	Man-Days
Decontamination		
Remove Equipment & Survey Component	0.50	1.50
Decontaminate	3.00	9.00
Monitor	0.25	0.75
Reclean Hot Spots & Monitor	0.75	2.25
Subtotals	4.75	14.25
50% Ancillary Time	2.35	7.00
Totals	7.10	21.25
Packaging & Disposal w/o Volume Reduction		
Remove Equipment & Survey Component	0.50	1.50
Fix Contamination	1.50	4.50
Disconnect Services & Prepare for Packaging	0.50	2.50
Package Component	0.50	1.50
Subtotals	3.00	10.00
50% Ancillary Time	1.50	5.00
Totals	4.50	15.00

contaminated ventilation ductwork attached to the hood. The hood and associated items are wrapped in plastic and packaged for shipment in a plastic-lined plywood box. Decontamination wastes for this option include one 208-ℓ drum of solid waste and one drum of solidified liquid waste.

F.1.2 Glove Boxes

Estimated costs for decommissioning a glove box by the DECON options of 1) decontamination to unrestricted release levels or 2) packaging and disposal of the contaminated hood at an authorized disposal site are shown in Table F.1-6. Total costs include manpower, equipment and supplies, and waste

TABLE F.1-4. Comparison of Residual Contamination Levels on Fume Hoods with Allowable Contamination Limits for Unrestricted Release[a]

	Contaminant ^{241}Am
Residual Contamination[b] (d/m/100 cm^2	10^3 to 10^4
Release Level[c] (d/m/100 cm^2	2×10^1

(a) The numbers refer to removable contamination.
(b) From Chapter 5.
(c) Based on NRC guidelines for decontamination of facilities and equipment prior to release for unrestricted use (Reference 1).

TABLE F.1-5. Postulated Procedures for the Decontamination of Fume Hoods[a]

Decontamination Step	Contaminant ^{241}Am
Remove Contaminated Equipment	x
Initial Radiation Survey	x
Dry Vacuum	x
Sweep	
Mop	
Wet Wipe	x
Spray	
Steam Clean	
Wash	x
Scrub	
Scrape	
Strip Paint	
Final Radiation Survey	x
Reclean Hot Spots & Monitor	x

(a) An "x" indicates that the step is party of the decontamination procedure for a fume hood with the indicated contaminant.

TABLE F.1-6. Estimated Costs for DECON of a Glove Box

Cost Item	Cost ($ thousands) for DECON of a Component Contaminated by ^{241}Am[(a)]
Decontamination	
Manpower	2.18
Equipment & Supplies	1.65
Waste Management	
Packaging	0.25
Transportation	0.07
Disposal	0.25
Subtotals	4.40
25% Contingency	1.10
Totals	5.50
Packaging & Disposal w/o Volume Reduction	
Manpower	1.29
Equipment & Supplies	1.98
Waste Management	
Packaging	0.24
Transportation	0.06
Disposal	0.24
Subtotals	2.81
25% Contingency	1.40
Totals	4.21

(a) Number of figures shown is for computational accuracy only.
(b) There are no glove boxes in the reference ^{137}Cs laboratory facility.

management costs. Costs for the packaging and disposal option are shown for 1) the case in which the glove box is packaged without sectioning and 2) for the case in which the glove box is sectioned and other wastes are compacted or incinerated to reduce the volume of radioactive material shipped to a shallow-land burial ground.

Time and manpower requirements for the DECON of a glove box are shown in Table F.1-7.

TABLE F.1-7. Details of Estimated Time and Manpower Requirements for DECON of a Fume Hood

DECON Option	Requirements for DECON of a Component Contaminated by ^{241}Am	
	Time (days)	Man-Days
Decontamination		
Remove Equipment & Survey Component	0.50	1.00
Decontaminate	3.50	7.00
Monitor	0.25	0.50
Reclean Hot Spots & Monitor	0.75	1.50
Subtotals	5.00	10.00
50% Ancillary Time	2.50	5.00
Totals	7.50	15.00
Packaging & Disposal w/o Volume Reduction		
Remove Equipment & Survey Component	0.50	1.00
Fix Contamination	0.75	1.50
Disconnect Services & Prepare for Packaging	0.50	2.00
Package Component	0.50	1.50
Subtotals	2.25	6.00
50% Ancillary Time	1.12	3.00
Totals	3.37	9.00

For the decontamination option, time and manpower requirements are based on reducing the levels of contamination in the glove boxes from residual levels to unrestricted release levels. These contamination levels are shown in Table F.1-8. Postulated decontamination procedures are listed in Table F.1-9. A decontamination step that reduces the surface contamination by a factor of about 100 is assumed to require two hours for completion for glove boxes contaminated with ^{3}H or ^{14}C. For glove boxes contaminated with ^{125}I, a single decontamination step is assumed to reduce surface contamination by a factor of 50. For glove boxes contaminated with ^{241}Am, a single decontamination step is assumed to reduce surface contamination by about a factor of 50 and to require

TABLE F.1-8. Comparison of Residual Contamination Levels on Glove Boxes with Allowable Contamination Limits for Unrestricted Release[a]

	^{241}Am
Residual Contamination[b] (d/m/100 cm^2)	10^7 to 10^9
Release Level[c] (d/m/100 cm^2)	2×10^1

(a) The numbers refer to removable contamination.
(b) From Chapter 5.
(c) Based on NRC guidelines for decontamination of facilities and equipment prior to release for unrestricted use (Reference 1).

TABLE F.1-9. Postulated Procedures for the Decontamination of Glove Boxes[a]

Decontamination Step	^{241}Am
Remove Contaminated Equipment	x
Initial Radiation Survey	x
Dry Vacuum	x
Sweep	
Mop	
Wet Wipe	x
Spray	x
Steam Clean	
Wash	x
Scrub	
Scrape	
Strip Paint	
Final Radiation Survey	x
Reclean Hot Spots & Monitor	x

(a) An "x" indicates that the step is part of the decontamination procedure for a glove box with the indicated contamination.

four hours for completion. Re-cleaning of hot spots is assumed to require twice as much time for a glove box contaminated with ^{241}Am as is required for other glove boxes. A work crew consisting of a foreman and one technician is assumed to perform the work.

For the packaging and disposal option, the manpower requirements shown in Table F.1-7 include those needed to prepare and package the glove box for shipment. An electrician and a pipefitter are added to the work crew on a temporary basis to disconnect services and assist in preparing the glove box for packaging. A second technician is added to the work crew to assist in packaging the glove box.

Material costs for the decontamination option are assumed to include the costs of replacement filters and glove box gloves. Waste management costs for this option include the costs of packaging, transportation, and disposal of the decontamination liquids and cleaning supplies used to clean the glove boxes to unrestricted release levels. Decontamination wastes include three 208-ℓ drums of solid waste (including contaminated filters and glove box gloves) and one drum of solidified liquid waste.

Waste management costs for the packaging and disposal option include the costs of disposal of the glove box and of the roughing and HEPA filters and 1 m of contaminated ventilation ductwork attached to the box. The glove box and associated items are wrapped in plastic and packaged for shipment in a plastic-lined plywood box. Decontamination wastes for this option include one 208-ℓ drum of solid waste and one drum of solidified liquid waste.

F.1.3 Laboratory Workbenches

Estimated costs for decommissioning a laboratory workbench by the DECON options of 1) decontamination to unrestricted release levels or 2) packaging and disposal of the contaminated workbench are shown in Table F.1-10. Total costs include manpower, equipment and supplies, and waste management costs. The workbench is assumed to be 0.9 m high, 0.75 m wide, and 4.6 m long.

Time and manpower requirements for the DECON of a workbench are shown in Table F.1-11.

For the decontamination option, time and manpower requirements are based on reducing the levels of contamination on the bench top and other surfaces from residual levels to unrestricted release levels. These contamination levels are shown in Table F.1-12. Because bench tops are used mostly for the assembly of apparatus and the preparation of non-radioactive chemical componds, radioactive contamination is kept at low levels by routine monitoring and housekeeping procedures during the operation of the laboratory. Postulated decontamination procedures are listed in Table F.1-13. Decontamination is performed by a work crew consisting of one foreman and one technician.

TABLE F.1-10. Estimated Costs for DECON of a Laboratory Workbench

Cost Item	Cost ($ thousands) for DECON of a Component Contaminated by ^{241}Am[(a)]
Decontamination	
Manpower	0.48
Equipment & Supplies	0.74
Waste Management	
Packaging	0.17
Transportation	0.04
Disposal	0.17
Subtotals	1.60
25% Contingency	0.40
Totals	2.0
Packaging & Disposal	
Manpower	0.74
Equipment & Supplies	0.73
Waste Management	
Packaging	0.61
Transportation	0.30
Disposal	1.34
Subtotals	3.72
25% Contingency	0.93
Totals	4.6

(a) Number of figures shown is for computational accuracy only.

Cleaning supplies and contaminated liquids from the decontamination option are packaged for disposal in two 208-ℓ steel drums (one for cleaning supplies and one for solidified liquids).

For the packaging and disposal option, the manpower needed to prepare and package the bench for shipment to a shallow-land burial ground is shown in Table F.1-11. An electrician and a pipefitter are temporarily added to the work crew to disconnect services. A second technician is added to the work crew to assist in packaging the bench. The bench is cut into two sections, each 2.3 m long, for ease of packaging. It is then packaged in two large plywood boxes.

TABLE F.1-11. Details of Estimated Time and Manpower Requirements for DECON of a Laboratory Workbench

DECON Option	Requirements for DECON of a Component Contaminated by ^{241}Am Time (days)	Man-days
Decontamination		
Remove Equipment & Survey Component	0.26	0.50
Decontaminate	0.50	1.0
Monitor	0.13	0.25
Reclean Hot Spots & Monitor	0.25	0.50
Subtotals	1.14	2.25
50% Ancillary Time	0.57	1.13
Totals	1.7	3.4
Packaging & Disposal		
Remove Equipment & Survey Component	0.25	0.50
Fix Contamination	0.25	0.50
Disconnect Services & Prepare for Packaging	0.25	1.0
Package Component	0.50	1.50
Subtotals	1.25	3.5
50% Ancillary Time	0.63	1.75
Totals	1.9	5.25

TABLE F.1-12. Comparison of Residual Contamination Levels on Laboratory Workbenches with Allowable Contamination Limits for Unrestricted Release[(a)]

	^{241}Am
Residual Contamination[(b)] (d/m/100 cm^2)	10^1 to 2×10^2
Release Level[(c)] (d/m/100 cm^2)	2×10^1

(a) The numbers refer to removable contamination.
(b) From Chapter 5.
(c) Based on NRC guidelines for decontamination of facilities and equipment prior to release for unrestricted use (Reference 1).

TABLE F.1-13. Postulated Procedures for the Decontamination of Laboratory Workbenches[(a)]

Decontamination Step	^{241}Am
Remove Contaminated Equipment	
Initial Radiation Survey	x
Dry Vacuum	x
Sweep	
Mop	
Wet Wipe	x
Spray	
Steam Clean	
Wash	x
Scrub	x
Scrape	
Strip Paint[(b)]	x
Final Radiation Survey	x
Reclean Hot Spots & Monitor	x

(a) An "x" indicates that the step is part of the decontamination procedure for a laboratory work bench with the indicated contaminant.
(b) Paint stripping may be necessary to remove hot spots on painted bench tops.

F.1-4 Ventilation Ductwork

Dirt that accumulates on inside surfaces of ventilation ductwork makes decontamination very difficult. Therefore, the usual practice when decommissioning a laboratory in which radioactive materials have been processed is to package the ductwork for disposal at a shallow-land burial ground. Estimated costs for this DECON option are shown in Table F.1-14. the estimates are based on the packaging and disposal of 20 m of 0.20-m-diameter sheet metal ductwork plus 20 m of 0.25-m by 0.60-m rectangular sheet metal ductwork. Cost estimates are made for the case in which the ductwork is packaged without compaction and for the case in which the ductwork is compacted before being packaged for shipment.

TABLE F.1-14. Estimated Costs for DECON of Ventilation Ductwork

Cost Item	Cost ($ thousands) for DECON of a Component Contaminated by ^{241}Am[(a)]
Packaging & Disposal w/o Volume Reduction	
Manpower	1.91
Equipment & Supplies	0.94
Waste Management	
Packaging	0.66
Transportation	0.29
Disposal	1.26
Subtotals	5.06
25% Contingency	1.27
Totals	6.40

(a) Number of figures shown is for computational accuracy only.

Time and manpower requirements for the disassembly and packaging of the ductwork are shown in Table F.1-15. Levels of radioactive contamination on inside surfaces of the ductwork are shown in Table F.1-16.

A work crew that includes a foreman, a technician, and a sheet metal worker are postulated to section the ductwork and wrap each section in plastic. For the packaging step, a foreman and two technicians are required. For packaging without compaction, the ductwork is cut into sections 2 m long. Smaller sections, each 1 m long, are required if the ductwork is to be compacted prior

TABLE F.1-15. Details of Estimated Time and Manpower Requirements for DECON of Ventilation Ductwork

DECON Option	Requirements for DECON of a Component Contaminated by ^{241}Am	
	Time (days)	Man-Days
Packaging & Disposal w/o Volume Reduction		
Survey Ductwork	0.50	1.00
Fix Contamination	0.50	1.00
Section Ductwork	1.50	4.50
Package Ductwork	0.50	1.50
Subtotals	3.00	8.00
50% Ancillary Time	1.50	4.00
Totals	4.50	12.00

TABLE F.1-16. Comparison of Residual Contamination Levels on Ventilation Ductwork with Allowable Contamination Limits for Unrestricted Release[(a)]

	^{241}Am
Residual Contamination[(b)] (d/m/100 cm^2	10^1 to 10^3
Release Level[(c)] (d/m/100 cm^2	2×10^1

(a) The numbers refer to removable contamination.
(b) From Chapter 5.
(c) Based on NRC guidelines for decontamination of facilities and equipment prior to release for unrestricted use (Reference 1).

to packaging. To estimate the time requirements for cutting the ductwork, it is postulated that each cut requires approximately 20 minutes.

F.1-5. Building Surfaces

Building surfaces include walls and floors. Decontamination to unrestricted release levels is the DECON option evaluated for these surfaces. Some

contaminated material, such as floor tiles or concrete chipped from walls, might be packaged and shipped to a shallow-land burial ground.

The reference laboratories assumed for these decommissioning cost evaluations measure 6 m by 10 m, with walls 3 m high. Building materials used in individual laboratories are specified in the laboratory descriptions of Chapter 5.

Walls

Estimated costs for decontamination of the walls of the reference laboratories to unrestricted release levels are shown in Table F.1-17. Total costs include manpower, equipment and supplies, and waste management costs.

TABLE F.1-17. Estimated Costs for DECON of Walls

Cost Item	Cost ($ thousands) for DECON of a Component Contaminated by ^{241}Am(a)
Decontamination	
Manpower	6.02
Equipment & Supplies	4.31
Waste Management	
Packaging	2.10
Transportation	0.39
Disposal	1.44
Subtotals	14.26
25% Contingency	3.56
Totals	17.8

(a) Number of figures shown is for computational accuracy only.

Time and manpower requirements for wall decontamination are shown in Table F.1-18. these requirements are based on reducing the levels of contamination from residual levels to unrestricted release levels. These contamination levels are shown in Table F.1-19. Postulated decontamination procedures are listed in Table F.1-20.

The decontamination work crew includes a foreman and two technicians. Decontamination of walls by steam cleaning is estimated to require less time than decontamination by washing and scrubbing. Surfaces covered with epoxy or acrylic paint require less re-cleaning of hot spots than do surfaces covered with latex enamel paint.

TABLE F.1-18. Details of Estimated Time and Manpower Requirements for DECON of Walls

DECON Option	Requirements for DECON of a Component Contaminated by ^{241}Am	
	Time (days)	Man-Days
Decontamination		
Initial Survey	0.50	1.50
Decontaminate	5.00	18.00
Monitor	1.50	4.50
Reclean Hot Spots & Monitor	1.50	4.50
Subtotals	9.50	28.50
50% Ancillary Time	4.75	14.25
Totals	14.20	42.70

TABLE F.1-19. Comparison of Residual Contamination Levels on Walls with Allowable Contamination Limits for Unrestricted Release[a]

	^{241}Am
Residual Contamination[b] (d/m/100 cm^2	10^1 to 10^2
Release Level[c] (d/m/100 cm^2	2×10^1

(a) The numbers refer to removable contamination.
(b) From Chapter 5.
(c) Based on NRC guidelines for decontamination of facilities and equipment prior to release for unrestricted use (Reference 1).

Wastes generated during decontamination operations include eight drums of solid waste (rags, brushes, contaminated clothing, etc.) and 16 drums of solidified liquid waste. Liquid wastes from steam cleaning operations are solidified with cement and packaged in 208-ℓ drums.

TABLE F.1-20. Postulated Procedures for the Decontamination of Walls[(a)]

Decontamination Step	^{241}Am
Remove Contaminated Equipment	
Initial Radiation Survey	x
Dry Vacuum	
Sweep	
Mop	
Wet Wipe	x
Spray	
Steam Clean	
Wash	x
Scrub	
Scrape	
Strip Paint	
Final Radiation Survey	x
Reclean Hot Spots & Monitor	x

(a) An "x" indicates that the step is part of the decontamination procedure for a wall with the indicated contaminant.

Liquid wastes from cleaning operations that are organic decontamination solutions are adsorbed on diatomaceous earth or some other adsorbent contained in 113-ℓ drums. The 113-ℓ drums are then overpacked in 208-ℓ drums. Therefore, waste packaging costs for operations that utilize organic decontaminants are greater than those for operations that use steam cleaning.

Floors

Estimated costs for decontaminating the floors of the reference laboratories to unrestricted release levels are shown in Table F.1-21. Total costs include manpower, equipment and supplies, and waste management costs.

Time and manpower requirements for floor decontamination are shown in Table F.1-22. These requirements are based on reducing the levels of contamination from residual levels to unrestricted release levels. These contamination levels are shown in Table F.1-23. Postulated decontamination procedures are listed in Table F.1-24.

TABLE F.1-21. Estimated Costs for DECON of Floors

Cost Item	Cost ($ thousands) for DECON of a Component Contaminated by ^{241}Am (a)
Decontamination	
Manpower	2.30
Equipment & Supplies	2.16
Waste Management	
Packaging	1.40
Transportation	0.27
Disposal	0.95
Subtotals	7.08
25% Contingency	1.77
Totals	8.8

(a) Number of figures shown is for computational accuracy only.

TABLE F.1-22. Details of Estimated Time and Manpower Requirements for DECON of Floors

DECON Option	Requirements for DECON of a Component Contaminated by ^{241}Am	
	Time (days)	Man-Days
Decontamination		
Remove Equipment & Survey Component	0.25	0.75
Decontaminate	2.0	6.0
Monitor	0.50	1.50
Reclean Hot Spots & Monitor	0.50	1.50
Subtotals	3.25	9.75
50% Ancillary Time	1.63	4.88
Totals	4.9	14.6

TABLE F.1-23. Comparison of Residual Contamination Levels on Floors with Allowable Contamination Limits for Unrestricted Release[a]

	^{241}Am
Residual Contamination[b] (d/m/100 cm^2	10^3 to 10^4
Release Level[c]	2×10^1

(a) The numbers refer to removable contamination.
(b) From Chapter 5.
(c) Based on NRC guidelines for decontamination of facilities and equipment prior to release for unrestricted use (Reference 1).

TABLE F.1-24. Postulated Procedures for the Decontamination of Floors[a]

Decontamination Step	^{241}Am
Remove Contaminated Equipment	
Initial Radiation Survey	x
Dry Vacuum	x
Sweep	
Mop	x
Wet Wipe	
Spray	
Steam Clean	
Wash	
Scrub	x
Scrape	
Strip Paint	
Final Radiation Survey	x
Reclean Hot Spots & Monitor	x
Remove Contaminated Tile	

(a) An "x" indicates that the step is part of the decontamination procedure for a wall with the indicated contaminant.

The decontamination work crew includes a foreman and two technicians. With the exception of the floor in the ^{241}Am laboratory, all of the floors are covered with asphalt tile. The floor in the ^{241}Am laboratory is covered with linoleum with heat-treated semas. Because the linoleum is free from cracks, it is easier to decontaminate and requires less re-cleaning than do the asphalt tile floors.

Wastes generated during decontamination operations include four drums of solid waste and eight drums of solidified liquids.

F.2 DETAILS OF DECOMMISSIONING THE REFERENCE LABORATORY FOR THE MANUFACTURE OF ^{241}AM SEALED SOURCES

The reference laboratory for the manufacture of ^{241}Am sealed sources is described in Chapter 5. The DECON options postulated for the contaminated components and building surfaces of this laboratory are shown in Table F.2-1.

TABLE F.2-1. DECON Options for Facility Components in the Reference Laboratory for the Manufacture of ^{241}Am Sealed Sources[a]

	DECON Option	
Facility Component	Clean to Unrestricted Release Levels	Dismantle and Package for Disposal
Fume Hoods	X	
Glove Boxes[b]	X	X
Laboratory Benches	X	
Other Components		
Transfer Tunnels[c]		X
Filters		X
Ventilation Ductwork		X
Ceiling	X	
Walls	X	
Floor	X	

(a) An "X" indicates that the facility component is decommissioned by the indicated options.
(b) One glove box is cleaned to unrestricted release levels. The remaining six glove boxes are decontaminated to acceptance levels for shallow-land burial and are then packaged for disposal.
(c) Transfer tunnels are decontaminated to acceptance levels for shallow-land burial and are then packaged for disposal.

These DECON options provide a basis for estimating the manpower and waste management requirements and costs of decommissioning the laboratory.

The locations of fume hoods and glove boxes in the reference ^{241}Am laboratory are shown schematically in Chapter 5. The fume hoods and the glove box in the low-level alpha lab are postulated to be decontaminated to unrestricted release levels. The glove boxes and transfer tunnels in the high-level alpha lab are decontaminated to remove loose or lightly held contamination and to reduce total transuranic contamination to acceptable levels for shallow-land burial of these components. These glove boxes and transfer funnels are then packaged and shipped to a shallow-land burial site for disposal. Laboratory benches are decontaminated to unrestricted release levels. Ventilation ductwork is sectioned and packaged for disposal. HEPA and roughing filters are packaged for disposal. The ceiling, walls, and floor of the laboratory are decontaminated to unrestricted release levels.

Details of estimated manpower requirements and costs for DECON of the reference ^{241}Am laboratory are shown in Table F.2-2. Manpower costs for planning and preparation are estimated to account for about 22% of the total decommissioning manpower costs. Manpower costs for the final radiation survey are estimated to account for about 6% of the total manpower costs.

Details of estimated waste management requirements and costs for DECON of the reference ^{241}Am laboratory are shown in Table F.2-3. A total volume of 54.5 m^3 of contaminated components, equipment, and cleaning supplies is postulated to be packaged in 15 plywood boxes and in one hundred eighty-five 208-ℓ steel drums and to be shipped to a shallow-land burial site for disposal. All of the decontamination liquids are organic liquids that are absorbed on diatomaceous earth and packaged in 113-ℓ drums before being overpacked in 208-ℓ drums.

TABLE F.2-2. Details of Estimated Manpower Requirements and Costs for DECON of the Reference Laboratory for the Manufacture of ^{137}Cs Sealed Sources

Operation	Time (days)[(a)]	Worker Man-Days: Supervisor	Foreman	Craftsman	H. P. Technician	Technician	Secretary	Total Man-Days	Manpower Costs ($ thousands)[(b)]
Planning and Preparation									
Prepare Documentation	15	7.5	15	--	--	--	7.5	30	5.39
Preform Radiological Survey	4.5	--	4.5	--	9	00	00	13.5	2.08
Develop Work Plan	10	5	10	00	5	00	5	25	4.29
Subtotals	29.5	12.5	29.5	00	14	--	12.5	68.5	11.76
Decommissioning									
Fume Hoods	9.6	4.8	9.6	00	4.8	28.8	--	48	7.71
Glove Boxes	21.6	10.6	21.1	14.1	10.6	63.4	--	120	19.14
Laboratory Benches	0.8	0.37	0.7	--	0.37	2.2	--	3.7	0.59
Ductwork	2	1	2	2	1	6	--	12	1.91
Other Components	2	1	2	--	1	6	--	10	1.61
Ceiling	8.1	4.1	8.2	--	4.1	24.7	--	41	6.59
Walls	16.2	8.1	16.2	--	8.1	48.6	--	81	13.00
Floor	2.7	1.6	3.2	--	1.6	9.6	--	16	9.6
Subtotals	63.0	31.6	63	16.1	31.6	189.3	--	331.7	60.15
Final Radiological Survey	5	2.5	5	--	10	--	5	22.5	3.48
25% Cost Contingency	--	--	--	--	--	--	--	--	15.91
Totals	98	47	98	16	56	189	18	423	91.3

(a) 50% ancillary time is included in estimates of decommissioning times.
(b) Costs are in 1981 dollars. Number of cost figures shown is for computational accuracy only.

TABLE F.2-3. Details of Waste Management Requirements and Costs for DECON of the Reference Laboratory for the Manufacture of ^{241}Am Sealed Sources

Waste Category	Container Type	Number of Containers	Shipping Volume (m^3)	Disposable Container Cost[a] ($)	Transportation Cost[a] ($)	Burial Cost[a] ($)	Total Waste Management Cost ($)[a]
Components and Equipment	Plywood Box	10	5.0	520	262	1 160	1 942
Ventilation Ductwork	Plywood Box	5	5.0	520	262	1 160	1 942
HEPA and Roughing Filters	Steel Drum 208-ℓ	3	0.63	104	38	148	290
Solidified Decontamination Liquids	Steel Drum 208-ℓ	110	23.1	9 900	1 440	5 375	16 715
Trash	Steel Drum 208-ℓ	72	15.12	2 490	942	3 520	6 952
Cost Subtotals				13 500	2 944	11 363	27 841
25% Contingency							6 960
Totals		15 Boxes 185 Drums	54.42				34 800

(a) Costs are in 1981 dollars. Number of significant figures shown is for computational accuracy only.

REFERENCES

1. Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use of Termination of Licenses for Byproduct, Source, or Special Nuclear Material, U.S. Nuclear Regulatory Commission, Washington, D.C., November 1976.

APPENDIX G

DETAILS OF ORE PROCESSING SITE CLEANUP AND DECOMMISSIONING

APPENDIX G

DETAILS OF ORE PROCESSING SITE CLEANUP AND DECOMMISSIONING

This appendix provides details to support the description of the decommissioning of the ore processing site following an accident presented in Chapter 11. The reference site is described in Section 5.5.

The decommissioning alternatives for contaminated sites are 1) site stabilization followed by long-term care, and 2) removal of the contaminated material to an approved shallow-land burial ground. Details of the technology and costs of these two alternatives are given in another report on the technology, safety, and costs of decommissioning a low-level waste burial ground.(1) For convenience of reference, brief descriptions of several site stabilization options are given in Section G.1.

The following key bases and assumptions are used for estimating manpower requirements and costs:

1. The decommissioning of a site is performed by a contractor hired by the owner/operator of the site. Separate contractors might be hired for the site survey and for the actual decommissioning operations. (In some instances, the owner/operator would perform his own site survey.)

2. To determine the total time required to decommission a radioactively contaminated site, an estimate is made of the time required for efficient performance of the work by a postulated work crew. This time estimate is then increased by 50% to provide for preparation and set-up time, rest periods, etc.

3. All radioactive wastes from the decommissioning of contaminated sites are shipped by truck a distance of 800 km to a shallow-land burial ground.

4. Transportation and waste disposal operations are subcontracted activities. The manpower costs for the transportation and disposal of radioactive material are included in the total costs of these items.

5. Decommissioning includes the backfilling of a site from which wastes have been exhumed and the restoration of the decommissioned site by grading the site and/or planting grass or other appropriate vegetative cover. Costs of backfilling and site restoration are included in the costs of decommissioning.

6. If a site is to be released for unrestricted public use, the final decommissioning activity is a site survey to verify that residual levels of radioactivity are below unrestricted release limits. Costs of this final radiation survey are included in the estimated costs of decommissioning.

For ease in evaluating time and manpower requirements for the decommissioning of sites, each decommissioning alternative is divided into a sequence of tasks or steps. For the site stabilization alternative, the steps are listed below:

- planning and preparation (including initial site survey)
- mobilization/demobilization
- site stabilization
- revegetation.

For the removal alternative, the steps are as follows:

- planning and preparation (including initial site survey)
- mobilization/demobilization
- removal of overburden
- exhumation and packaging of contaminated material
- transportation and disposal of contaminated material at a shallow-land burial ground
- backfill and restoration of site
- final site survey.

G.1 SITE STABILIZATION DETAILS

Various stabilization techniques can be used to reduce the potential for radionuclide migration from the sites analyzed in this study. Some stabilization techniques are described in this section:

- soil cover
- hard cover
- rock cover
- site topography adjustment
- improved drainage
- revegetation
- leachability reduction.

A more complete description of site stabilization techniques is given in Reference 1.

G.1.1 Soil Cover

A layer of soil (backfill) can be added to a contaminated site to provide a cover over the radioactive material. The backfill used is generally selected to provide a suitable base for subsequent revegetation of the area. The material is hauled in, dumped, and graded to form a layer of uniform specified depth. Standard earthmoving techniques are used. The soil is then compacted either by packing the area using heavy rolling equipment (e.g., a sheepsfoot roller,[a] wobbly-wheel roller,[b] or road roller) or by vibrating the earth with a vibrating baseplate compactor. Other measures can be taken to aid in compaction, the most common being the use of water sprays to wet the soil. Little or no surface preparation is needed prior to backfilling and compaction of an area, although removal of vegetation and debris is desirable. Reference 2 provides a detailed treatment of fill compaction.

The new surface can be graded to preserve the original site contours, or new contours can be established. Site contours are chosen to control the drainage from the area and to reduce the potential for the accumulation of water on the surface. After completion of the contouring operation, the surface is revegetated or otherwise stabilized.

Backfilling and compaction can be used as a control measure against subsidence. Backfill returns the surface to its original level, and compaction reduces the extent of subsidence that might be caused by future settling.

The addition of a layer of soil can reduce the background radiation level existing on the site from contaminated surface soil or from tailings dumped on the ground. The thickness of backfill required depends on the level of surface contamination and the radionuclides involved. Generally, a soil thickness of 0.3 m to 3.0 m is required.

G.1.2 Hard Cover

A hard cover may be composed of any of a variety of materials, including concrete, asphalt, asphalt-soil, soil cement, bentonite[3] or other clays, and other mineral or chemical materials. The thickness of the layer is dependent on the material used and on the structural strength desired, but is generally in the range of 20 to 200 mm.[4]

(a) A sheepsfoot roller is a cylindrical steel drum to which knob-headed spikes are fastened.
(b) A wobbly-wheel roller is a roller with freely suspended pneumatic tires.

Prior to emplacement of a hard cover, the surface should be prepared by the removal of vegetation and by grading and/or compacting the surface. Provision should be made for drainage of rainwater and snowmelt from the surface. The hardcover may be placed directly on the ground surface after site preparation, it may be placed as a stabilizing agent over a layer of backfill, or it may be covered with a layer of topsoil. When bentonite or asphalt is used, a protective cover of soil is often added to reduce the rate of cracking and deterioration of the hard layer, thereby reducing annual maintenance costs.

The hard layer provides a physical barrier to digging and burrowing animals, human penetration, and plant-root penetration by presenting a relatively impenetrable layer in the soil profile. It also serves to limit erosive action and can reduce the percolation of water into the soil.

To maintain the effectiveness of a surface hard layer, a certain amount of upkeep is necessary. Cracks and other damage to the layer must be repaired. Without this upkeep, the effectiveness of the layer is severely reduced, particularly in preventing water percolation.

G.1.3 Rock Cover

A rock layer[4] may be placed on the surface of a site as ground cover, or it may be a subsurface layer covered by a blanket of topsoil.

A surface rock layer is composed of rocks or large gravel. It is placed directly on the surface to a depth of 0.15 m to 0.4 m after a minimum of ground surface preparation (leveling and removal of vegetation and debris). The surface of the rock is leveled to obtain a layer of uniform specified depth.

A subsurface rock layer is a thick blanket of rock placed in the soil profile. It is topped with a material to prevent soil from sifting down into the void spaces between the rocks. The rock layer is then covered with topsoil to provide a base for surface stabilization. The layer is composed of rock or cobbles at least 40 mm in diameter, placed to a thickness of 0.3 m to 1.0 m. Plastic or other composite sheeting, layers of progressively smaller gravel or rock chips, or a polymeric or asphaltic sealer can be used to prevent topsoil from sifting down between the rocks.

A rock layer provides protection against erosive action by presenting a relatively erosion-resistant surface. Animal burrowing is restricted by the difficulty of digging through the layer. The layer also acts as a deterrent to inadvertent human excavation. The barrier protects against penetration by plant roots, because of the hostile environment present to the roots by the rocks and the void spaces between them. Thus, agriculture is essentially eliminated by a surface rock cover. However, shallow-rooted vegetation can be planted in the soil that covers a subsurface rock layer.

G.1.4 Site Topography Adjustment

Site topography adjustment is the grading, scraping, or other movement of surface soils to alter site contours. Site topography is adjusted using standard earthmoving and surface contouring techniques. After completion of the contouring operation, the surface is stabilized as desired, using one of the surface stabilization techniques described in this section.

Adjustment of site topography can be very effective in reducing radionuclide migration. Topography is a factor in both wind and water erosion, and adjustment therefore provides a method of reducing erosion damage. The alteration of site contours is a means of controlling runoff from rainfall and snowmelt, and therefore is useful in adjusting the hydrological parameters of a site.

G.1.5 Improved Drainage

In addition to being adjusted by the alteration of site contours, site drainage can be improved by the construction of an engineered drainage system to route runoff from incident precipitation away from the site. A drainage system is designed and installed after a civil survey of the site and an analysis of the drainage requirements. Runoff from rainwater and snowmelt is channeled away from the site by a system of pipes and/or trenches. Surface waters are drained, if desired, in the same manner. Pipes and trenches can be sealed, where necessary, to prevent leakage that can percolate into the soil. The drainage system is installed using standard construction techniques.

A peripheral drainage and diversion system can also be designed for the interception and diversion of surface and/or ground waters either at the site boundaries or outside the site. Some techniques for peripheral drainage and diversion are described in Reference 5. Ditches for the drainage of surface water can be lined to prevent leakage if desired, but ditches used to intercept groundwater are unlined to allow the water to seep into the ditch. The ditch banks are stabilized using one of the surface stabilization techniques discussed in this section.

Improved site drainage prevents the accumulation of water on the surface of the site, and reduces the percolation of moisture into the soil. Surface water runoff from onsite is improved, and surface runoff from offsite is intercepted and diverted away from the site. By reducing the potential for overflow seepage, the local level of the water table can be reduced in areas where percolation significantly influences the groundwater flow. Groundwater can also be intercepted, thus reducing the potential for water intrusion into radioactive material buried on the site.

G.1.6 Revegetation

Revegetation is the establishment of a vegetative ground cover on a site where the surface has been disturbed. A variety of vegetation types and species can be used, depending on soil and climate conditions and also on the results desired. Shallow-rooted plants are preferred in order to limit root penetration into buried radioactive material.

Before revegetation begins, soil tests are made at the site to determine the plant species to be used and the nutrient balance in the soil. After the surface to be revegetated is graded or leveled as desired and cleared of debris, the area is planted with selected vegetation species. Use of fertilizers and soil amendments to improve soil texture and nutrient balance is common, as is the use of mulches and/or chemical stabilizers to conserve moisture and protect the surface until the vegetation becomes established.

A vegetated surface must be managed to ensure the continued viability of the vegetative community and to provide remedial measures for incidental problems. A vegetation management program can include, but is not limited to, the following elements: herbicides, acting at the surface and/or subsurface to control undesirable plant growth and to limit plant-root penetration; use of competing plant species to control growth of undesirable species; periodic clearing of undesirable vegetation from the site; use of bacterial and/or insect controls to limit the growth of undesirable species; and replanting of areas damaged by erosion, pests, or human activities.

Revegetation can be used to control wind and water erosion of the ground surface.[6,7] It also affects the site moisture balance by reducing runoff and increasing moisture return to the atmosphere through evapotranspiration. Revegetation may, in some cases, reduce mass wasting by anchoring the soil. One possible disadvantage of revegetation is that plant roots may penetrate areas where radioactivity is located.

The erosion protection afforded a site by a vegetation cover increases as the plant community becomes more established. This results in a gradual improvement of the site over several years, until the plant community reaches maturity.

G.1.7 Leachability Reduction

Leachability reduction involves the injection of suitable material into the buried radioactive material (e.g., a tailings pile) to chemically and/or physically bond the radionuclides into a stable mass, thus reducing leaching. The technique involves the injection of grout material into the radioactive waste and the surrounding soil. Possible grouting materials include cement, clays, asphalts, bitumens, silicates, lignochromes, lignosulfates, epoxy

resins, acrylamide, polyester resins, polyphenolics, resorcinolformaldehyde, and other chemical polymers.[4] These materials are injected by pumping them through distribution pipes driven into the soil or tailings pile. Injection techniques are described in Reference 8.

By reducing waste leachability, radionuclide releases caused by hydrological action are decreased by limiting or eliminating dissolution of the radionuclides. Grouting to reduce leachability is a relatively expensive operation with costs ranging as high as $\$350/m^3$.[4] A useful life of 25 to 100 years is anticipated for the technique, assuming no regular maintenance.

G.2 DETAILS OF DECOMMISSIONING A TAILINGS PILE

Time and manpower requirements and total costs for decommissioning a tailings pile following an accident by the alternatives of 1) stabilization of the pile or 2)removal of the pile are evaluated in this section. Annual requirements and costs of long-term care following pile stabilization are also evaluated.

The tailings pile is described in Section 5.5. It is actually a settling pond that contains the residue from ore refinery operations in which tin slag is processed for the recovery of niobium and tantalum. The residue from these operations contains 0.2 wt% U_3O_8 and 0.5 wt% ThO_2. The pond measures 100 m long by 50 m wide by 5 m deep with a slope of 2.5 to 1 on each side. It contains 16,400 m^3 of glassy residue weighing 4.1 x 107 kg.

G.2.1 Decommissioning Procedures

Decommissioning begins with planning and preparation activities that include a radiological survey of the site, the preparation of documentation describing anticipated environmental effects of proposed decommissioning procedures, and the formulation of written work procedures.

The initial radiological survey provides data to guide the planning of decommissioning operations. The survey includes the following measurements:

- measurements of external gamma radiation levels at 1 m above the ground surface on the pile and on the site
- surface soil samples at several onsite locations
- measurements of the rate of radon emanation from the pile
- measurements of the concentrations of radon and daughters in air on the site

- measurements of gamma radiation at various depths in core holes drilled into the soil near the edge of the pile

- subsurface soil samples obtained from these core holes.

Equipment and techniques for making radiological measurements at a site are described in Section 10.1.1. At the reference site, ten cores are drilled to a depth of eight meters. Three soil samples are obtained from each core. The samples are sent to a commercial laboratory for analysis of 226Ra, 232Th, and 238U concentrations.

Site Stabilization Alternative

Several site stabilization techniques are described in Section G.1. To provide an example of the costs of stabilization, the following set of techniques is assumed for stabilization of the reference tailings pile. The pile is covered with a layer of asphalt 50 mm thick. This asphalt layer is then covered with 1 m of soil. The soil is mounded slightly at the center of the pile to allow water to drain from the soil cover and to prevent the accumulation of runoff from rainfall or snowmelt. After compaction and contouring of the soil cover, the area is seeded with grass.

Long-term care activities following stabilization include administrative control, site maintenance, environmental monitoring, and vegetation management.

Removal Alternative

Removal of the pile is accomplished by using conventional earthmoving equipment. Bulldozers and front-end loaders are used to break up the pile and transfer the residue to plastic-lined plywood boxes for shipment to a shallow-land burial ground. A layer of potentially contaminated soil 0.6 m thick is also removed from beneath the settling pond and around the edges of the hole. Some manual excavation work is required for the removal of spots of low-level contamination.

The site is restored by backfilling with soil. After the fill soil is compacted and graded, grass is planted on the site. A final site survey is performed to verify that levels of radioactivity remaining on the site are less than limits prescribed for unrestricted release.

G.2.2 Manpower and Cost Details

Details of estimated manpower requirements for decommissioning a tailings pile are presented in Table G.2-1. Cost details are presented in Table G.2-2.

TABLE G.2-1. Details of Estimated Time and Manpower Requirements for Decommissioning a Tailings Pile

Operation	Time (Days)[a]	Worker Man-Days: Supervisor[b]	Foreman	Equipment Operator	Truck Driver	Health Physics Technician	Laborer	Secretary	Total Man-Days	Manpower Costs ($ thousands)[c,d]
Site Stabilization Option										
Planning and Preparation	20	20	20	--	--	10	--	20	70	9.81
Mobilize/Demobilize	2	1	2	4	--	--	4	--	11	1.90
Placement of Asphalt Layer	2	1	2	4	--	2	4	--	13	2.10
Placement of Soil Cover	6	3	6	12	40	2	12	--	75	11.71
Revegetation	2	1	--	2	--		2	--	5	0.88
Totals	32	26	30	22	40	14	22	20	174	26.40
Long-Term Care (Annual Values)										
Administration	2	2	--	--	--	--	--	2	4	0.51
Site Maintenance	3	--	3	3	--	--	3	--	9	1.10
Environmental Surveillance	1	--	--	--	--	2	--	--	2	0.20
Vegetation Management	4	--	4	--	--	--	8	--	12	1.36
Totals	10	2	7	3		2	11	2	27	3.17
Removal Option										
Planning and Preparation	20	20	20	--	--	10	--	20	70	9.81
Mobilize/Demobilize	4	2	4	24	--	--	24	--	54	9.07
Exhume and Package Tailings	90	45	90	540	--	90	540	--	1 305	213.16
Backfill and Restore Site	20	10	20	40	100	--	40	--	210	33.54
Final Site Survey	5	3	5	--	--	10	--	--	18	2.45
Totals	139	80	139	604	100	110	604	20	1 657	268.03

(a) 50% ancillary time is included in estimates.
(b) Charged half-time to project.
(c) Costs are in 1978 dollars. Number of cost figures shown is for computational accuracy only.
(d) 25% contingency not included.

TABLE G.2-2. Cost Details for Decommissioning a Tailings Pile

Cost Item	Cost ($ thousands)[a] Site Stabilization	Long-Term Care (Annual Costs)	Pile Removal
Manpower	26.4	3.2	268.0
Equipment	19.2	1.0	104.4
Material	66.6	0.5	46.2
Soil Analyses	5.0	1.0	7.0
Contractors Fee[b]	8.3	--	157.4
Waste Management			
Packaging	--	--	1568.9
Transportation	--	--	1295.0
Disposal	--	--	3258.7
Subtotals	125.4	5.7	6705.6
25% Contingency	31.3	1.4	1676.4
TOTALS	157.0	7.0	8382.0

(a) Costs are in 1981 dollars. Number of figures shown is for computational accuracy only.
(b) Based on 8% of the sum of contractor's charges for manpower, equipment, and materials.

Site Stabilization Alternative

The asphalt for the hard cover over the tailings pile is delivered to the site in tanker trucks. It is then transferred to a self-propelled soil stabilizer for application to the surface of the pile. The asphalt is applied at an assumed rate of 50 ℓ/m2. Two days are required to complete this operation, which is performed by a work crew consisting of a foreman, two equipment operators, and two laborers.

The soil used as backfill over the hard cover is hauled to the site in 10 m^3 dump trucks. Approximately 5600 m^3 of soil is required. After the soil is in place, it is graded to the specified contours and compacted with a roller. Six days are required to complete this operation, which is performed by a work crew that includes a foreman, two equipment operators, eight truck drivers, and two laborers.

After the soil cover over the tailings pile is compacted and contours are established, the area is planted with grass. Two equipment operators and two laborers perform this operation.

The total cost of site stabilization is estimated to be about $157,000. More than half of this cost is for the asphalt and the soil used to establish the cover over the tailings pile.

The total annual cost of long-term care is estimated to be about $7,000. Manpower costs represent almost 60% of this cost.

Removal Alternative

Two work crews, working at opposite ends of the pile, are employed to remove and package the residue from the tailings pile. Each crew includes three equipment operators and three laborers. A foreman supervises the work, and a health physics technician assists the crews. Bulldozers and front-end loaders are used to break up the residue and load it into 1.2 m-by-1.2 m-by-2.4 m (3.4 m^3) plastic-lined, plywood boxes for shipment to the shallow-land burial ground. Approximately 5,700 boxes are required for the 19,400 m^3 of tailings residue and contaminated soil removed from the site. The boxes are shipped by truck to the burial ground. Shipments are weight-limited and restricted to five boxes per flat-bed trailer. Therefore, 1140 shipments must be made to decommission the site.

After the contaminated material is removed, soil is brought from offsite in 20-m^3-capacity scraper-haulers to fill the hole. The site is then graded and seeded with grass.

Approximately 114 work days (23 weeks) are required to remove the contaminated material and restore the site.

The total cost of the removal option is estimated to be almost $8.4 million. Most of this cost (approximately 91%) is associated with the packaging, transportation, and disposal of the exhumed material. The waste management costs could be reduced by about $1.5 million if the contaminated material was transported to the shallow-land burial ground in plastic-lined, 10-m^3-capacity dump trucks instead of being packaged in plywood boxes.

REFERENCES

1. E.S. Murphy and G.M. Holter, Technology, Safety and Costs of Decommissioning a Reference Low-Level Waste Burial Ground, NUREG/CR-0570, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, June 1980.

2. R.L. Soderberg and R.A. Busch, Design Guide for Metal and Nonmetal Tailings Disposal, IC-8755, pp. 60-63, U.S. Department of the Interior, Bureau of Mines, 1977.

3. R.H. Hawkins, and J.H. Horton. "Bentonite as a Protective Cover for Buried Radioactive Waste," Health Physics, Vol. 13, pp. 287-292, 1967.

4. Study of Engineering and Water Management Practices that will Minimize the Infiltration of Precipitation into Trenches Containing Radioactive Waste, ORP LV-78-5, SCS Engineers for U.S. Environmental Protection Agency, June 1978.

5. J.O. Duguid, Annual Progress Report of Burial Ground Studies at Oak Ridge National Laboratory: Period Ending September 30, 1975, ORNL-5141, pp. 37-39, Oak Ridge National Laboratory, Oak Ridge, Tennessee, October 1976.

6. K.C. Dean, R. Havens, and M.W. Glantz, Methods and Costs of Stabilizing Fine-Sizes Mineral Wastes, RI-7896, pp. 7-13, U.S. Department of the Interior, Bureau of Mines, 1974.

7. R.P. Donovan, R.M. Felder, and H.H. Rogers, Vegetative Stabilization of Mineral Waste Heaps, EPA-600/2-76-087, Research Triangle Institute for U.S. Environmental Protection Agency, April 1976.

8. R. Bowen, Grouting in Engineering Practice, Applied Science Publishers, Ltd., London, England, 1975.

APPENDIX H

COST-ESTIMATING BASES

APPENDIX H

COST-ESTIMATING BASES

Cost data are presented that can be used to develop cost estimates for accident cleanup and for decommissioning. Categories for which basic cost data are presented include labor, waste packaging, transportation, waste disposal, and equipment and supplies. The data presented are all early-1981 costs, whereas earlier decommissioning studies in this series used a 1978 cost base. The cost updating in this study is consistent with that performed previously in Reference 1.

H.1 LABOR COSTS

Labor cost data for typical accident cleanup and decommissioning staff positions are given in Table H.1-1. both owner/operator staff and contractor staff are included. The 1978 data base used in earlier decommissioning studies and referenced in the table has been adjusted by a factor of 1.2, based on building trades labor cost trends reported in the Handy-Whitman Index.(2) The base pay rates for owner/operator staff in Table H.1-1 are increased by 70% for nonunion employees and by 50% for union employees to account for owner costs such as fringe benefits, taxes, and insurance. An overhead rate of 110% is applied to contractor staff positions to account for anticipated additional expenses.

The labor costs shown are representative of average labor costs rather than labor costs for a particular decommissioning project at a given location. A recent decommissioning costs study(3) estimates that regional labor costs can deviate by as much as 17% from the national average. Costs at individual locations might deviate even more. In addition, the owner cost will depend on the values used to estimate fringe benefits, taxes, insurance, and other owner overhead expenses.

H.2 WASTE-PACKAGING COSTS

The costs of packaging radioactive waste materials prior to shipment to a shallow-land burial site or other authorized waste repository include the shipping container cost, the cost of additional shielding provided by overpacks and casks, and the cost of a solidifying or dewatering agent for radioactive liquids or wet wastes. These costs are discussed in the following subsections.

TABLE H.1-1. Decommissioning Labor Cost Data

Position	Base Pay ($/yr)	Assumed Overhead Rate (%)	Cost ($/yr)	Reference[(a)]
Owner/Operator's Staff				
Project Manager	52 000	70	88 400	b
Project Engineer	44 700	70	76 000	b
Health & Safety Supervisor	35 200	70	59 800	c
Health Physicist	27 600	70	46 900	c
Health Physics Technician	20 000	50	30 000	d
Security Force Supervisor	32 900	70	55 900	c
Security Patrolman	16 900	50	25 400	e
Contracts & Accounting Specialist/ Accountant	23 100	70	39 300	c
SNM Accounting Specialist	26 900	70	45 700	c
SNM Accounting Clerk	19 000	50	28 500	c
Radioactive Shipment Specialist	23 100	70	39 300	c
QA Engineer	27 600	70	46 900	c
Planning Engineer	27 600	70	46 900	b
Engineering Technician	20 000	50	30 000	d
Operations Supervisor	30 700	70	52 200	b
Maintenance & Crafts Supervisor	27 600	70	46 900	c
Crew Leader/Foreman	26 100	70	44 400	d
Craftsman/Instrument Technician/ Maintenance Mechanic	21 400	50	32 100	d
Custodian	19 000	50	28 500	c
Equipment Operator	26 100	50	39 100	c
Truck Driver	20 600	50	30 900	c
Laborer	20 600	50	30 900	e
Secretary/Word Processor/Clerk	16 100	50	24 200	c
Contractor's Staff				
Supervisor	30 700	110	64 500	b
Crew Leader/Foreman	26 100	110	54 800	d
Craftsman/Maintenance Mechanic	21 400	110	44 900	d
Technician	20 000	110	42 000	d
Equipment Operator	26 100	110	54 800	c
Truck Driver	20 600	110	43 300	c
Laborer	20 600	110	43 300	e
Secretary/Clerk	16 100	110	33 800	c

(a) References for 1978 data base, which has been adjusted upward by a factor of 1.19 to update it to early-1981.
(b) U.S. Department of Labor, Bureau of Labor Statistics, Bulletin March 1975.
(c) Author's estimate.
(d) Hanford Atomic Metal Trades Council Pay Scales.
(e) R. S. Means Co., Building Construction Cost Data - 1975, 33rd Edition.

H.2.1 Shipping Container Costs

The shipping containers assumed to be used for packaging radioactive materials for disposal are listed in Table H.2-1. Because of increases in labor and material costs, some container costs have increased significantly since 1978. Suppliers and users of these containers were consulted to obtain 1981 cost information.

TABLE H.2-1. Unit Costs of Shipping Containers for Radioactive Materials

Description	Burial Volume (m^3)	Estimated Unit Cost ($)
Standard Steel Drum 0.21 m^3, 23 kg empty	0.21	30
Small Steel Drum 0.11 m^3, 18 kg empty	0.11	20
Polyethylene Drum Liner	(a)	1
Fiberglassed Plywood Box 1.2 m x 1.2 m x 2.4 m, 175 kg empty	3.46	400
Fiberglassed Plywood Box Specially Fabricated	Variable	40/m^2 of Surface
Steel Box	Variable	275/m^2 of Surface

(a) Included in outer steel drum, no added burial volume.

H.2.2 Overpack and Cask Charges

Some packaged wastes with high surface dose rates require transport to a burial site in shielded casks. Containers of TRU waste are assumed to be overpacked in a DOT-approved type B container (Super Tiger®). In general, it is more economical to rent casks and overpacks than to purchase them, especially those used infrequently or for a short time period. The casks and overpacks assumed for use in this study are listed in Table H.2-2, together with physical characteristics and estimated rental charges.

H.2.3 Solidifying Agent Costs

The solidifying agents assumed to be used for packaging of wet solid and liquid wastes are listed in Table H.2-3 together with their respective costs.

® Registered trademark of Protective Packaging, Inc., subsidiary of Nuclear Engineering Company, Inc., Jeffersontown, Kentucky.

TABLE H.2-2. Rental Charges for Casks and Overpacks

Description	Empty Weight (kg)	Daily Rental ($)
1.95 m OD x 1.04 m high 55-mm Pb thickness (7D-3L cask)	7000	225
2.44 m x 2.44 m x 6.10 m double-walled steel with fire-resistant insulation (Super Tiger®)	6800	300

TABLE H.2-3. Solidifying Agent Costs

Item	Estimated Unit Cost ($)
Cement (45-kg bag)	6/bag
Diatomaceous Earth (23-kg bag)	12/bag

H.3 TRANSPORTATION COSTS

Shipments of radioactive wastes to a shallow-land burial site or to an authorized waste repository are assumed to be by exclusive-use truck. Transportation costs for these shipments are based on the published rates of a carrier licensed to transport radioactive materials.[4] To compute transportation costs, the following assumptions are made:

- One-way shipping distance is 1600 km.
- Shipments not requiring casks or overpacks are separate one-way shipments destined for west of the Mississippi River (the highest rate category). Cask or overpack shipments are continuous-excursion round trips.
- A fuel surcharge is levied at a rate of 18%.[a]
- Where applicable, overweight charges are computed at the rate for the state of Washington.

A trend that could add significantly to future nuclear transportation costs is the requirement by state and local governments for permits in advance

(a) The fuel surcharge rate is subject to change as fuel prices increase or decrease. The 18% rate was in effect as of February 12, 1981.

of each radioactive material shipment through their jurisdiction. A major carrier plans to charge its customers $25, plus the cost of the permit, for each such permit required.[5] In the future, these permit charges could be substantial for long-distance shipments. However, no such permit charges are included in the transportation cost estimates of this study.

The rate schedule for truck shipments of legal size and weight that forms the basis for transportation costs in this study is shown in Table H.3-1. The gross vehicle weight (GVW) for legal-weight shipments by truck is assumed to be less than 21.32 Mg. The maximum allowed GVW is assumed to be 38.55 Mg.[4] Overweight charges by states vary widely. The additional charges assumed in this study to be levied by the carrier and the state for overweight shipments are shown in Table H.3-2.

Example shipping costs, calculated for several different payloads and for one-way and round-trip shipments, are shown in Table H.3-3. For a one-way 1600-km shipment, the base charge is that shown in Column 2 of Table H.3-1. To this must be added the 18% fuel surcharge, as well as any applicable overweight charges shown in Table H.3-2.

Casks and overpacks are assumed to be picked up loaded at the site of the decommissioning operations, delivered to the disposal site to be unloaded, and then returned to the original site. Thus, each 3200-km round trip consists of two 1600-km one-way moves, with charges based on continuous-excursion rates shown in Column 3 of Table H.3-1. From the reference rate schedule, the basic charge for the round trip is $2272. With the additional 18% fuel surcharge, this is increased to $2681. Applicable overweight charges must also be added. To ensure rapid turnaround on these shipments and to minimize cask rental charges, a second driver is assumed to be used, costing an additional $0.093/km.[4]

H.4 WASTE DISPOSAL COSTS

A basic assumption of this study is that nearly all of the radioactive material resulting from cleanup and decommissioning of the reference facilities can be disposed of by burial at a commercial shallow-land burial facility. The only exception is the transuranic (TRU) waste from the MOX facility, which is assumed to be placed in deep geologic disposal. The unit costs of waste disposal are given in the following subsections.

H.4.1 Shallow-Land Burial

The shallow-land burial costs used in this study are based on a November 1980 price list from U.S. Ecology, Inc.,[6] which operates burial sites at

TABLE H.3-1. Transportation Rates for Legal Weight Shipments (effective August 15, 1980)[a-c]

Kilometers One-way (Not Over)	Rate in Cents/Kilometer Column 1[d]	Column 2[e]	Column 3[f]	Kilometers One-Way (Not Over)	Rate in Cents/Kilometer Column 1[d]	Column 2[e]	Column 3[f]
160	233	244	168	1200	86	103	71
200	214	226	155	1280	82	100	71
240	196	209	143	1360	81	99	71
280	179	192	133	1440	80	98	71
320	155	169	121	1520	79	97	71
360	147	162	115	1600	77	95	71
400	141	156	108	1760	77	94	71
440	134	150	101	1920	77	94	71
480	128	144	96	2080	77	93	71
520	125	141	91	2240	77	92	71
560	121	137	88	2400	77	92	71
600	116	132	84	2560	77	91	71
640	111	128	82	2720	77	91	71
680	108	124	80	2880	77	90	71
720	102	119	78	3040	77	89	71
760	100	117	76	3200	77	89	71
800	96	114	75	3360	77	88	71
880	94	111	73	3520	77	88	71
960	92	109	71	3680	77	87	71
1040	89	106	71	3840	77	86	71
1120	87	104	71	4000 and Beyond	77	86	71

(a) Reproduced from the published rates of a carrier[4] licensed to transport radioactive materials.
(b) Effective August 15, 1980.
(c) Rates do not include a fuel surcharge, which amounted to 18% of the base rate as of February 13, 1981.
(d) Column 1 rates apply to one-way shipments having a destination east of the Mississippi River.
(e) Column 2 rates apply to one-way shipments having a destination west of the Mississippi River.
(f) Column 3 rates apply to continuous excursion moves in which a subsequent shipment is made available to the carrier within 24 hours after arrival at the point of loading or unloading.

Richland, Washington, and Beatty, Nevada. These prices are comparable to those charged by Chem-Nuclear Services, Inc.,[7] at their Barnwell, South Carolina, disposal site. Burial ground charges are shown in Table H.4-1.

TABLE H.3-2. Additional Charges when Gross Vehicle Weight Exceeds 21.32 Mg(a,b)

Gross Vehicle Weight (Mg)	State Surcharge ($)	Carrier Surcharge ($)	Total Overweight Surcharge ($)
21.32 to 23.12	10 + 0.031/km	0.131/km	10 + 0.162/km
23.13 to 25.84	10 + 0.062/km	0.131/km	10 + 0.193/km
25.85 to 28.56	10 + 0.093/km	0.131/km	10 + 0.224/km
28.57 to 31.28	10 + 0.155/km	0.131/km	10 + 0.286/km
31.29 to 34.00	10 + 0.218/km	0.131/km	10 + 0.349/km
34.01 to 36.72	10 + 0.280/km	0.131/km	10 + 0.411/km
36.73 to 38.55	10 + 0.373/km	0.131/km	10 + 0.504/km

(a) State surcharge is based on rates for the state of Washington.
(b) Carrier surcharge is based on the published rates[4] of a carrier licensed to transport radioactive materials.

TABLE H.3-3. Example Shipping Costs of Truck Shipments

Status	Number of Drivers	Payload (Mg)	GVW (Mg)	Cost ($)
Legal weight, one-way[a]	1	8.61	21.31	1794
Overweight, one-way[a]	1	19.95	32.65	2362
Overweight, one-way[a]	1	25.85	38.55	2610
Overweight, round-trip[b]	2	19.95	32.65	4105
Overweight, round-trip[b]	2	25.85	38.55	4601

(a) 1600-km distance.
(b) Shipments involving casks or overpacks, with overweight charges applicable both directions. Charges computed on the basis of two 1600-km trips.

H.4.2 Deep Geologic Disposal of TRU Wastes

Disposal requirements for TRU wastes such as those resulting from decommissioning of a MOX facility are not currently defined. For this study, it is assumed that these wastes are placed in deep geologic disposal, as was assumed in the previous study of decommissioning a small MOX facility following normal shutdown.[8] Since a facility for deep geologic disposal does not presently exist, disposal costs at such a facility are somewhat speculative. A deep geologic disposal cost of $30,000/m^3 is assumed for this study.

TABLE H.4-1. Commercial Shallow-Land Burial Charges[a,b]

I. DISPOSAL CHARGES, NON-TRU WASTE

A. Steel Drums, Wood Boxes

Container Surface Dose Rate (R/hr)[c]			Price/Unit Volume ($/m^3)
0.00	to	0.20	307.20
0.201	to	1.00	335.45
1.01	to	2.00	376.05
2.01	to	5.00	459.05
5.01	to	10.00	542.00
10.01	to	20.00	702.65
20.01	to	40.00	870.40
40.01	to	60.00	1332.95
60.01	to	80.00	1601.30
80.01	to	100.00	1765.50
	>100		by request

B. Disposable Liners

Container Surface Dose Rate (R/hr)[c]			Surcharge/Liner ($)	Price/Unit Volume ($/m^3)
0.00	to	0.20	None	307.20
0.201	to	1.00	119.00	307.20
1.01	to	2.00	292.00	307.20
2.01	to	5.00	411.00	307.20
5.01	to	10.00	594.00	307.20
10.01	to	20.00	758.00	307.20
20.01	to	40.00	941.00	307.20
40.01	to	60.00	1116.00	307.20
60.01	to	80.00	1288.00	307.20
80.01	to	100.00	1463.00	307.20
	>100		by request	by request

II. SURCHARGES

A. State of Washington Surcharge:	$10.60/m^3
B. Curie Surcharge (per load):	
Less than 100 curies	No charge
101 to 300 curies	$660.00
301 to License Limits (i.e., 50,000 Ci)	$660.00 + $0.09/Ci
C. Handling Surcharge:	
0 to 4.54 Mg	No Charge
>4.54 Mg	$87.50 + $0.44/kg over 4.54 Mg
Special Equipment	By special quotation
D. Cask Handling Fee	$335.00/cask

(a) Reproduced from the published rates[6] of a licensed burial ground operator.
(b) Prices effective November 17, 1980.
(c) Maximum reading at container surface, irrespective of physical size or configuration.

H.5 COSTS OF SPECIAL EQUIPMENT AND SUPPLIES

Costs of special equipment and supplies from the 1978 data base have been reviewed and updated as appropriate to reflect 1981 costs. Costs of construction-type items (hoists, cranes, lifts, etc.) are based on costs shown in the 1981 catalog of building construction costs published by the R. S. Means Company.(9) Costs of special equipment and supplies purchased during decommissioning are shown in Table H.5-1.

Unit charges for equipment owned by decommissioning contractors hired during the project are shown in Table H.5-2. The monthly charges shown in the table are calculated on the basis of 3 to 6% of the capital cost of equipment and include allowances for equipment depreciation, maintenance and operating expenses (e.g., fuel, lubrication, etc.), decontamination following use, and return on investment. They do not include the operator's wage. Weekly charges are estimated to be approximately one-third of the monthly charges.(9)

Unit costs for supplies and materials needed for site decommissioning activities are shown in Table H.5-3.

TABLE H.5-1. Unit Costs for Equipment and Supplies

Item	Estimated Unit Cost ($ thousands)
Equipment	
Oxyacetylene Torch	1
Portable Plasma-Arc Torch	20
Arc Saw	120
Guillotine Pipe Saw	1
Tube Cutter	0.3
Ratcheting Pipe Cutter	0.1
Reciprocating Hacksaw	1
Nibbler	1
Electric/Pneumatic Hammer	2
Steam Cleaner	4
Wet/Dry Vacuum	1-5[a]
Powered Floor Scrubber	0.3
High-Velocity Liquid Jet	20
Low-Velocity Liquid Jet	4
Waste Compactor	12
Concrete Drill with HEPA-Filtered Dust Collection System	2
Concrete Surface Spaller	5
Electropolishing Decontamination System	100[b]
Portable Filtered Ventilation Enclosure	2-10[a]
Filtered-Exhaust Fan Unit	5
Portable A-Frames	3
Portable Wash Tanks	2
Paint Sprayer	0.5-1[c]
Incinerator	100-300[c]
Supplies	
HEPA Filter	0.2
Roughing Filter	0.1
Supplied Air Plastic Suit	0.05
Disposable Anti-Contamination Clothing (per person per week)	0.1
Polyethylene Sheeting (per 1000 m^3)	1
Paint (per 1000 ℓ)	5
EDTA (per 1000 kg)	1.3
Oxalic Acid (per 1000 kg)	1.8
Citric Acid (per 1000 kg)	1.8
10 M Nitric Acid (per 1000 ℓ)	0.7
Phosphoric Acid (per 1000 ℓ)	1.6
Freon (per 1000 ℓ)	2.4
Soap (per 1000 kg)	0.2
Decontamination Solution (per 0.21-m^3 drum)	0.5
Hand-Powered Brushes	0.2

(a) Depends on size and complexity.
(b) Electrolyte tank has dimensions of 1.2 m x 2.4 m.
(c) Depends on capacity of system.

TABLE H.5-2. Charges for Contractor Equipment[a]

Item	Estimated Weekly Charge ($)	Estimated Monthly Charge ($)
Tractor, farm-type	500	1 500
Grader, self-propelled	1 000	3 000
Roller, sheepsfoot, self-propelled	1 000	3 000
Front loader (2-m^3-capacity)	1 350	4 100
Backhoe (1-m^3-capacity)	750	2 200
Bulldozer	1 450	4 300
Soil stabilizer, self-propelled	5 000	15 000
Scraper-hauler (20-m^3-capacity)	2 350	7 000
Truck, 10-m^3-capacity dump	775	2 300
Lift truck (10-Mg-capacity)		
Crane, boom-type (10-Mg-capacity)	1 000	3 000
Light-duty drilling rig	2 500	7 500
Disc-harrow, tractor-drawn	200	550
Seeder, tractor-drawn	250	750

(a) Includes equipment depreciation, operating expenses (fuel, lubrication, etc.), decontamination following use, and return on investment. Does not include operator's wage.

TABLE H.5-3. Unit Costs of Supplies and Materials for Decommissioning of Sites

Item	Unit	Estimated Unit Cost ($)
Backfill (topsoil)	m^3	7[a]
Backfill (common borrow)	m^3	2[a]
Gravel (graded)	m^3	8.5[a]
Asphalt emulsion	ℓ	0.2
Seed	kg	3
Fertilizer	kg	0.3
Straw	bale	1.5
PVC pipe (0.15-m diameter)	m	6
Chain-link fencing (1.8-m wide)	m	24
Soil Analysis	each	150
Cutie Pie detector	each	600
G-M probe	each	100
Gamma scintillation probe	each	500
Ratemeter	each	400
Phoswich detector	each	8000

REFERENCES

1. E. S. Murphy and G. M. Holter, Technology, Safety and Costs of Cleanup and Decommissioning at a Reference Pressurized Water Reactor Involved in an Accident, NUREG/CR-2601, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, to be published.

2. Handy-Whitman Index of Public Utility Construction Costs, to July 1, 1980, Bulletin No. 112, Whitman, Requart and Associates, Baltimore, Maryland, 19810.

3. W. J. Manion and T. S. La Guardia, Decommissioning Handbook, DOE/EV/10128-1, Nuclear Energy Services, Inc., Danbury, Connecticut, November 1980.

4. MF-I.C.C. No. 195, Local Commodity Tariff No. 1045-E, Tri-State Motor Transit Co., Joplin, Missouri, August 1980.

5. S. A. Dupree and L. C. O'Malley, Economics of Radioactive Material Transportation in the Light-Water Reactor Nuclear Fuel Cycle, SAND80-0035, Sandia National Laboratories, Albuquerque, New Mexico, October 1980.

6. Washington Nuclear Center and Nevada Nuclear Center Schedule of Charges, U.S. Ecology, Inc., Richland, Washington, November 17, 1980.

7. Barnwell Low-Level Radioactive Waste Disposal Facility Rate Schedule, Chem-Nuclear Services, Inc., Barnwell, South Carolina, January 1, 1981.

8. C. E. Jenkins, E. S. Murphy, and K. J. Schneider, Technology, Safety and Costs of Decommissioning a Reference Small Mixed Oxide Fuel Fabrication Plant, NUREG/CR-0129, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, February 1979.

9. R. S. Godfrey, ed., Building Construction Cost Data - 1981, 39th Edition, R. S. Means, Co., Inc., Kingston, Massachusetts, 1980.

APPENDIX I

SAFETY ASSESSMENT DETAILS

APPENDIX I

SAFETY ASSESSMENT DETAILS

The purpose of this appendix is to quantify the parameters and define the methodology for estimating the impacts to public and occupational safety from post-accident cleanup and decommissioning of the reference non-reactor nuclear plants. Radiological and nonradiological impacts of both routine activities and selected generic industrial and transportation accidents during post-accident cleanup and decommissioning are evaluated.

The following sections contain detailed discussions of the technical approach to safety assessment and of the safety impacts resulting from accident cleanup and from decommissioning. A summary of this information is given in Chapter 12.

A basic assumption of the analyses presented in this appendix is that the radioactive waste materials from accident cleanup and decommissioning are shipped offsite for disposal at the time of decommissioning.

I.1 TECHNICAL APPROACH

To estimate the safety impacts from post-accident cleanup and decommissioning of the reference plants, the following basic assumption are made:

1. Appropriate radiation protection and contamination control techniques are applied to conform with the principle of keeping occupational radiation doses and radioactivity levels in effluents as low as reasonably achievable (ALARA).

2. The assessments of the safety impacts from post-accident decommissioning use information pertaining to the decommissioning of the reference plant following normal shutdown, to the maximum extent possible. Appropriate adjustments are made to account for differences between post-accident and normal-shutdown radionuclide inventories and decommissioning requirements.

3. HEPA filters in the plant ventilation systems are tested in place on a regular basis and replaced as required. The measured particle collection efficiency of these filters is 99.95%.[1] Atmospheric releases of radioactivity are assumed to pass through a single HEPA filter with a transmission factor of 5×10^{-4}.[1]

4. Unneeded hazardous chemicals and equipment are removed from the plant after the plant is stabilized following the postulated accident. Decontamination agents such as phosphoric acid, ethylenediaminetetra-acetic acid, oxalic acid, and citric acid are available in the plant.

5. In areas with high levels of radioactive contamination, a temporarily installed "greenhouse," or contamination control envelope, is assumed to be used. The contamination control envelope is assumed to be vented through a HEPA filter with a transmission factor of 5×10^{-4} to reduce the airborne radionuclide concentrations in the buildings from selected accident cleanup and decommissioning operations.

6. The airborne concentrations of dust or liquid droplets are assumed to be 1×10^{-2} g/m^3, equal to the concentrations observed at the decommissioning of the Elk River reactor.[2,3] For tasks involving blasting or explosions, the airborne concentrations are assumed to be higher by a factor of ten, or 1×10^{-1} g/m^3.[4]

7. All offsite radioactive waste shipments are assumed to be conducted in accordance with Department of Transportation (DOT) regulations. The one-way shipping distance is assumed to be 1600 km.

8. Radiation doses to the maximum-exposed individual and to the population residing within 80 km of the reference site are calculated using the environmental data and assumptions discussed in Appendix E of Reference 2. These methods are consistent with those outlined in Regulatory Guide 1.109.[5]

Other assumptions relating to specific accident cleanup and decommissioning tasks are discussed at the point at which they apply to the analysis.

I.2 MOX PLANT ACCIDENT CLEANUP

The accident cleanup activities at the reference MOX plant precede the actual refurbishment or decommissioning of the plant and are essentially independent of whether the facility is to be refurbished or decommissioned. In the latter case, they are also independent of the alternative chosen for completing the decommissioning. As a practical matter, accident cleanup efforts contribute to the refurbishment or decommissioning effort. However, in this appendix, accident cleanup is addressed separately from decommissioning for the MOX and U-Fab plants. Accident cleanup for the non-fuel cycle facilities is discussed with decommissioning.

This section contains the detailed analysis of the safety impacts resulting from accident cleanup activities. The radiological and nonradiological impacts of both routine activities and selected generic industrial and transportation accidents are considered. Radiological safety impacts to the public are assessed in Section I.2.1. Occupational safety impacts of accident cleanup are discussed in Section I.2.2. Transportation safety impacts, both public and occupational, are addressed in Section I.2.3.

I.2.1 Public Safety Aspects of Accident Cleanup

The public safety impacts of onsite activities during accident cleanup are discussed in the following subsections. Public radiation doses from atmospheric releases that result from routine tasks and from postulated industrial accidents during accident cleanup are considered. Nonradiological safety impacts to the public from onsite activities are judged to be negligible and are not considered further. Public safety impacts from offsite shipment of radioactive waste materials during accident cleanup are included in the assessment of transportation safety impacts presented in Section I.2.3.

During accident cleanup, the routine tasks and the postulated industrial accidents can generate airborne radioactivity in the plant, primarily in the form of solid particulates and/or suspended liquid droplets. The airborne radionuclide concentration depends on the particular task or accident considered and on the corresponding radionuclide inventory at the location involved. (The post-accident radionuclide inventories in the reference, MOX plant are discussed in detail in Appendix B.) Contamination control measures, where applied, and HEPA filters in plant ventilation systems reduce the levels of radioactivity in the air leaving the plant.

The atmospheric releases and corresponding radiation doses to the public during accident cleanup at the reference MOX plant are discussed in the following subsections. The atmospheric releases are estimated by determining the realistic maximum atmospheric release for each task or industrial accident and then using this value whenever the particular release situation occurs, even for areas with lower levels of radioactive contamination.

Public Radiation Doses from Routine Tasks During Accident Cleanup

A complete discussion of the tasks required for accident cleanup of the reference MOX plant is contained in Appendix D. To quantify the radiation doses to the public that result from these tasks, atmospheric releases of radioactivity are estimated for the particular radionuclide inventories involved, and the resulting doses to the maximum-exposed individuals and to the population are calculated.

The radiation doses to the public from these releases are calculated using the dose models discussed in Reference 6, in conjunction with characteristics of the reference site described in Appendix A of this report. Dose conversion factors are used that are appropriate for the post-accident radionuclide inventories at the reference plant. Each of the atmospheric releases is assumed to be a chronic release (i.e., one that occurs at a uniform rate for a period of one year) to allow direct comparisons of the impacts of individual accident cleanup tasks. The first-year doses and the fifty-year committed dose equivalents to both the maximum-exposed individual and to the population residing within 80 km of the site are calculated for each accident cleanup task. The calculated doses include direct exposure, inhalation, and ingestion pathways; radiation doses from air submersion are not calculated since they have been shown to be insignificant in Reference 6.

The estimated atmospheric releases of radioactivity and the resulting doses to the maximum-exposed individual from routine tasks during accident cleanup following the reference accident are shown in Table I.2-1. The releases and the resulting doses to the population residing within 80 km of the site from these tasks following the reference accident are shown in Table I.2-2.

Doses to the maximum-exposed individual in any given year are estimated to be below the appropriate dose design objectives as set forth in 10 CFR 50, Appendix I.[6]

The atmospheric releases and resulting public radiation doses presented in this study for accident cleanup are based on cleanup activities in the process building of the reference MOX plant.

Public Radiation Doses from Releases Due to Postulated Industrial Accidents During Accident Cleanup

Estimates of releases of radioactivity due to industrial accidents during accident cleanup and of the resulting first-year doses and fifty-year committed dose equivalents to the maximum-exposed individual are presented in Table I.2-3. Each release is assumed to occur during a one-hour period so that a comparison of the releases and associated doses can be made.

While it is beyond the scope of this study to evaluate every potential industrial accident situation that could result in a release of radioactivity during accident cleanup, the releases presented here are judged to represent the range of credible events and to reflect realistic maximum impacts to the public from industrial accident situations. Multiple-failure-event accidents are not considered (i.e., each release considered is the result of a single failure and does not require a chain of failure events to occur).

TABLE I.2-1. Calculated Radiation Doses to the Maximum-Exposed Individual from Airborne Radionuclides During Accident Cleanup

Activity or Location	Release to Atmosphere (μCi)	First-Year Dose, mrem Total Body	Bone	Lung
Preparation for Accident Cleanup			3.7×10^{-8}	5.8×10^{-8}
Chemical Decontamination:				
Flushing of Wet Systems	--(a)			
Surface Cleaning:				
Spray Decontamination (Dry Processing Glove Boxes)	4.6×10^{-3}	3.8×10^{-11}	8.2×10^{-10}	6.2×10^{-8}
Spray Decontamination (Wet Processing Glove Boxes)	1.2×10^{-2}	1.6×10^{-9}	3.7×10^{-8}	5.8×10^{-8}
Handwiping	--			
Physical Decontamination of Surfaces:				
Metal Surface Scraping	2.9	2.4×10^{-9}	5.4×10^{-8}	3.8×10^{-6}
Exhaust Duct Decontamination	52	4.4×10^{-7}	9.2×10^{-6}	6.8×10^{-4}
Filter Replacement	990	7.9×10^{-6}	1.8×10^{-4}	1.3×10^{-2}
Radiation Survey				
TOTALS	1 042	8.2×10^{-6}	1.9×10^{-4}	1.3×10^{-2}

(a) A dash means that the atmospheric release value is less than 2×10^{-4} Ci.

TABLE I.2-1. (cont)

Activity or Location	Fifty-Year Dose Commitment, mrem Total Body	Bone	Lung
Preparation for Accident Cleanup		2.8×10^{-6}	7.4×10^{-8}
Chemical Decontamination:			
Flushing of Wet Systems	--[(a)]		
Surface Cleaning:			
Spray Decontamination (Dry Processing Glove Boxes)	1.8×10^{-8}	3.8×10^{-7}	2.8×10^{-7}
Spray Decontamination (Wet Processing Glove Boxes)	1.3×10^{-7}	2.8×10^{-6}	7.4×10^{-8}
Handwiping	--		
Physical Decontamination of Surfaces:			
Metal Surface Scraping	1.1×10^{-6}	2.4×10^{-5}	1.8×10^{-5}
Exhaust Duct Decontamination	2.0×10^{-4}	4.4×10^{-3}	3.2×10^{-3}
Filter Replacement	3.9×10^{-3}	7.9×10^{-2}	1.4×10^{-2}
Radiation Survey	--		
TOTALS	4.0×10^{-3}	8.2×10^{-2}	1.7×10^{-2}

(a) A dash means that the atmospheric release value is less than 2×10^{-4} Ci.

TABLE I.2-2. Calculated Radiation Doses to the Population from Airborne Radionuclides Released During Accident Cleanup

Activity or Location	Release to Atmosphere (μCi)	First-Year Dose, man-rem Total Body	Bone	Lung
Preparation for Accident Cleanup			5.9×10^{-8}	4.4×10^{-6}
Chemical Decontamination:				
Flushing of Wet Systems	--[a]			
Surface Cleaning:				
Spray Decontamination (Dry Processing Glove Boxes)	4.6×10^{-3}	4.2×10^{-11}	9.0×10^{-10}	7.1×10
Spray Decontamination (Wet Processing Glove Boxes)	1.2×10^{-2}	2.1×10^{-9}	4.7×10^{-8}	7.6×10^{-8}
Handwiping	--			
Physical Decontamination of Surfaces:				
Metal Surface Scraping	2.9	2.6×10^{-9}	5.9×10^{-8}	4.4×10^{-6}
Exhaust Duct Decontamination	52	4.8×10^{-7}	1.0×10^{-5}	8.0×10^{-4}
Filter Replacement	990	8.0×10^{-6}	2.0×10^{-4}	1.4×10^{-2}
Radiation Survey	--			
TOTALS	1 042	9.1×10^{-6}	2.1×10^{-4}	1.6×10^{-4}

(a) A dash means that the atmospheric release value is less than 2×10^{-4} Ci

TABLE I.2-2. (contd)

Activity or Location	Fifty-Year Dose Commitment, man-rem Total Body	Bone	Lung
Preparation for Accident Cleanup		2.8×10^{-5}	2.0×10^{-5}
Chemical Decontamination:			
Flushing of Wet Systems	--[(a)]		
Surface Cleaning:			
Spray Decontamination (Dry Processing Glove Boxes)	2.0×10^{-8}	4.3×10^{-7}	3.2×10^{-7}
Spray Decontamination(Wet Processing Glove Boxes)	1.7×10^{-7}	3.5×10^{-6}	9.5×10^{-8}
Handwiping	--		
Physical Decontamination of Surfaces:			
Metal Surface Scraping	1.3×10^{-6}	2.7×10^{-5}	2.0×10^{-5}
Exhaust Duct Decontamination	2.3×10^{-4}	4.8×10^{-3}	3.6×10^{-3}
Filter Replacement	4.0×10^{-3}	9.2×10^{-2}	7.0×10^{-2}
Radiation Survey	--		
TOTALS	4.3×10^{-3}	9.6×10^{-2}	7.4×10^{2}

(a) A dash means that the atmospheric release value is less than 2×10^{-4} Ci.

TABLE I.2-3. Calculated Radiation Doses to the Maximum-Exposed Individual from Accidental Airborne Radionuclides During Accident Cleanup

Incident	Release to Atmosphere (μCi)	First-Year Dose, mrem Total Body	Bone	Lung
Loss of Intermediate-Stage HEPA Filter After Exhaust Duct Decontamination	1.0×10^{4}	2.4×10^{-2}	5.2	32
Explosion and/or Fire of Ion Exchange Resin	83	3.1×10^{-3}	7.0×10^{-2}	6.6×10^{-2}
Loss of Local Airborne Contamination Control/ Loss of Vacuum Filter	3.5	8.3×10^{-6}	1.9×10^{-4}	1.1×10^{-2}
Temporary Loss of Services:				
Electricity (Normal and Emergency	1.4	3.4×10^{-6}	7.4×10^{-5}	4.4×10^{-3}
Other	--[a]			
Liquid Leak, Chemical Decontamination	16	6.0×10^{-4}	1.4×10^{-2}	1.3×10^{-2}
Fire Involving Contaminated Clothing or Combustible Waste	0.11	4.1×10^{-6}	9.2×10^{-5}	8.8×10^{-5}
Natural Phenomenon:				
Tornado	Not calculated			
Earthquake	Not calculated			

(a) A dash means that the atmospheric release value is less than 2×10^{-4} Ci.

TABLE I.2-3. (contd)

Incident	Fifty-Year Dose Commitment, mrem		
	Total Body	Bone	Lung
Loss of Intermediate-Stage HEPA Filter After Exhaust Duct Decontamination	5.2	1.1×10^{2}	77
Explosion and/or Fire of Ion Exchange Resin	1.2	2.5	6.6×10^{-2}
loss of Local Airborne Contamination Control/ Loss of Vacuum Filter	1.8×10^{-3}	3.9×10^{-2}	2.8×10^{-2}
Temporary Loss of Services:			
Electricity (Normal and Emergency	7.0×10^{-4}	1.5×10^{-2}	1.1×10^{-2}
Other			
Liquid Leak, Chemical Decontamination	2.3×10^{-2}	4.8	1.3×10^{-2}
Fire Involving Contaminated Clothing or Combustible Waste	1.5×10^{-4}	3.3×10^{-3}	8.8×10^{-5}
Natural Phenomenon:			
Tornado			
Earthquake			

I.2.2 Occupational Safety Aspects of Accident Cleanup

The occupational safety impacts of accident cleanup activities are discussed in the following subsections, including radiation doses to workers performing the accident cleanup tasks and potential industrial-accident (non-radiological) impacts to these workers. The information developed here is based on the detailed description of accident cleanup activities presented in Appendix D of this study.

Occupational Radiation Doses from Accident Cleanup Activities

The estimated occupational radiation doses accumulated by cleanup workers are based on postulated external gamma radiation dose rates in various areas of the reference plant during accident cleanup and on estimated staff labor requirements for completing the accident cleanup tasks. Workers are assumed to use respiration equipment as appropriate to protect against inhalation of radioactive materials.

Summaries of the estimated occupational radiation doses during accident cleanup following the reference accident are given in Table I.2-4.

I.3 DECOMMISSIONING

Decommissioning activities at the reference MOX plant follow completion of accident cleanup activities at the plant. Accident cleanup efforts contribute to the total decommissioning effort, but in this study, accident cleanup and decommissioning are addressed separately for the MOX and U-Fab plants.

This section contains the details of the analysis of the safety impacts resulting from the post-accident decommissioning activities at the reference plant. Radiological and nonradiological impacts of both routine activities and selected generic industrial and transportation accidents are considered.

I.3.1 Public Safety Aspects of Post-Accident Decommissioning Activities

The public safety impacts from onsite activities during post-accident decommissioning (following completion of accident cleanup activities) are discussed in the following subsections. Public radiation doses from atmospheric releases that result from routine decommissioning tasks and postulated industrial accidents during decommissioning are considered . Nonradiological safety impacts to the public from onsite activities are judged to be negligible and are not considered further.

TABLE I.2-4. Estimated Occupational Radiation Dose for Accident Cleanup

Event Description	Foremen: Average Exposure Rate (R/hr)	Foremen: Total Exposure Man-Hours	Foremen: Dose Man-Rem	Operators: Average Exposure Rate (R/hr)	Operators: Total Exposure Man-Hours	Operators: Dose Man-Rem	H. P. Technicians: Average Exposure Rate (R/hr)	H. P. Technicians: Total Exposure Man-Hours	H. P. Technicians: Dose Man-Rem	Craftsmen: Average Exposure Rate (R/hr)	Craftsmen: Total Exposure Man-Hours	Craftsmen: Dose Man-Rem	Event Total Dose Man-Rem
Flush solvent extraction system	7×10^{-4}	240	0.17	1.4×10^{-3}	720	0.97	1×10^{-3}	135	0.14	1.4×10^{-3}	120	0.16	1.4
Flush wet process and scrap recovery system	5×10^{-4}	600	0.3	9×10^{-4}	1800	1.6	7×10^{-4}	340	0.24	9×10^{-4}	300	0.27	2.4
Flush waste treatment equipment	4×10^{-4}	120	4.8×10^{-2}	8×10^{-4}	360	0.29	6×10^{-4}	65	3.9×10^{-2}	8×10^{-4}	60	4.8×10^{-2}	0.43
Decontaminate Rooms 121-123, 126	1.4×10^{-4}	60	8.4×10^{-3}	3.3×10^{-4}	360	0.12	2.4×10^{-4}	25	6.0×10^{-3}	3.3×10^{-4}	60	2×10^{-2}	0.15
Decontaminate Room 155	2.3×10^{-4}	45	1×10^{-2}	6.7×10^{-4}	270	0.18	4.5×10^{-4}	55	2.5×10^{-2}	6.7×10^{-4}	30	2×10^{-2}	0.24
Decontaminate Room 156	2.3×10^{-4}	30	6.9×10^{-3}	6.7×10^{-4}	180	0.12	4.5×10^{-4}	35	1.6×10^{-2}	6.7×10^{-4}	15	1×10^{-2}	0.15
Decontaminate Room 124	6×10^{-4}	180	0.11	1.1×10^{-3}	1080	1.1	8.3×10^{-4}	65	5.4×10^{-2}	1.1×10^{-3}	180	0.19	1.5
Decontaminate Room 128	5×10^{-4}	300	0.15	1×10^{-3}	1800	1.8	7.5×10^{-4}	405	0.30	1×10^{-3}	180	0.18	2.4
Decontaminate Room 127	4×10^{-4}	180	7.2×10^{-2}	8×10^{-4}	1080	0.86	6×10^{-4}	235	0.14	8×10^{-4}	106	8.4×10^{-2}	1.2
Decontaminate Rooms 130-133, 135-143	6×10^{-5}	90	5.4×10^{-3}	7×10^{-5}	540	3.8×10^{-2}	6.5×10^{-5}	115	7.5×10^{-3}	7×10^{-5}	60	4.2×10^{-3}	5.5×10^{-2}
Decontaminate Room 116	6×10^{-5}	30	1.8×10^{-3}	6×10^{-5}	180	1.1×10^{-2}	6×10^{-5}	35	2.1×10^{-3}	6×10^{-5}	15	9×10^{-4}	1.6×10^{-2}
Decontaminate Room B01	5×10^{-4}	135	6.8×10^{-2}	9×10^{-4}	810	0.73	7×10^{-4}	180	0.13	9×10^{-4}	75	6.8×10^{-2}	0.99
Decontaminate Room B02	4×10^{-4}	90	3.6×10^{-2}	8×10^{-4}	540	0.43	6×10^{-4}	110	6.6×10^{-2}	8×10^{-4}	60	4.8×10^{-2}	0.58
Decontaminate Room 129	6×10^{-5}	45	2.7×10^{-3}	7×10^{-5}	270	1.9×10^{-2}	6.5×10^{-5}	55	3.6×10^{-3}	7×10^{-5}	30	2.1×10^{-3}	2.7×10^{-2}
Deactivate Rooms 121-123, 126	1.4×10^{-4}	30	4.2×10^{-3}	3.2×10^{-4}	90	2.9×10^{-2}	2.3×10^{-4}	25	5.8×10^{-3}	3.2×10^{-4}	75	2.4×10^{-2}	6.3×10^{-2}
Deactivate Room 124	4×10^{-4}	90	3.6×10^{-2}	8.5×10^{-4}	270	0.23	6.3×10^{-4}	55	3.5×10^{-2}	8.5×10^{-4}	210	0.18	0.48
Deactivate Rooms 155 and 156	2.2×10^{-4}	45	9.9×10^{-3}	6.6×10^{-4}	135	8.9×10^{-2}	4.4×10^{-4}	35	1.5×10^{-2}	6.6×10^{-4}	105	6.9×10^{-2}	0.18
Deactivate Cold Chem. Prep. Room	6×10^{-5}	45	2.7×10^{-3}	6×10^{-5}	135	8.1×10^{-3}	6×10^{-5}	10	6.0×10^{-4}	6×10^{-5}	105	6.3×10^{-3}	1.8×10^{-2}
Deactivate Room B05	4×10^{-4}	150	6×10^{-2}	4×10^{-4}	450	0.18	4×10^{-4}	100	4.0×10^{-2}	4×10^{-4}	360	0.14	0.38
Deactivate Wall Storage Tanks	4×10^{-4}	120	4.8×10^{-2}	8×10^{-4}	360	0.29	6×10^{-4}	80	4.8×10^{-2}	8×10^{-4}	300	0.24	0.63
Deactivate Room 128	4×10^{-4}	150	6×10^{-2}	8.5×10^{-4}	450	0.38	6.3×10^{-4}	100	6.3×10^{-2}	8.5×10^{-4}	360	0.31	0.81
Deactivate Room 127	4×10^{-4}	90	3.6×10^{-2}	8×10^{-4}	270	0.22	6×10^{-4}	55	3.3×10^{-2}	8×10^{-4}	210	0.17	0.43
Deactivate Rooms 130-133, 135-143	6×10^{-5}	60	3.6×10^{-3}	6.5×10^{-5}	180	1.2×10^{-2}	6.3×10^{-5}	35	2.2×10^{-3}	6.5×10^{-5}	150	9.8×10^{-3}	2.8×10^{-2}
Deactivate Room B01	4×10^{-4}	75	3×10^{-2}	8×10^{-4}	225	0.18	6×10^{-4}	45	2.7×10^{-2}	8×10^{-4}	180	0.14	0.38
Deactivate Room B02	3×10^{-4}	45	1.4×10^{-2}	7×10^{-4}	135	9.5×10^{-2}	5×10^{-4}	35	1.8×10^{-2}	7×10^{-4}	105	7.4×10^{-2}	0.20
Deactivate Rooms 129 and 134	6×10^{-5}	30	1.8×10^{-3}	6.5×10^{-5}	90	5.9×10^{-3}	6.3×10^{-5}	25	1.6×10^{-3}	6.5×10^{-5}	75	4.9×10^{-3}	1.4×10^{-2}
Deactivate Room 116	6×10^{-5}	15	9×10^{-4}	6×10^{-5}	45	2.7×10^{-3}	6×10^{-5}	10	6.0×10^{-4}	6×10^{-5}	30	1.8×10^{-3}	6.0×10^{-3}
Deactivate misc. unneccessary systems	3×10^{-4}	30	9×10^{-3}	7×10^{-4}	90	6.3×10^{-2}	5×10^{-4}	90	4.5×10^{-2}	7×10^{-4}	120	8.4×10^{-2}	0.20
Deactivate Room 117	6×10^{-5}	120	7.2×10^{-3}	6×10^{-5}	360	2.2×10^{-2}	6×10^{-5}	90	5.4×10^{-3}	6×10^{-5}	480	2.9×10^{-2}	6.4×10^{-2}
Check safety systems, install alarms, etc.	3×10^{-4}	165	5×10^{-2}	7×10^{-4}	495	0.35	5×10^{-4}	495	0.25	7×10^{-4}	660	0.46	1.1
Final checkout of safety, security, operating systems	3×10^{-4}	60	1.8×10^{-2}	7×10^{-4}	180	0.13	5×10^{-4}	450	0.23	7×10^{-4}	240	0.17	0.54
Operate scrap recovery and waste treatment	4.5×10^{-4}	1020	0.46	8.5×10^{-4}	4080	3.5	6.5×10^{-4}	1090	0.71	8.5×10^{-4}	1185	1	5.7
Totals		4485	1.84		18,030	14.1		4680	2.62		6240	4.14	22.8

During decommissioning, as during accident cleanup, the routine tasks and postulated industrial accidents can generate airborne radioactivity in the plant. Contamination control measures, where applied, and HEPA filters in plant ventilation systems reduce the levels of radioactivity in the air leaving the plant. The radioactivity released depends on the specific task or industrial accident considered and on the corresponding radionuclide inventory at that particular location.

The radionuclide inventories used in this study for post-accident decommissioning are the same as those used in Reference 6 for decommissioning following normal MOX plant shutdown.

In the following subsections, the atmospheric releases and resulting radiation doses to the public are discussed. Analyses are performed for decommissioning following the reference MOX plant accident. The atmospheric releases are estimated by determining the realistic maximum atmospheric release for each situation and then using this value whenever similar conditions occur, even for areas with lower levels of radioactive contamination.

Public Radiation Doses from Routine Tasks During Post-Accident Decommissioning

The atmospheric releases of radioactivity for post-accident decommissioning are based on estimated values for decommissioning the reference MOX plant following normal shutdown, presented in Appendix I of Reference 6. Each of the atmospheric releases is assumed to be a chronic release (i.e., one that occurs at a uniform rate over a one-year period) to allow direct comparisons of the impacts from individual decommissioning tasks. The first-year dose and the fifty-year committed dose equivalents to both the maximum-exposed individual and to the population residing within 80 km of the site are calculated. The dose calculation includes direct exposure, inhalation, and ingestion pathways.

The estimated atmospheric releases of radioactivity and the resulting doses to the maximum-exposed individual from routine tasks during DECON are shown in Table I.3-1. The releases and the resulting doses to the population residing within 80 km of the site from these routine tasks during DECON and during preparations for safe storage are shown in Table I.3-2.

Public Radiation Doses from Releases Due to Postulated Industrial Accidents During Post-Accident Decommissioning

Unexpected situations may arise during decommissioning that lead to the accidental atmospheric release of radioactivity from the plant. Estimated atmospheric releases of radioactivity and the resulting doses to the population are shown in Table I.3-2. The industrial accident situations considered for post-accident decommissioning are the same as those considered in Reference 6 for decommissioning following normal plant shutdown.

TABLE I.3-1. Calculated Radiation Doses to the Maximum-Exposed Individual from Airborne Radionuclides During Normal DECON of the MOX Plant

Activity or Location	Release to Atmosphere (μCi)	First-Year Dose, mrem				Fifty-Year Dose Commitment, mrem			
		Total Body	Bone	Liver	Lung	Total Body	Bone	Liver	Lung
Chemical Decontamination:									
Flushing of Wet Systems	--[(a)]								
Electropolishing (station)	210	2.7×10^{-5}	6.6×10^{-4}	4.9×10^{-4}	1.0×10^{-3}	2.3×10^{-3}	4.9×10^{-2}	3.0×10^{-2}	1.3×10^{-3}
Electropolishing (in-situ)	2.1×10^{-2}	2.7×10^{-9}	6.6×10^{-8}	4.9×10^{-8}	1.0×10^{-7}	2.3×10^{-7}	4.9×10^{-6}	3.0×10^{-6}	1.3×10^{-7}
Surface Cleaning:									
Spray Decontamination (Dry Processing Glove Boxes)	4.6×10^{-3}	3.8×10^{-11}	8.1×10^{-10}	6.2×10^{-10}	6.2×10^{-8}	1.8×10^{-8}	3.8×10^{-7}	2.4×10^{-7}	2.8×10^{-7}
Spray Decontamination (Wet Processing Glove Boxes)	1.2×10^{-2}	1.6×10^{-9}	3.7×10^{-8}	2.8×10^{-8}	5.8×10^{-8}	1.3×10^{-7}	2.8×10^{-6}	1.7×10^{-6}	7.4×10^{-8}
Handwiping	--								
Physical Decontamination:									
Scraping Metal Surfaces	2.9	2.4×10^{-9}	5.4×10^{-8}	3.8×10^{-8}	3.8×10^{-6}	1.1×10^{-6}	2.4×10^{-5}	1.5×10^{-5}	1.8×10^{-5}
Scraping Fire Brick	5.5	4.7×10^{-9}	9.7×10^{-8}	7.2×10^{-8}	7.2×10^{-6}	2.2×10^{-6}	4.7×10^{-5}	2.9×10^{-5}	3.4×10^{-5}
Concrete Removal	340	2.8×10^{-6}	6.4×10^{-5}	4.4×10^{-5}	4.4×10^{-4}	1.3×10^{-3}	2.8×10^{-2}	1.8×10^{-2}	2.1×10^{-2}
Exhaust Duct Decontamination	52	4.4×10^{-7}	9.2×10^{-6}	6.8×10^{-6}	6.8×10^{-4}	2.0×10^{-4}	4.4×10^{-3}	2.7×10^{-3}	3.2×10^{-3}
Removal of Concrete Rubble	--								
Segmenting Equipment:									
Arc Saw	97	8.0×19^{-7}	1.7×10^{-5}	1.3×10^{-5}	1.3×10^{-3}	3.8×10^{-4}	8.0×10^{-3}	5.1×10^{-3}	5.9×10^{-3}
Plasma Torch	2.1×10^{4}	1.7×10^{-4}	3.8×10^{-3}	2.8×10^{-3}	2.8	8.4×10^{-2}	1.7	1.1	1.3
Nibbler	--								
Filter Replacement	990	7.9×10^{-6}	1.8×10^{-4}	1.3×10^{-4}	1.3×10^{-2}	3.9×10^{-3}	7.9×10^{-2}	5.3×10^{-2}	6.2×10^{-2}
Radiation Survey	--								
TOTALS	2.25×10^{4}	2.2×10^{-4}	5.1×10^{-3}	3.6×10^{-3}	2.9	9.2×10^{-2}	1.9	1.2	1.4

(a) A dash means that the atmospheric release value is less than 2×10^{-4} μCi.

TABLE I.3-2. Calculated Radiation Doses to the Population from Airborne Radionuclides Released During Normal DECON of the MOX Plant

Activity or Location	Release to Atmosphere (μCi)	First-Year Dose, man-rem				Fifty-Year Dose Commitment, man-rem			
		Total Body	Bone	Liver	Lung	Total Body	Bone	Liver	Lung
Chemical Decontamination:									
Flushing of Wet Systems	--[(a)]								
Electropolishing (station)	210	3.2×10^{-5}	7.2×10^{-4}	5.3×10^{-4}	1.2×10^{-3}	2.5×10^{-3}	5.3×10^{-2}	3.3×10^{-2}	1.4×10^{-3}
Electropolishing (in-situ)	2.1×10^{-2}	3.2×10^{-9}	7.2×10^{-8}	5.3×10^{-8}	1.2×10^{-7}	2.5×10^{-7}	5.3×10^{-6}	3.3×10^{-6}	1.4×10^{-7}
Surface Cleaning:									
Spray Decontamination (Dry Processing Glove Boxes)	4.6×10^{-3}	4.2×10^{-11}	9.0×10^{-10}	7.1×10^{-10}	7.1×10^{-8}	2.0×10^{-8}	4.3×10^{-7}	2.7×10^{-7}	3.2×10^{-7}
Spray Decontamination (Wet Processing Glove Boxes)	1.2×10^{-2}	1.8×10^{-9}	4.1×10^{-8}	3.0×10^{-8}	6.6×10^{-8}	1.4×10^{-7}	3.0×10^{-6}	1.9×10^{-6}	8.3×10^{-8}
Handwiping	--								
Physical Decontamination:									
Scraping Metal Surfaces	2.9	2.6×10^{-9}	5.9×10^{-8}	4.4×10^{-8}	4.4×10^{-6}	1.3×10^{-6}	2.7×10^{-5}	1.7×10^{-5}	2.0×10^{-5}
Scraping Fire Brick	5.5	5.1×10^{-9}	1.1×10^{-7}	8.5×10^{-8}	8.5×10^{-6}	2.4×10^{-6}	5.1×10^{-5}	3.2×10^{-5}	3.9×10^{-5}
Concrete Removal	340	3.1×10^{-6}	6.9×10^{-5}	5.1×10^{-5}	5.1×10^{-3}	1.5×10^{-3}	3.2×10^{-2}	2.0×10^{-2}	2.4×10^{-2}
Exhaust Duct Decontamination	52	4.8×10^{-7}	1.0×10^{-5}	8.0×10^{-6}	8.0×10^{-4}	2.3×10^{-4}	4.8×10^{-3}	3.0×10^{-3}	3.6×10^{-3}
Removal of Concrete Rubble	--								
Segmenting Equipment:									
Arc Saw	97	8.9×10^{-7}	1.9×10^{-5}	1.5×10^{-5}	1.5×10^{-3}	4.2×10^{-4}	8.9×10^{-3}	5.5×10^{-3}	6.7×10^{-3}
Plasma Torch	2.1×10^{4}	1.9×10^{-4}	4.2×10^{-3}	3.2×10^{-3}	0.32	9.3×10^{-2}	2.0	1.2	1.5
Nibbler	--								
Filter Replacement	990	8.8×10^{-6}	2.0×10^{-4}	1.5×10^{-4}	1.5×10^{-2}	4.4×10^{-3}	9.2×10^{-2}	5.7×10^{-2}	7.0×10^{-2}
Radiation Survey									
TOTALS	2.25×10^{4}	2.5×10^{-4}	5.5×10^{-3}	4.1×10^{-3}	3.4×10^{-1}	1.0	2.2	1.3	1.6

(a) A dash means that the atmospheric release value is less than 2×10^{-4} μCi.

Estimates of the releases of radioactivity due to postulated industrial accidents during DECON following an accident, together with the resulting first-year doses and fifty-year committed dose equivalents to the maximum-exposed individual, are shown in Table I.3-3.

It is beyond the scope of this study to evaluate every potential industrial accident situation that could lead to the release of radioactivity during decommissioning. However, the postulated situations presented here are judged to represent the range of credible events and to reflect realistic maximum impacts from such situations to the public.

I.3.2 Occupational Safety Aspects of Post-Accident Decommissioning

The occupational safety impacts of post-accident decommissioning activities at the reference MOX plant are discussed in the following subsections. Included are occupational radiation doses and potential industrial-accident (nonradiological) impacts to the decommissioning workers. The information developed here is based on the detailed description of decommissioning activities presented in Appendix D of this study.

Occupational Radiation Doses from Decommissioning Activities

Summaries of the estimated occupational radiation doses during DECON following the reference accident are given in Table I.3-4.

I.4 U-FAB PLANT ACCIDENT CLEANUP

The accident cleanup activities at the reference U-Fab plant precede the actual refurbishment or decommissioning of the plant and are essentially independent of whether the facility is to be refurbished or decommissioned and, in the latter case, of the alternative chosen for completing the decommissioning. As a practical matter, accident cleanup efforts contribute to the refurbishment or decommissioning effort. However, in this appendix, accident cleanup is addressed separately from decommissioning for the MOX and U-Fab plants.

I.4.1 Public Safety Aspects of Accident Cleanup

The public safety impacts of onsite activities during accident cleanup are discussed in the following subsections. Public radiation doses from atmospheric releases that result from routine tasks and from postulated industrial accidents during accident cleanup are considered. Nonradiological safety impacts to the public from onsite activities are judged to be negligible and are not considered further.

TABLE I.3-3. Calculated Radiation Doses to the Maximum-Exposed Individual from Accidental Airborne Radionuclide Releases During DECON of the MOX Plant

Incident	Release to Atmosphere (µCi)	First-Year Dose, mrem				Fifty-Year Dose Commitment, mrem				Expected Frequency of Occurrence[(a)]
		Total Body	Bone	Liver	Lung	Total Body	Bone	Liver	Lung	
Loss of Intermediate-Stage HEPA Filter After Exhaust Duct Decontamination	1.0×10^{4}	2.4×10^{-2}	5.2×10^{-1}	4.0	32	5.2	1.1×10^{2}	69	78	High
Inadvertent Cutting of Undecontaminated Metal	1.6×10^{2}	3.9×10^{-4}	8.5×10^{-3}	6.5×10^{-3}	5.0	8.0×10^{-2}	1.8	1.1	1.3	High
Explosion and/or Fire of Ion Exchange Resin	83	3.1×10^{-3}	7.0×10^{-2}	5.2×10^{-2}	6.6×10^{-2}	1.2	2.5	1.5	6.6×10^{-2}	Medium
Inadvertent Dumping of Contaminated Solid Wastes:										
Abraded Firebrick	14	3.4×10^{-5}	7.4×10^{-4}	5.7×10^{-4}	4.4×10^{-2}	7.0×10^{-3}	1.5	9.6×10^{-2}	1.1	High
Concrete Dust	1.4	3.4×10^{-6}	7.4×10^{-5}	5.7×10^{-5}	4.4×10^{-3}	7.0×10^{-4}	1.5×10^{-2}	9.6×10^{-3}	1.1×10^{-2}	High
Condensed Metal Vapor	7.0×10^{-2}	1.7×10^{-7}	3.8×10^{-6}	2.8×10^{-6}	2.2×10^{-4}	3.6×10^{-5}	7.9×10^{-4}	4.8×10^{-4}	5.7×10^{-4}	High
Loss of Local Airborne Contamination Control/Loss of Vacuum Filter	3.5	8.2×10^{-6}	1.9×10^{-4}	1.4×10^{-4}	1.1×10^{-2}	1.8×10^{-3}	3.8×10^{-2}	2.4×10^{-2}	2.8×10^{-2}	High
Temporary Loss of Services:										
Electricity (Normal and Emergency)	1.4	3.4×10^{-6}	7.4×10^{-5}	5.7×10^{-5}	4.4×10^{-3}	7.0×10^{-4}	1.5×10^{-2}	9.6×10^{-3}	1.1×10^{-2}	Medium
Other	--[(b)]									Not Estimated
Liquid Leak:										
Chemical Decontamination	16	6.0×10^{-4}	1.4×10^{-2}	1.0×10^{-2}	1.3×10^{-2}	2.3×10^{-2}	4.8	2.9	1.3×10^{-2}	High
Electropolishing	2.8×10^{-2}	2.4×10^{-7}	5.4×10^{-6}	4.0×10^{-6}	5.1×10^{-6}	9.0×10^{-6}	1.9×10^{-4}	1.2×10^{-4}	5.1×10^{-6}	Medium
Fire Involving Contaminated Clothing or Combustible Waste	0.11	4.2×10^{-6}	9.6×10^{-5}	7.0×10^{-5}	9.2×10^{-5}	1.6×10^{-4}	3.4×10^{-3}	2.1×10^{-3}	9.2×10^{-5}	Medium
Explosion of Hydrogen During Electropolishing	7.1×10^{-3}	2.6×10^{-7}	5.9×10^{-6}	4.6×10^{-6}	5.5×10^{-6}	1.0×10^{-5}	2.1×10^{-4}	1.3×10^{-4}	5.9×10^{-6}	High
Natural Phenomenon:										
Tornado	Not Calculated									Low
Earthquake	Not Calculated									Low

(a) Frequency of Occurrences: High $>1.0 \times 10^{-2}$; Medium 1.0×10^{-2} to 1.0×10^{-5}; Low $<1.0 \times 10^{-5}$ per year.
(b) A dash means that the atmospheric release value is less than 2.0×10^{-4} µCi.

TABLE I.3-4. Estimated Occupational Radiation Dose for DECON of the MOX Plant

Event Description	Foremen			Operators			H.P. Technicians			Craftsmen			Event Total Dose Man-Rem
	Average Exposure Rate (R/hr)	Total Exposure Man-Hours	Dose Man-Rem	Average Exposure Rate (R/hr)	Total Exposure Man-Hours	Dose Man-Rem	Average Exposure Rate (R/hr)	Total Exposure Man-Hours	Dose Man-Rem	Average Exposure Rate (R/hr)	Total Exposure Man-Hours	Dose Man-Rem	
Flush solvent extraction system	7×10^{-4}	240	0.17	1.4×10^{-3}	720	1	1×10^{-3}	225	0.23	1.4×10^{-3}	465	0.65	2.1
Flush wet process and scrap recovery system	5×10^{-4}	600	0.3	9×10^{-4}	1800	1.6	7×10^{-4}	555	0.39	9×10^{-4}	1170	1.1	3.41
Flush waste treatment	4×10^{-4}	120	4.8×10^{-2}	8×10^{-4}	480	0.38	6×10^{-4}	105	6.3×10^{-2}	8×10^{-4}	240	0.19	0.61
Decontaminate Rooms 121, 123, 126	1.4×10^{-4}	60	8.4×10^{-3}	3.3×10^{-4}	360	0.12	2.4×10^{-4}	30	7.2×10^{-3}	3.3×10^{-4}	60	2×10^{-2}	0.16
Decontaminate Room 155	2.3×10^{-4}	45	1×10^{-2}	6.7×10^{-4}	270	0.18	4.5×10^{-4}	45	2×10^{-2}	6.7×10^{-4}	45	3×10^{-2}	0.24
Decontaminate Room 124	6×10^{-4}	210	0.17	1.1×10^{-3}	1260	1.4	8.3×10^{-4}	195	0.16	1.1×10^{-3}	210	0.23	1.96
Decontaminate Room B05	7×10^{-4}	150	0.11	1.4×10^{-3}	900	1.3	8.5×10^{-4}	135	0.11	1.4×10^{-3}	300	0.42	1.94
Decontaminate Room 128	5×10^{-4}	360	0.18	1×10^{-3}	2160	2.2	7.5×10^{-4}	330	0.25	1×10^{-3}	360	0.36	2.95
Decontaminate Room 127	4×10^{-4}	210	8.4×10^{-2}	8×10^{-4}	1260	1	6×10^{-4}	195	0.12	8×10^{-4}	210	0.17	1.37
Decontaminate Room 156	2.3×10^{-4}	30	6.9×10^{-3}	6.7×10^{-4}	180	0.12	4.5×10^{-4}	30	1.4×10^{-2}	6.7×10^{-4}	30	2×10^{-2}	0.16
Decontaminate Room 116	6×10^{-5}	15	9×10^{-4}	6×10^{-5}	90	5.4×10^{-3}	6×10^{-5}	15	9×10^{-4}	6×10^{-5}	15	9×10^{-4}	8.1×10^{-3}
Decontaminate Room 130-133, 135-143	6×10^{-5}	90	5.4×10^{-3}	7×10^{-5}	540	3.8×10^{-2}	6.5×10^{-5}	45	2.9×10^{-3}	7×10^{-5}	90	6.3×10^{-3}	5.3×10^{-2}
Decontaminate Room B01	5×10^{-4}	150	7.5×10^{-2}	9×10^{-4}	900	0.81	7×10^{-4}	135	9.5×10^{-2}	9×10^{-4}	150	0.14	1.12
Decontaminate Room B02	4×10^{-4}	90	3.6×10^{-2}	8×10^{-4}	540	0.43	6×10^{-4}	90	5.4×10^{-2}	8×10^{-4}	90	7.2×10^{-4}	0.59
Decontaminate Room 129	6×10^{-5}	45	2.7×10^{-3}	7×10^{-5}	270	1.9×10^{-2}	6.5×10^{-5}	45	2.9×10^{-3}	7×10^{-5}	45	3.2×10^{-3}	2.8×10^{-2}
Decontaminate Room 201	1×10^{-3}	90	9×10^{-2}	1×10^{-3}	360	0.36	1×10^{-3}	90	9×10^{-2}	1×10^{-3}	90	9×10^{-2}	0.63
Decontaminate Sewage Lagoon	6×10^{-5}	270	1.6×10^{-2}	6×10^{-5}	1080	6.5×10^{-2}	6×10^{-5}	270	1.6×10^{-2}	6×10^{-5}	—	0	9.7×10^{-2}
Dismantle Rooms 121, 123, 126	1.4×10^{-4}	120	1.7×10^{-2}	3.2×10^{-4}	480	0.15	2.3×10^{-4}	60	1.4×10^{-2}	3.2×10^{-4}	240	7.7×10^{-2}	0.26
Dismantle Room 155	2.2×10^{-4}	45	9.9×10^{-3}	6.6×10^{-4}	180	0.12	4.4×10^{-4}	45	2×10^{-2}	6.6×10^{-4}	90	5.9×10^{-2}	0.21
Dismantle Room 124	4×10^{-4}	240	9.6×10^{-2}	8.5×10^{-4}	960	0.82	6.3×10^{-4}	225	0.14	8.5×10^{-4}	465	0.4	1.1
Dismantle Room B05	4×10^{-4}	750	0.3	4×10^{-4}	3000	1.2	4×10^{-4}	690	0.28	4×10^{-4}	2940	1.2	2
Dismantle Room 128	4×10^{-4}	510	0.2	8.5×10^{-4}	2040	1.7	6.3×10^{-4}	510	0.32	8.5×10^{-4}	990	0.84	3.1
Dismantle Room 127	4×10^{-4}	420	0.17	8×10^{-4}	1680	1.3	6×10^{-4}	420	0.25	8×10^{-4}	810	0.65	2.4
Dismantle Room 156	2.2×10^{-4}	30	6.6×10^{-3}	6.6×10^{-4}	120	7.9×10^{-2}	4.4×10^{-4}	30	1.3×10^{-2}	6.6×10^{-4}	60	4×10^{-2}	0.14
Dismantle Rooms 130-133, 135-143	6×10^{-5}	210	1.3×10^{-2}	6.5×10^{-5}	840	5.5×10^{-2}	6.3×10^{-5}	210	1.3×10^{-2}	6.5×10^{-5}	405	2.6×10^{-2}	0.11
Dismantle Room 116	6×10^{-5}	45	2.7×10^{-3}	6×10^{-5}	180	1.1×10^{-2}	6×10^{-5}	45	2.7×10^{-3}	6×10^{-5}	90	5.4×10^{-3}	2.2×10^{-2}
Dismantle Cold Chem Prep. Room	6×10^{-5}	60	3.6×10^{-3}	6×10^{-5}	240	1.4×10^{-2}	6×10^{-5}	—	0	6×10^{-5}	120	7.2×10^{-3}	2.5×10^{-2}
Dismantle Wall Storage Tank	4×10^{-4}	900	0.36	8.5×10^{-4}	4500	3.8	6.3×10^{-4}	900	0.58	8.5×10^{-4}	1770	1.5	6.24
Dismantle Room B01	4×10^{-4}	300	0.12	8×10^{-4}	1200	0.96	6×10^{-4}	300	0.18	8×10^{-4}	585	0.47	1.73
Dismantle Room B02	3×10^{-4}	180	5.4×10^{-2}	7×10^{-4}	720	0.5	5×10^{-4}	180	9×10^{-2}	7×10^{-4}	360	0.25	0.89
Dismantle Rooms 129 and 134	6×10^{-5}	135	8.1×10^{-3}	6.5×10^{-5}	540	3.5×10^{-2}	6.3×10^{-5}	135	8.5×10^{-3}	6.5×10^{-5}	270	1.8×10^{-2}	7×10^{-2}
Dismantle Electropolishing Station	2.1×10^{-4}	60	1.3×10^{-2}	6.2×10^{-4}	240	0.15	4.1×10^{-4}	60	2.5×10^{-2}	6.2×10^{-4}	240	0.15	0.34
Dismantle Rooms 108-111	6×10^{-5}	60	3.6×10^{-3}	6×10^{-5}	240	1.4×10^{-2}	6×10^{-5}	60	3.9×10^{-3}	6×10^{-5}	60	3.9×10^{-3}	2.5×10^{-2}
Dismantle Room 117	6×10^{-5}	90	5.9×10^{-3}	6×10^{-5}	360	2.3×10^{-2}	6×10^{-5}	—	0	6×10^{-5}	360	2.3×10^{-2}	5.2×10^{-2}
Dismantle Rooms 201 and 202	5×10^{-4}	210	0.11	5×10^{-4}	840	0.42	5×10^{-4}	210	0.11	5×10^{-4}	405	0.2	0.84
Final Decon. Rooms 121, 123, 126	6×10^{-5}	60	3.9×10^{-3}	6×10^{-5}	360	2.3×10^{-2}	6×10^{-5}	60	3.9×10^{-3}	6×10^{-5}	—	0	3.1×10^{-2}
Package and ship contaminated rubble	6×10^{-5}	45	2.9×10^{-3}	6×10^{-5}	270	1.8×10^{-2}	6×10^{-5}	90	5.9×10^{-3}	6×10^{-5}	—	0	2.7×10^{-2}
Set up electropolishing, packaging	2.1×10^{-4}	90	1.9×10^{-2}	6.2×10^{-4}	360	0.22	4.1×10^{-4}	45	1.6×10^{-2}	6.2×10^{-4}	360	0.22	0.48
Operate electropolishing station	2.1×10^{-4}	3855	0.81	6.2×10^{-4}	11565	7.2	4.1×10^{-4}	3960	1.6	6.2×10^{-4}	7560	4.7	14.3
Operate packaging and shipping	2.1×10^{-4}	4200	0.88	6.2×10^{-4}	8400	5.2	4.1×10^{-4}	4350	1.8	6.2×10^{-4}	4110	2.5	10.4
Operate scrap recovery and waste treatment	4.5×10^{-4}	1140	0.51	8.5×10^{-4}	4560	3.9	6.5×10^{-4}	1020	0.66	8.5×10^{-4}	2220	1.9	7
Totals		16,530	5.0		57,045	38.9		16,140	7.8		28,080	18.7	70.2

During accident cleanup, the routine tasks and the postulated industrial accidents can generate airborne radioactivity in the plant, primarily in the form of solid particulates and/or suspended liquid droplets. The airborne radionuclide concentration depends on the particular task or accident considered and on the corresponding radionuclide inventory at the location involved. (The post-accident radionuclide inventories in the reference U-Fab plant are discussed in detail in Appendix B.) Contamination control measures, where applied, and HEPA filters in plant ventilation systems reduce the levels of radioactivity in the air leaving the plant.

In the following subsections, the atmospheric releases and corresponding radiation doses to the public during accident cleanup at the reference U-Fab plant are discussed. The atmospheric releases are estimated by determining the realistic maximum atmospheric release for each task or industrial accident and then using this value whenever the particular release situation occurs, even for areas with lower levels of radioactive contamination.

Public Radiation Doses from Routine Tasks During Accident Cleanup

A complete discussion of the tasks required for accident cleanup of the reference U-Fab plant is contained in Appendix E. To quanti ' the radiation doses to the public that result from these tasks, atmospheric releases of radioactivity are estimated for the particular radionuclide inventories involved, and the resulting doses to the maximum-exposed individual and to the population are calculated.

The radiation doses to the public from these releases are calculated using the dose models discussed in Reference 8, in conjunction with characteristics of the reference site described in Appendix A of this report. Dose conversion factors are used that are appropriate for the post-accident radionuclide inventories at the reference plant. Each of the atmospheric releases is assumed to be a chronic release (i.e., one that occurs at a uniform rate for a period of one year) to allow direct comparisons of the impacts of individual accident cleanup tasks. The first-year doses and the fifty-year committed dose equivalents to both the maximum-exposed and individual and to the population residing within 80 km of the site are calculated for each accident cleanup task. The calculated doses include direct exposure, inhalation, and ingestion pathways; radiation doses from air submersion are not calculated since they have been shown to be insignificant in Reference 8.

The estimated atmospheric releases of radioactivity and the resulting doses to the maximum-exposed individual from routine tasks during accident cleanup following the reference accident are shown in Table I.4-1. The releases and the resulting doses to the population residing within 80 km of the site from these tasks following the reference accident are shown in Table I.4-2.

TABLE I.4-1. Calculated Radiation Doses to the Maximum-Exposed Individual from Airborne Radionuclides Released during Accident Cleanup

Activity or Location	Release to Atmosphere (μCi)	First-Year Dose, mrem			Fifty-Year Committed Dose Equivalent, mrem		
		Total Body	Bone	Lung	Total Body	Bone	Lung
Surface Cleaning Operations							
Spray decontamination of glove boxes	2.9×10^{-5}	1.0×10^{-11}	1.7×10^{-10}	4.1×10^{-9}	3.5×10^{-11}	5.9×10^{-10}	2.0×10^{-8}
Physical Decontamination of Surfaces							
Scraping metal surfaces	1.2×10^{-2}	8.3×10^{-9}	7.0×10^{-8}	1.7×10^{-6}	1.5×10^{-8}	2.5×10^{-7}	8.3×10^{-6}
Exhaust duct decontamination	84	5.7×10^{-5}	4.8×10^{-4}	1.2×10^{-2}	1.0×10^{-4}	1.7×10^{-3}	5.7×10^{-2}
Exhaust Filter Removal	8.6×10^{-2}	5.5×10^{-8}	4.7×10^{-7}	1.2×10^{-5}	9.9×10^{-8}	1.6×10^{-6}	5.5×10^{-5}
Totals	84	5.7×10^{-5}	4.8×10^{-4}	1.2×10^{-2}	1.0×10^{-4}	1.7×10^{-3}	5.7×10^{-2}

TABLE I.4-2. Calculated Radiation Doses to the Population from Airborne Radionuclides Released during Accident Cleanup

Activity or Location	Release to Atmosphere (μCi)	First-Year Dose, man-rem			Fifty-Year Committed Dose Equivalent, man-rem		
		Total Body	Bone	Lung	Total Body	Bone	Lung
Surface Cleaning Operations							
Spray decontamination of glove boxes	2.9×10^{-5}	2.0×10^{-11}	1.7×10^{-10}	4.8×10^{-9}	3.5×10^{-11}	5.9×10^{-10}	2.2×10^{-8}
Physical Decontamination of Surfaces							
Scraping metal surfaces	1.2×10^{-2}	8.3×10^{-9}	7.0×10^{-8}	2.0×10^{-6}	1.5×10^{-8}	2.5×10^{-7}	9.1×10^{-6}
Exhaust duct decontamination	84	5.7×10^{-5}	4.8×10^{-4}	1.4×10^{-3}	1.0×10^{-4}	1.7×10^{-3}	6.3×10^{-2}
Exhaust Filter Removal	8.6×10^{-2}	5.5×10^{-8}	4.7×10^{-7}	1.4×10^{-5}	9.9×10^{-8}	1.6×10^{-6}	6.2×10^{-5}
Totals	84	5.7×10^{-5}	4.8×10^{-4}	1.4×10^{-2}	1.0×10^{-4}	1.7×10^{-3}	6.3×10^{-2}

Doses to the maximum-exposed individual in any given year are estimated to be below the appropriate dose design objectives as set forth in 10 CFR 50, Appendix I.(7)

The atmospheric releases and resulting public radiation doses presented in this study for accident cleanup are based on cleanup activities in the process building of the reference U-Fab plant.

Public Radiation Doses from Releases Due to Postulated Industrial Accidents During Accident Cleanup

Estimates of releases of radioactivity due to industrial accidents during accident cleanup and of the resulting first-year doses and fifty-year committed dose equivalents to the maximum-exposed individual are presented in Table I.4-3. Each release is assumed to occur during a one-hour period so that a comparison of the releases and associated doses can be made.

TABLE I.4-3. Calculated Radiation Doses to the Maximum-Exposed Individual from Accidental Airborne Radionuclide Release During Accident Cleanup

Incident	Release to Atmosphere (μCi)	First-Year Dose, mrem			Fifty-Year Committed Dose Equivalent, mrem		
		Total Body	Bone	Lung	Total Body	Bone	Lung
Loss of Intermediate Stage HEPA Filter after Duct Decontamination	2.7	2.3×10^{-4}	2.3×10^{-3}	7.6×10^{-2}	2.7×10^{-4}	4.5×10^{-3}	1.9×10^{-1}
Loss of Airborne Contamination Control, Loss of Vacuum Filter	0.70	6.0×10^{-5}	6.0×10^{-4}	2.0×10^{-2}	6.9×10^{-5}	1.1×10^{-3}	4.9×10^{-2}
Temporary Loss of Services							
Electricity (Normal and Emergency)	2.8×10^{-5}	6.7×10^{-9}	6.7×10^{-8}	2.2×10^{-6}	7.8×10^{-9}	1.3×10^{-7}	5.6×10^{-6}
Liquid Leak during Chemical Decontamination	4.5×10^{-3}	3.7×10^{-7}	3.7×10^{-6}	1.3×10^{-4}	4.4×10^{-7}	7.3×10^{-6}	3.1×10^{-4}

While it is beyond the scope of this study to evaluate every potential industrial accident situation that could result in a release of radioactivity during accident cleanup, the releases presented here are judged to represent the range of credible events and to reflect realistic maximum impacts to the public from industrial accident situations.

I.4.2 Occupational Safety Aspects of Accident Cleanup

The occupational safety impacts of accident cleanup activities are discussed in the following subsections, including radiation doses to workers performing the accident cleanup tasks and potential industrial-accident (nonradiological) impacts to these workers. The information developed here is based on the detailed description of accident cleanup activities presented in Appendix E of this study.

Occupational Radiation Doses from Accident Cleanup Activities

The estimated occupational radiation doses accumulated by cleanup workers are based on postulated external gamma radiation dose rates in various areas of the reference plant during accident cleanup and on estimated staff labor requirements for completing the accident cleanup tasks. Workers are assumed to use respiration equipment as appropriate to protect against inhalation of radioactive materials.

Summaries of the estimated occupational radiation doses during accident cleanup following the reference accident are given in Table I.4-4.

TABLE I.4-4. Estimated Occupational Radiation Dose for Accident Cleanup

	Foremen			H. P. Technicians			Operators			Craftsmen			
Event Description	Average Exposure Rate (R/hr)	Total Exposure (man-hours)	Dose (man-rem)	Average Exposure Rate (R/hr)	Total Exposure (man-hours)	Dose (man-rem)	Average Exposure Rate (R/hr)	Total Exposure (man-hours)	Dose (man-rem)	Average Exposure Rate (R/hr)	Total Exposure (man-hours	Dose (man-rem)	Event Total Dose (man-rem)
Drain and Ship Residuals from Nitrate Lagoon	3.7×10^{-3}	40	1.5×10^{-3}	3.7×10^{-5}	40	1.5×10^{-3}	3.7×10^{-5}	160	5.9×10^{-3}	3.7×10^{-5}	20	7.4×10^{-4}	9.6×10^{-3}
Drain and Cover Other Lagoons	3.7×10^{-5}	80	3.0×10^{-3}	3.7×10^{-5}	40	1.5×10^{-3}	3.7×10^{-5}	240	8.9×10^{-3}	3.7×10^{-5}	40	1.5×10^{-3}	1.5×10^{-2}
Audit all Pumps and Pipelines	1.5×10^{-4}	40	6.0×10^{-3}	2.1×10^{-4}	40	8.4×10^{-3}	2.6×10^{-4}	80	2.1×10^{-2}	2.6×10^{-4}	80	2.1×10^{-2}	5.6×10^{-2}
Secure Valves, Hoods and Conveyers	1.5×10^{-4}	40	6.0×10^{-3}	2.1×10^{-4}	40	8.4×10^{-3}	2.6×10^{-4}	120	3.1×10^{-2}	2.6×10^{-4}	80	2.1×10^{-2}	6.6×10^{-2}
Disconnect Services No Longer Needed	3.7×10^{-5}	80	3.0×10^{-3}	6.6×10^{-5}	40	2.6×10^{-3}	9.4×10^{-5}	80	7.5×10^{-3}	9.4×10^{-5}	160	1.5×10^{-2}	2.8×10^{-2}
Tag Equipment and Systems to Identify Status	3.7×10^{-5}	40	1.5×10^{-3}	6.6×10^{-5}	80	5.3×10^{-3}	9.4×10^{-5}	80	7.5×10^{-3}	9.4×10^{-5}	80	7.5×10^{-3}	2.2×10^{-2}
Safety Audit	3.7×10^{-5}	40	1.5×10^{-3}	6.6×10^{-5}	C0	5.3×10^{-3}	9.4×10^{-5}	80	7.5×10^{-3}	9.4×10^{-5}	80	7.5×10^{-3}	2.2×10^{-2}
Install Building Access Locks and Warning Signs	3.7×10^{-5}	40	1.5×10^{-3}	3.7×10^{-5}	--	--	3.7×10^{-5}	40	1.5×10^{-3}	3.7×10^{-5}	80	3.0×10^{-3}	6.0×10^{-3}
Perform Building Systems Check	3.7×10^{-5}	40	1.5×10^{-3}	6.6×10^{-5}	40	2.6×10^{-3}	9.4×10^{-5}	80	7.5×10^{-3}	9.4×10^{-5}	80	7.5×10^{-3}	1.9×10^{-2}
Install Fences and Locks on Outside Facilities	3.7×10^{-5}	40	1.5×10^{-3}	3.7×10^{-5}	--	--	3.7×10^{-5}	40	1.5×10^{-3}	3.7×10^{-5}	40	1.5×10^{-3}	4.5×10^{-3}
Complete Offsite Shipment of all Recovered Uranium	3.7×10^{-5}	40	1.5×10^{-3}	6.6×10^{-5}	80	5.3×10^{-3}	9.4×10^{-5}	160	1.5×10^{-2}	9.4×10^{-5}	20	1.9×10^{-3}	2.4×10^{-2}
Complete Intrusion Alarm System Installation	3.7×10^{-5}	40	1.5×10^{-3}	6.6×10^{-5}	40	2.6×10^{-3}	9.4×10^{-5}	80	7.5×10^{-3}	9.4×10^{-5}	240	1.9×10^{-3}	2.4×10^{-2}
Complete Radiation Monitoring System Installation	3.7×10^{-5}	40	1.5×10^{-3}	6.6×10^{-5}	40	2.6×10^{-3}	9.4×10^{-5}	80	7.5×10^{-3}	9.4×10^{-5}	160	1.5×10^{-2}	2.7×10^{-2}
Perform Comprehensive Radiation Survey	3.7×10^{-5}	40	1.5×10^{-3}	6.6×10^{-5}	160	1.1×10^{-2}	9.4×10^{-5}	160	1.5×10^{-2}	9.4×10^{-5}	--	--	2.7×10^{-2}
Totals		640	3.3×10^{-2}		720	5.7×10^{-2}		1480	0.145		1160	0.126	0.361

I.5 U-FAB PLANT POST-ACCIDENT DECOMMISSIONING

Decommissioning activities at the reference U-Fab plant follow completion of accident cleanup at the plant. Accident cleanup efforts contribute to the total decommissioning effort, but in this study, accident cleanup and decommissioning are addressed separately for the MOX and U-Fab plants.

This section contains the details of the analysis of the safety impacts resulting from the post-accident decommissioning activities at the reference plant. Radiological and nonradiological impacts of both routine activities and selected generic industrial and transportation accidents are considered.

I.5.1 Public Safety Aspects of Post-Accident Decommissioning Activities

The public safety impacts from onsite activities during post-accident decommissioning (following completion of accident cleanup activities) are discussed in the following subsections. Public radiation doses from atmospheric releases that result from routine decommissioning are considered. Nonradiological safety impacts to the public from onsite activities are judged to be negligible and are not considered further.

During decommissioning, as during accident cleanup, the routine tasks and postulated industrial accidents can generate airborne radioactivity in the plant. Contamination control measures, where applied, and HEPA filters in plant ventilation systems reduce the levels of radioactivity in the air leaving the plant. The radioactivity released depends on the specific task or industrial accident considered and on the corresponding radionuclide inventory at that particular location.

The radionuclide inventories used in this study for post-accident decommissioning are the same as those used in Reference 8 for decommissioning following normal U-Fab plant shutdown.

In the following subsections, the atmospheric releases and resulting radiation doses to the public are discussed. Analyses are performed for decommissioning following the reference U-Fab plant accident. The atmospheric releases are estimated by determining the realistic maximum atmospheric release for each situation and then using this value whenever similar conditions occur, even for areas with lower levels of radioactive contamination.

Public Radiation Doses from Routine Tasks During Post-Accident Decommissioning

The atmospheric releases of radioactivity for post-accident decommissioning are based on estimated values for decommissioning the reference U-Fab plant following normal shutdown, presented in Appendix I of Reference 8. Each of the atmospheric releases is assumed to be a chronic release (i.e., one that occurs

at a uniform rate over a one-year period) to allow direct comparisons of the impacts from individual decommissioning tasks. The first-year dose and the fifty-year committed dose equivalents to both the maximum-exposed individual and to the population residing within 80 km of the site are calculated. The dose calculation includes direct exposure, inhalation, and ingestion pathways.

The estimated atmospheric releases of radioactivity and the resulting doses to the maximum-exposed individual from routine tasks during DECON are shown in Table I.5-1.

Public-Radiation Doses from Releases Due to Postulated Industrial Accidents During Post-Accident Decommissioning

During decommissioning, unexpected situations may arise that lead to the accidental atmospheric release of radioactivity from the plant. Estimated atmospheric releases of radioactivity and the resulting doses to the population are shown in Table I.5-2. The industrial accident situations considered for

TABLE I.5-1. Calculated Radiation Doses to the Maximum-Exposed Individual from Airborne Radionuclides Released During DECON

Activity or Location	Release to Atmosphere (μCi)	First-Year Dose, mrem: Total Body	First-Year Dose, mrem: Bone	First-Year Dose, mrem: Lung	First-Year Dose, mrem: GI-LLI	Fifty-Year Committed Dose Equivalent, mrem: Total Body	Fifty-Year Committed Dose Equivalent, mrem: Bone	Fifty-Year Committed Dose Equivalent, mrem: Lung	Fifty-Year Committed Dose Equivalent, mrem: GI-LLI
Radiation Survey	--[a]								
Chemical Decontamination									
Flushing of wet systems	--								
Surface Cleaning Operations	–								
Handwiping									
Spray decontamination of gloveboxes	2.9×10^{-5}	1.0×10^{-11}	1.7×10^{-10}	4.1×10^{-9}	1.3×10^{-11}	3.5×10^{-11}	5.9×10^{-10}	2.0×10^{-8}	1.3×10^{-11}
Physical Decontamination of Surfaces									
Scraping metal Surfaces	1.2×10^{-2}	8.3×10^{-9}	7.0×10^{-8}	1.7×10^{-6}	5.7×10^{-9}	1.5×10^{-8}	2.5×10^{-7}	8.3×10^{-6}	5.7×10^{-9}
Scraping firebrick	7.[illegible] $\times 10^{-4}$	4.8×10^{-10}	4.0×10^{-9}	1.0×10^{-7}	3.2×10^{-10}	8.5×10^{-10}	1.4×10^{-8}	4.8×10^{-7}	3.2×10^{-10}
Concrete removal	2.[illegible] $\times 10^{-3}$	1.8×10^{-9}	1.5×10^{-8}	3.7×10^{-7}	1.2×10^{-9}	3.2×10^{-9}	5.5×10^{-8}	1.8×10^{-6}	1.2×10^{-9}
Exhaust Duct decontamination	84	5.7×10^{-5}	4.8×10^{-4}	1.2×10^{-2}	4.0×10^{-5}	1.0×10^{-4}	1.7×10^{-3}	5.7×10^{-2}	4.0×10^{-5}
Removal of contaminated concrete rubble	--								
Segmenting and Transfer of Equipment									
Arc saw	2.3×10^{-4}	1.5×10^{-10}	1.3×10^{-9}	3.2×10^{-8}	1.0×10^{-10}	2.7×10^{-10}	4.6×10^{-9}	1.5×10^{-7}	1.0×10^{-10}
Plasma torch	1.8×10^{-2}	1.2×10^{-8}	1.0×10^{-7}	2.5×10^{-6}	8.2×10^{-9}	2.1×10^{-8}	3.6×10^{-7}	1.2×10^{-5}	8.2×10^{-9}
Nibbler	--								
Packaging and Transfer	--								
Exhaust Filter Removal	8.6×10^{-2}	5.5×10^{-8}	4.7×10^{-7}	1.2×10^{-5}	3.7×10^{-8}	9.9×10^{-8}	1.6×10^{-6}	5.5×10^{-5}	3.7×10^{-8}
Totals	84.1	5.7×10^{-5}	4.0×10^{-4}	1.2×10^{-2}	4.0×10^{-5}	1.0×10^{-4}	1.7×10^{-3}	5.7×10^{-2}	4.0×10^{-5}

(a) A dash means the atmospheric release value is less than 1×10^{-5} μCi.

TABLE I.5-2. Calculated Radiation Doses to the Population from Airborne Radionuclides Released During DECON

Activity or Location	Release to Atmosphere (μCi)	First-Year Dose, man-rem				Fifty-Year Committed Dose Equivalent, man-rem			
		Total Body	Bone	Lung	GI-LLI	Total Body	Bone	Lung	GI-LLI
Radiation Survey	--[(a)]								
Chemical Decontamination									
Flushing of wet systems	--								
Surface Cleaning Operations									
Handwiping	--								
Spray decontamination of glove boxes	2.9×10^{-5}	2.0×10^{-11}	1.7×10^{-10}	4.8×10^{-9}	9.0×10^{-12}	3.5×10^{-11}	5.9×10^{-10}	2.2×10^{-8}	9.1×10^{-12}
Physical Decontamination of Surfaces									
Scraping metal surfaces	1.2×10^{-2}	8.3×10^{-9}	7.0×10^{-8}	2.0×10^{-6}	3.8×10^{-9}	1.5×10^{-8}	2.5×10^{-7}	9.1×10^{-6}	3.8×10^{-9}
Scraping firebrick	7.2×10^{-4}	4.7×10^{-10}	4.0×10^{-9}	1.2×10^{-7}	2.2×10^{-10}	8.5×10^{-10}	4.4×10^{-8}	5.2×10^{-7}	2.2×10^{-10}
Concrete removal	1.1×10^{-2}	1.8×10^{-9}	1.5×10^{-8}	4.5×10^{-7}	8.2×10^{-10}	3.2×10^{-9}	5.5×10^{-8}	2.0×10^{-6}	8.2×10^{-10}
Exhaust Duct Decontamination	84	5.7×10^{-5}	4.8×10^{-4}	1.4×10^{-2}	2.7×10^{-5}	1.0×10^{-4}	1.7×10^{-3}	6.3×10^{-2}	2.7×10^{-5}
Removal of Contaminated Concrete Rubble	--								
Segmenting and Transfer of Equipment									
Arc saw	2.3×10^{-4}	1.5×10^{-10}	1.3×10^{-9}	3.7×10^{-8}	7.0×10^{-11}	2.7×10^{-10}	4.6×10^{-9}	1.7×10^{-7}	7.0×10^{-11}
Plasma torch	1.8×10^{-2}	1.2×10^{-8}	1.0×10^{-7}	2.9×10^{-6}	5.5×10^{-9}	2.1×10^{-8}	3.6×10^{-7}	1.3×10^{-5}	5.5×10^{-9}
Nibbler	--								
Packaging and Transfer	--								
Exhaust Filter Removal	8.6×10^{-2}	5.5×10^{-8}	4.7×10^{-7}	1.4×10^{-5}	2.6×10^{-8}	9.9×10^{-8}	1.6×10^{-6}	6.2×10^{-5}	2.6×10^{-8}
Totals	**84**	5.7×10^{-5}	4.8×10^{-4}	1.4×10^{-2}	2.7×10^{-5}	1.0×10^{-4}	1.7×10^{-3}	6.3×10^{-2}	2.7×10^{-5}

(a) A dash means the atmospheric release value is less than 1×10^{-5} μCi.

post-accident decommissioning are the same as those considered in Reference 8 for decommissioning following normal plant shutdown.

Estimates of the releases of radioactivity due to postulated industrial accidents during DECON following an accident, together with the resulting first-year doses and fifty-year committed dose equivalents to the maximum-exposed individual, are shown in Table I.5-3.

It is beyond the scope of this study to evaluate every potential industrial accident situation that could lead to the release of radioactivity during decommissioning. However, the postulated situations presented here are judged to represent the range of credible events and to reflect realistic maximum impacts from such situations to the public.

TABLE I.5-3. Calculated Radiation Doses to the Maximum-Exposed Individual from Accidental Airborne Radionuclide Releases During DECON

Incident	Release to Atmosphere (Ci)	First-Year Dose, mrem			Fifty-Year Committed Dose Equivalent, mrem		
		Total Body	Bone	Lung	Total Body	Bone	Lung
Loss of Intermediate HEPA Filter after Duct Decontamination	2.7	2.3×10^{-4}	2.3×10^{-3}	7.6×10^{-2}	2.7×10^{-4}	4.5×10^{-3}	1.9×10^{-1}
Inadvertent Cutting of Undecontaminated metal	6.9×10^{-5}	5.9×10^{-9}	5.9×10^{-8}	1.9×10^{-6}	6.8×10^{-9}	1.1×10^{-7}	4.9×10^{-6}
Inadvertent Dumping of Contaminated Solid Waste							
Abreded firebrick	3.4×10^{-6}	8.2×10^{-10}	8.2×10^{-9}	2.7×10^{-7}	9.5×10^{-10}	1.6×10^{-8}	6.8×10^{-7}
Concrete dust	--[(a)]						
Condensed metal vapor	1.7×10^{-6}	4.1×10^{-10}	4.1×10^{-9}	1.3×10^{-7}	4.7×10^{-10}	8.0×10^{-9}	3.4×10^{-7}
Loss of Local Airborne Contamination Control, Loss of Vacuum Filter	0.70	6.0×10^{-5}	6.0×10^{-4}	2.0×10^{-2}	6.9×10^{-5}	1.1×10^{-3}	4.9×10^{-2}
Temporary Loss of Services							
Electricity	2.8×10^{-5}	6.7×10^{-9}	6.7×10^{-8}	2.2×10^{-6}	7.8×10^{-9}	1.3×10^{-7}	5.6×10^{-6}
Other	--						
Liquid Leak During Chemical Decontamination	4.5×10^{-3}	3.7×10^{-7}	3.7×10^{-6}	1.3×10^{-4}	4.4×10^{-7}	7.3×10^{-6}	3.1×10^{-4}
Fire Involving Contaminated Waste	--						
Natural Phenomena--Not Calculated							

(a) A dash means the atmospheric release value is less than 1×10^{-5} Ci

I.5.2 Occupational Safety Aspects of Post-Accident Decommissioning

The occupational safety impacts of post-accident decommissioning activities at the reference U-Fab plant are discussed in the following subsections. Included are occupational radiation doses and potential industrial accident (nonradiological) impacts to the decommissioning workers. The information developed here is based on the detailed description of decommissioning activities presented in Appendix E of this study.

Occupational Radiation Doses from Decommissioning Activities

Summaries of the estimated occupational radiation doses during DECON following the reference accident are given in Table I.5-4.

I.6 DETAILS OF OCCUPATIONAL DOSE ESTIMATES FOR NON-FUEL CYCLE FACILITIES

Models and assumptions used to estimate worker dose rates from the decommissioning of the reference laboratory and components are described in this section. The estimated worker dose rates form the bases for occupational dose calculations in Section 12.5. Dose rate calculations are based on residual contamination levels on individual facility components given in Chapters 6 and 10. Both direct-exposure dose rates and inhalation dose rates are estimated.

TABLE I.5-4. Estimated Occupational Radiation Dose for DECON

	Foremen			H. P. Technicians			Operators			Craftsmen			
Event Description	Average Exposure Rate (R/hr)	Total Exposure (man-hours)	Dose (man-rem)	Average Exposure Rate (R/hr)	Total Exposure (man-hours)	Dose (man-rem)	Average Exposure Rate (R/hr)	Total Exposure (man-hours)	Dose (man-rem)	Average Exposure Rate (R/hr)	Total Exposure (man-hours)	Dose (man-rem)	Event Total Dose (man-rem)
Decontaminate Powder warehouse	3.7×10^{-5}	80	3.0×10^{-3}	3.7×10^{-3}	40	1.5×10^{-3}	3.7×10^{-5}	480	1.8×10^{-2}	3.7×10^{-5}	40	1.5×10^{-3}	2.4×10^{-2}
Decontaminated UF_6 Cylinder Storage Room	3.7×10^{-5}	100	3.7×10^{-3}	3.7×10^{-5}	40	1.5×10^{-3}	3.7×10^{-5}	480	1.8×10^{-2}	3.7×10^{-5}	100	3.7×10^{-3}	2.7×10^{-2}
Dismantle Vaporization Room	3.7×10^{-5}	220	8.1×10^{-3}	1.2×10^{-4}	80	9.6×10^{-3}	2.1×10^{-4}	1 360	0.29	2.1×10^{-4}	200	4.2×10^{-2}	0.35
Dismantle Chemical and Powder Processing Area	1.5×10^{-4}	2 140	0.32	2.1×10^{-4}	800	0.18	2.6×10^{-4}	12 720	3.3	2.6×10^{-4}	2 460	0.64	4.4
Dismantle Powder Storage and Feed Room	1.5×10^{-4}	180	2.7×10^{-2}	4.9×10^{-4}	80	3.9×10^{-2}	8.2×10^{-4}	1 240	1.0	8.2×10^{-4}	80	6.6×10^{-2}	1.1
Dismantle Pelleting Room	1.5×10^{-4}	260	3.9×10^{-2}	4.9×10^{-4}	100	4.9×10^{-2}	8.2×10^{-4}	1 800	1.5	8.2×10^{-4}	300	0.25	1.8
Dismantle Sintering Room	1.5×10^{-4}	380	5.7×10^{-2}	2.1×10^{-4}	160	3.4×10^{-2}	2.6×10^{-4}	2 440	0.63	2.6×10^{-4}	300	7.8×10^{-2}	0.80
Dismantle Grinding Room	1.5×10^{-4}	240	3.6×10^{-2}	4.9×10^{-4}	100	4.9×10^{-2}	8.2×10^{-4}	1 360	1.1	8.2×10^{-4}	260	0.21	1.4
Dismantle Rodding Area	3.7×10^{-5}	200	7.4×10^{-3}	6.6×10^{-5}	80	5.3×10^{-3}	9.4×10^{-5}	1 240	0.12	9.4×10^{-5}	360	3.4×10^{-2}	0.17
Dismantle Gadolinia Shim Rod Production Facility	1.5×10^{-4}	300	4.5×10^{-2}	2.1×10^{-4}	120	2.5×10^{-2}	2.6×10^{-4}	1 600	0.42	2.6×10^{-4}	520	0.14	0.62
Dismantle Red Cap Area	1.5×10^{-4}	100	1.5×10^{-2}	2.1×10^{-4}	40	8.4×10^{-3}	2.6×10^{-4}	680	0.18	2.6×10^{-4}	200	5.2×10^{-2}	0.25
Dismantle Chemical and Metallurgical Testing Lab	3.7×10^{-5}	120	4.4×10^{-3}	6.6×10^{-5}	40	2.6×10^{-3}	9.4×10^{-5}	760	7.1×10^{-2}	9.4×10^{-5}	200	1.9×10^{-2}	9.7×10^{-2}
Dismantle Development Lab	1.5×10^{-4}	200	3.3×10^{-2}	2.1×10^{-4}	80	1.7×10^{-2}	2.6×10^{-4}	1 480	0.38	2.6×10^{-4}	360	9.4×10^{-2}	0.53
Dismantle Hot Maintenence and Instrument Shops	3.7×10^{-5}	140	5.2×10^{-3}	6.6×10^{-5}	60	4.0×10^{-3}	9.4×10^{-5}	680	6.4×10^{-2}	9.4×10^{-5}	520	4.9×10^{-2}	0.12
Dismantle Rad Waste Room	1.5×10^{-4}	80	1.2×10^{-2}	4.9×10^{-4}	40	2.0×10^{-2}	8.2×10^{-4}	600	0.49	8.2×10^{-4}	40	3.3×10^{-2}	0.56
Dismantle Decontamination Facility	3.7×10^{-5}	40	1.5×10^{-3}	1.2×10^{-4}	20	2.4×10^{-3}	2.1×10^{-4}	240	5.0×10^{-2}	2.1×10^{-4}	40	8.4×10^{-3}	6.3×10^{-2}
Dismantle Incineration Facility	3.7×10^{-5}	120	4.4×10^{-3}	1.2×10^{-4}	40	4.8×10^{-3}	2.1×10^{-4}	340	0.18	2.1×10^{-4}	160	3.4×10^{-2}	0.22
Decontaminate HEPA Filter Rooms	1.5×10^{-4}	240	3.6×10^{-2}	2.1×10^{-4}	100	2.1×10^{-2}	2.6×10^{-4}	1 800	0.47	2.6×10^{-4}	200	5.2×10^{-2}	0.58
Dismantle Laundry Room	3.7×10^{-5}	40	1.5×10^{-3}	6.6×10^{-5}	20	1.3×10^{-3}	9.4×10^{-5}	280	2.6×10^{-2}	9.4×10^{-5}	20	1.9×10^{-3}	3.1×10^{-2}
Dismantle Change Room	3.7×10^{-5}	40	1.5×10^{-3}	3.7×10^{-5}	20	7.4×10^{-4}	3.7×10^{-5}	200	1.0×10^{-2}	3.7×10^{-5}	40	1.5×10^{-3}	1.4×10^{-2}
Final Cleaning of Fuel Fabrication Building	3.7×10^{-5}	120	4.4×10^{-3}	3.7×10^{-5}	40	1.5×10^{-3}	3.7×10^{-5}	880	3.3×10^{-2}	3.7×10^{-5}	80	3.0×10^{-3}	4.1×10^{-2}
Dismantle Fluoride Waste Efffluent Treatment System	3.7×10^{-5}	820	3.0×10^{-2}	3.7×10^{-5}	320	1.2×10^{-2}	3.7×10^{-5}	5 920	0.22	3.7×10^{-5}	520	1.9×10^{-2}	0.28
Dismantle Nitrate Waste Effluent Treatment System	3.7×10^{-5}	200	7.4×10^{-3}	3.7×10^{-5}	80	3.0×10^{-3}	3.7×10^{-5}	1 280	4.7×10^{-2}	3.7×10^{-5}	160	5.9×10^{-3}	3.6×10^{-2}
Dismantle Waste Treatment Building	3.7×10^{-5}	100	3.7×10^{-3}	3.7×10^{-5}	40	1.5×10^{-3}	3.7×10^{-5}	680	2.5×10^{-2}	3.7×10^{-5}	160	5.9×10^{-3}	3.6×10^{-2}
Recovery and Disposal of Solid CaF_2 Waste	3.7×10^{-5}	300	1.1×10^{-2}	3.7×10^{-5}	120	4.4×10^{-3}	3.7×10^{-5}	2 440	9.0×10^{-2}	3.7×10^{-5}	--	--	0.11
Disposal of Stored Excess Contaminated Equipment	1.5×10^{-4}	300	4.5×10^{-2}	2.1×10^{-4}	120	2.5×10^{-2}	2.6×10^{-4}	2 160	0.56	2.6×10^{-4}	260	6.8×10^{-2}	0.70
Decontamination of Uranium Storage Pads	3.7×10^{-5}	20	7.4×10^{-3}	3.7×10^{-5}	20	7.4×10^{-4}	3.7×10^{-5}	80	3.0×10^{-3}	3.7×10^{-5}	--	--	4.4×10^{-3}
Dismantlement of Rad Waste Effluent Treatment System	1.5×10^{-4}	200	3.0×10^{-2}	4.9×10^{-4}	80	3.9×10^{-2}	8.2×10^{-4}	1 040	0.85	8.2×10^{-4}	520	0.43	1.3
Totals		7 300	0.793		2 960	0.563		46 800	12.1		8 200	2.28	15.7

I.6.1 Estimates of Direct Exposure Dose Rates

Estimates of direct-exposure dose rates are made for work with facility components contaminated with ^{241}Am. The results of these dose rate estimates are shown in Table I.6-1. Dose rates are given in mrem/hr at various distances from the different facility components.

Direct-exposure dose rates are calculated using the computer code ISOSHLD.[9,10] The ISOSHLD program uses a point-kernel integration technique to evaluate exposure rates at the detector. Photon-energy flux is calculated for 25 energy groups with average energies ranging from 15 keV to 3.0 meV. Twelve source/detector geometrics are available.

Components such as hoods, glove boxes, hot cells, and ductwork are modeled as rectangular boxes of the correct dimensions. A value for the total contamination inside a component is obtained by multiplying the average surface contamination per unit area by the total inside surface area of the component. For computational purposes, this total contamination is assumed to uniformly fill the volume of the box. Appropriate credit is taken for the shielding

TABLE I.6-1. Estimated Worker Dose Rates from Direct Exposure

Component	Isotope	Assumed Contamination Level on Internal Surfaces (d/m/100 cm^2)	Dose Rates (mrem/hr) at Various Distances		
			0.5 m from Component	1.0 m from Component	5.0 m from Component
Fume Hood	^{241}Am	2×10^3	4×10^{-5}	2×10^{-5}	2×10^{-6}
Glove Box	^{241}Am	2×10^8	2×10^0	5×10^{-1}	4×10^{-2}
Lab Bench	^{241}Am	5×10^1 (a)	5×10^{-7}	2×10^{-7}	1×10^{-8}
Ductwork	^{241}Am	1×10^2	2×10^{-5}	1×10^{-5}	1×10^{-6}
Wall	^{241}Am	2×10^1	1×10^{-6}	1×10^{-6}	1×10^{-7}
Floor	^{241}Am	1×10^2	--(b)	4×10^{-6}	--(b)

(a) Assumed contamination on bench top.
(b) Not estimated.

afforded by the walls of the component. Drain lines are modeled as cylindrical sources. Bench tops are modeled exactly. The floor is modeled as a disk having a 60-m^2 surface area (4.4-m radius). A wall is modeled as a disk having a 30-m^2 surface area (3.1-m radius). (Facility components are assumed to be located in a room that measures 10 m by 6 m, with walls 3 m high.)

I.6.2 Estimates of Inhalation Dose Rates

Estimates of inhalation dose rates are made using the equations in Appendix I of Reference 11:

$$R = \chi F \tag{I.1}$$

where:

R is the worker dose rate, rem/hr
χ is the air concentration in the room, pCi/m3
F is the dose factor, rem per pCi/m3 per hr.

The air concentration in a room is calculated using a resuspension rate analysis[12] described by the equation

$$\chi = \frac{f A \Omega}{Vn} \tag{I.2}$$

where:

f is the resuspension rate, h-1
A is the contaminated surface area in the room, m2
Ω is the surface contamination level, pCi/m2
V is the volume of air in the room, m3
n is the rate of air exchange in the room, h-1.

The resuspension rate for vigorous activity, including cleaning operations, is 5×10^{-3} h^{-1}.[9] Contaminated surface areas and assumed surface contamination levels for facility components are shown in Table I.6-2. Assumed surface contamination levels are derived from facility descriptions in Chapter 5. The room is assumed to measure 6 m by 10 m, with walls 3 m high. Ten air exchanges per hour are assumed.

Dose factors are calculated using the computer code DACRIN,[13] with an assumed breathing rate of 350 cm^3/sec[14] for workers engaged in moderately strenuous activity. Dose factors are shown in Table I.6-3. These factors

TABLE I.6-2. Assumed Surface Contamination Levels for Facility Components[(a)]

Component	Surface Area (m^2)	Assumed Surface Contamination (pCi/m^2) ^{241}Am
Hood	5.6	1×10^5
Glove Box[(b)]	2.9	1×10^{10}[(c)]
Hot Cell	8.6	--
Workbench	3.8	3×10^3
Drain[(b)]	0.1	--
Ductwork	5	5×10^3
Floor	60	5×10^3
Wall	96	1×10^3

(a) Surface contamination levels are based on facility descriptions in Chapter 5.

(b) To calculate dose rates, it is assumed that because these components are closed, only 0.01 of the surface contamination is available for resuspension.

(c) To calculate dose rates, it is assumed that because of special design, only 0.001 of the surface contamination is available for resuspension.

TABLE I.6-3. Inhalation Dose Factors[(a)]

Radioisotope	Organ	Dose Factor (rem per pCi/m^3 per hr) 1-Year Commitment	50-Year Commitment
^{241}Am	Total Body	2.0×10^{-6}	1.9×10^{-5}
	Bone	2.4×10^{-5}	1.1×10^{-3}
	Lung	2.6×10^{-4}	6.5×10^{-4}
	Thyroid	N.C.[(b)]	N.C.

(a) Inhalation dose to workers from 1 hr of exposure to air contaminated to 1 pCi/m^3 of the listed radioisotopes.

(b) Not calculated.

represent 1-year and 50-year committed dose equivalents from one hour of exposure to an air concentration of 1 pCi/m^3 of the indicated radioisotope. (The 50-year dose factors are used in the calculation.)

Estimated inhalation dose rates, calculated by using Equation I.1, are shown in Table I.6-4. Dose rates are estimated for the organ receiving the maximum exposure. The "dose rates" shown in Table I.6-4 are not true dose rates in the sense that a direct exposure rate is a true dose rate, because inhalation "dose rates" represent 50-year dose commitments from one hour of inhalation of radioactivity. Since inhalation results in the deposition of radioactivity in the organs of the body, the "dose rates" estimated in this manner are believed to provide reasonable measures of the radiological hazards of worker exposure to airborne radioactivity.

TABLE I.6-4. Estimated Worker Dose Rates from Inhalation[(a)]

Component	Inhalation Dose Rate[(b)] (rem/hr) for Given Contaminant: ^{241}Am
Hood	2×10^{-3}
Glove Box	9×10^{-2}
Workbench	4×10^{-5}
Ductwork	8×10^{-5}
Floor	9×10^{-4}
Wall	3×10^{-4}

(a) Estimated by the use of Equation I.1.
(b) Fifty-year committed dose equivalents from 1 hour of inhalation exposure.

REFERENCES

1. C. A. Burchsted, J. E. Kahn and A. B. Fuller, Nuclear Air Cleaning Handbook, ERDA 76-21, pp. 42-43, March 1976.

2. Final Elk River Reactor Program Report, COO-651-93, Revised, p. F-9, United Power Association, Elk River, Minnesota, November 1974.

3. Siting of Fuel Reprocessing and Waste Management Facilities, ORNL-4451, pp. 8-47, Oak Ridge National Laboratory, Oak Ridge, Tennessee, July 1970.

4. J. M. Selby, et al., Considerations in the Assessment of Consequences of Effluents from Mixed Oxide Fuel Fabrication Plants, BNWL-1697, Rev. 1, pp. 78-79, Pacific Northwest Laboratory, Richand, Washington, June 1975.

5. U.S. NRC, Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I, Regulatory Guide 1. 109, Rev. 1, U.S. Nuclear Regulatory Commission, Washington D.C., 1977.

6. C. E. Jenkins, E. S. Murphy, and K. J. Schneider, Technology, Safety and Costs of Decommissioning a Reference Small Mixed-Oxide Fuel Fabrication Plant, NUREG/CR-0129, Vols. 1 and 2, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, February 1979.

7. U.S. Code of Federal Regulations, Title 10, Part 50, Appendix I, "Numerical Guides for Design Objectives and Limiting Conditions for Operation to Meet the Criterion 'As Low as is Reasonably Achievable' for Radioactive Material in Light-Water-Cooled Nuclear Power Reactor Effluents," (10 CFR 50, App. I), U.S. Government Printing Office, Washington, D.C., 1980.

8. H. K. Elder and D. E. Blahnik, Technology, Safety and Costs of Decommissioning a Reference Uranium Fuel Fabrication Plant, NUREG/CR-1266, Vols. 1 and 2, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, October 1980.

9. R. L. Engel, J. G. Greenborg, and M. M. Hendrickson, ISOSHLD - A Computer Code for General Purpose Isotope Shielding Analysis, BNWL-236, Pacific Northwest Laboratory, Richland, Washington, June 1966.

10. G. L. Simmons, et al., ISOSHLD II Code Revision to Include Calculation of Dose Rates from Shielded Bremsstrahlung Sources, BNWL-236, Supplement 1, Pacific Northwest Laboratory, Richland, Washington, March 1967.

11. E. S. Murphy, Technology, Safety and Costs of Decommissioning Reference Non-Fuel-Cycle Nuclear Facilities, NUREG/CR-1754, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, February 1981.

12. J. W. Healy, Surface Contamination: Decision Levels, LA-4558-MS, Los Alamos Scientific Laboratory, Los Alamos, New Mexico.

13. J. R. Houston, D. L. Strenge, and E. C. Watson, DACRIN - A Computer Program for Calculating Organ Dose from Acute or Chronic Inhalation, BNWL-B-389, Pacific Northwest Laboratory, Richland, Washington, December 1974.

14. Task Group on Lung Dynamics for Committee 2 of the International Commission on Radiological Protection, "Deposition and Retention Models for Internal Dosimetry of the Human Respiratory Tract," Health Physics, Vol. 12, pp. 173-207, February 1966.

NRC FORM 335 (11-81)

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

1. REPORT NUMBER (Assigned by DDC): NUREG/CR-3293, Vol. 2

2. (Leave blank)

3. RECIPIENT'S ACCESSION NO.

4. TITLE AND SUBTITLE (Add Volume No., if appropriate): Technology, Safety and Costs of Decommissioning Reference Fuel Cycle and Non-Fuel Cycle Facilities Following Postulated Accidents: Appendices

5. DATE REPORT COMPLETED: MONTH March YEAR 1985

DATE REPORT ISSUED: MONTH May YEAR 1985

6. (Leave blank)

7. AUTHOR(S): H. K. Elder

8. (Leave blank)

9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code): Pacific Northwest Laboratory, Richland, Washington 99357

10. PROJECT/TASK/WORK UNIT NO.

11. FIN NO. B2117

12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code): Division of Engineering Technology, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, Washington, DC 20555

13. TYPE OF REPORT

PERIOD COVERED (Inclusive dates)

14. (Leave blank)

15. SUPPLEMENTARY NOTES

16. ABSTRACT (200 words or less)

This volume contains the appendices concerning the technical requirements, costs and safety aspects conceptually evaluated for post-accident cleanup and decommissioning of fuel cycle and non-fuel cycle facilities that have experienced a significant accident. Accident cleanup is postulated to include 1) initial decontamination of building surfaces to reduce the subsequent occupational dose to cleanup and decommissioning workers and 2) management of the resulting wastes. Decommissioning is assumed to follow accident cleanup. In order to ensure that worker doses are ALARA, despite higher radiation exposure to workers during post-accident operations, careful planning and rehearsal of cleanup operations and the use of remote and semi-remote cleaning techniques are required to reduce occupancy times in high-radiation areas and to minimize occupational exposures during cleanup. The public safety impacts of post-accident cleanup and decommissioning are also evaluated; these are below permissible radiation dose levels in unrestricted areas and well within the range of annual radiation doses from normal background.

17. KEY WORDS AND DOCUMENT ANALYSIS

17a. DESCRIPTORS

decommissioning

17b. IDENTIFIERS/OPEN-ENDED TERMS

18. AVAILABILITY STATEMENT: Unlimited

19. SECURITY CLASS (This report): Unclassified

20. SECURITY CLASS (This page): Unclassified

21. NO. OF PAGES

22. PRICE: $

NRC FORM 335 (11-81)

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

FOURTH CLASS MAIL
POSTAGE & FEES PAID
USNRC
WASH. D.C.
PERMIT No. G-67

120555078877 1 1AN1C01CY
US NRC
ADM-DIV OF TIDC
POLICY & PUB MGT BR-PDR NUREG
W-501
WASHINGTON DC 20555